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In This Issue . . .

In the first article of this *Review*, "Implications of Netting Arrangements for Bank Risk in Foreign Exchange Transactions," R. Alton Gilbert describes the risks assumed by banks in settling foreign exchange transactions with other banks. The risks involve default by the other parties to the transactions. As the author notes, the volume of transactions in the foreign exchange market is very high, and banks commonly engage in transactions with counterparties headquartered in other countries. Thus, a default by a major participant in the foreign exchange market could affect the operation of payments systems in several countries.

Central banks have interest in the design of any arrangements among banks that might reduce their risk in settling foreign exchange transactions. One way that banks may be able to reduce transaction costs and risks is through netting arrangements. The central banks of 10 developed countries recently issued a report on netting arrangements, which included a list of guidelines for their design. Gilbert examines the implications of netting arrangements for risk assumed by banks in settling foreign exchange transactions and indicates why some of the guidelines are important if netting arrangements are to reduce risk.

* * *

Financial transactions, like the buying and selling of securities, commodities, foreign exchange and bonds, have increasingly involved individuals and firms from different countries. In the second article of the *Review*, "Institutional Developments in the Globalization of Securities and Futures Markets," Jodi G. Scarlata describes recent institutional developments in this globalization and discusses the advantages and disadvantages of these changes. Substantial benefits, she notes, are occurring because of these developments. At the same time, domestic rules and regulations are not sufficient safeguards for many international trades. In particular, she stresses how some risks at various stages of the clearing and settlement process are more important in an international setting than in a strictly domestic setting.

Weaknesses in the clearing and settlement system have prompted world financial leaders to work toward global coordination. Scarlata concludes that significant steps remain in integrating the world's growing securities and futures markets.

* * *

In the third article in this issue, "Data Envelopment Analysis and Commercial Bank Performance: A Primer with Applications to Missouri Banks," Piyu Yue discusses a relatively new methodology for evaluating the technical or productive efficiency of business enterprises. The methodology is called Data Envelopment Analysis or DEA. After discussing the distinction between technical and economic efficiency, the author explains what DEA is and how it can be used to partition a group of firms into those that are DEA-efficient and those that are not. She illustrates the usefulness of the technique with data for 60 Missouri commercial banks for the period 1984-90.

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R. Alton Gilbert

R. Alton Gilbert is an assistant vice president at the Federal Reserve Bank of St. Louis. Richard I. Jako provided research assistance.

Implications of Netting Arrangements for Bank Risk in Foreign Exchange Transactions

THE MAJOR FINANCIAL institutions of many nations are active participants in the market for foreign exchange. The exchanges of currencies that take place through this market facilitate international trade and the international flow of capital for investments.

The volume of transactions in the foreign exchange market—already very large—has grown rapidly in recent years. As of April 1989, the date of the last international survey, foreign exchange transactions had an average value of $640 billion per business day.

With dollar amounts in this lofty range, participants in the foreign exchange market could incur substantial losses if the other parties to their transactions were to default on the payments required to settle their side of the transactions. To reduce the costs of transactions and limit the size of these possible losses, some banks engage in bilateral netting of their foreign exchange transactions.[1] In bilateral netting, two banks exchange daily only the net units of currencies in the transactions between them.

Some groups of banks have also studied the possibility of multilateral arrangements for netting foreign exchange transactions, though none are in operation at this time.[2] Members of a multilateral netting arrangement would settle transactions with each other by making payments to a clearing house for their net position in each currency with the other members.

As part of their responsibility to avoid disruptions in the operation of payment systems, central banks have a strong interest in such netting

[1]Netting agreements between pairs of banks may apply to payments in settlement of transactions other than foreign exchange. This paper, however, limits analysis to the netting of foreign exchange transactions. All participants in the foreign exchange market are called banks to simplify exposition. In some markets, the important participants include firms that are not banks. See Federal Reserve Bank of New York (1989) and Bank of England (1989). See glossary on page 14 for definition of netting and other terms used in this paper.

[2]See Deeg (1990), Duncan (1991), Luthringhausen (1990) and Polo (1990).

Table 1

Minimum Standards for the Design and Operation of Cross-Border and Multi-Currency Netting and Settlement Schemes

I. Netting schemes should have a well-founded legal basis under all relevant jurisdictions.

II. Netting scheme participants should have a clear understanding of the impact of the particular scheme on each of the financial risks affected by the netting process.

III. Multilateral netting systems should have clearly defined procedures for the management of credit risks and liquidity risks which specify the respective responsibilities of the netting provider and the participants. These procedures should also ensure that all parties have both the incentives and the capabilities to manage and contain each of the risks they bear and that limits are placed on the maximum level of credit exposure that can be produced by each participant.

IV. Multilateral netting systems should, at a minimum, be capable of ensuring the timely completion of daily settlements in the event of an inability to settle by the participant with the largest single net-debit position.

V. Multilateral netting systems should have objective and publicly disclosed criteria for admission which permit fair and open access.

VI. All netting schemes should ensure the operational reliability of technical systems and the availability of back-up facilities capable of completing daily processing requirements.

SOURCE: Bank for International Settlements (1990c).

arrangements.[3] Since foreign exchange transactions often involve parties headquartered in different countries, a default by one participant is likely to affect those in other countries. Banks adversely affected by such defaults typically would turn to their central banks for assistance in coping with liquidity problems.

In recent years, promoters of interbank netting arrangements have requested the views of central banks individually on projects that appeared to have implications for a number of countries. The central banks of 10 major industrialized countries recently issued a joint statement, through the Bank for International Settlements, about the netting of foreign exchange transactions. This is commonly called the "Lamfalussy Report," named after the committee chairman who drafted the report. The committee expressed concern about the risks involved in settling foreign exchange transactions and discussed the potential benefits and drawbacks of netting arrangements. The central bankers listed minimum standards for the design of netting arrangements for bankers who may develop them (see table 1).[4]

This paper illustrates the risk in settling foreign exchange transactions and the risk implications of netting, using a hypothetical example of transactions among three banks. This exercise illustrates how netting may reduce risk, if netting arrangements conform to the guidelines in the Lamfalussy Report.[5]

THE MARKET FOR FOREIGN EXCHANGE

A foreign exchange transaction is an agreement by two parties (generally large banks) to exchange currencies on a given date, called the value date of the transaction. The most common type of transaction between participants in the foreign exchange market, a *spot* transaction, is an agreement between two parties to exchange units of currencies two business days from the date the transaction is negotiated. A transaction with a value date more than two days after the

[3]See Summers (1991) for a discussion of the role of central banks in the operation of payment systems.

[4]Bank for International Settlements (1990c).

[5]Cody (1990) also provides an introduction to the risk in settling foreign exchange transactions and the implications of netting. See Juncker, Summers and Young (1991) for a general discussion of the issues raised by netting arrangements.

date of negotiation is called a *forward* transaction. Some forward transactions have value dates more than a year into the future, but most call for settlement within a month. Several other types of transactions, including futures contracts, options and swaps, have been developed to more effectively limit the effects of changes in exchange rates on the wealth of banks and their customers.[6]

Large commercial banks are the major participants in the foreign exchange market. The latest international survey of foreign exchange activity, in April 1989, indicates that the three most active centers are London, New York and Tokyo (table 2). The value of foreign exchange transactions has been growing faster than international trade in goods and services (table 3). Such growth reflects more than the growth of international trade; it also reflects international capital flows and transactions by banks and their customers to manage exchange rate risk.

Transactions in the foreign exchange market link the major financial institutions of the world. In the London market, for instance, 80 percent of the value of foreign exchange transactions in April 1989 was by firms with headquarters outside of England.[7] In the survey of foreign exchange market activity in New York, 40 percent of the value of transactions was reported by offices of foreign banks.[8] Thus, one of the important ways in which a major financial institution can affect institutions in other countries is by defaulting on foreign exchange transactions.

THE CONFIRMATION AND SETTLEMENT OF FOREIGN EXCHANGE TRANSACTIONS

The process of confirmation and settlement begins after traders at two banks agree on the terms of a transaction. Each bank sends the other a message specifying the terms of the transaction, using a variety of methods, including telephone calls. If the details of the messages match, the transaction is considered confirmed.

The next step depends on the value date of the transaction. If it is a forward transaction, with a value date several weeks or months into the future, the information is stored for future settlement. On the value date, banks transmit information to initiate payment. The steps to initiate payment depend on the payment system used in the country issuing the currency and the relationship of the paying bank to that pay-

Table 2

Foreign Exchange Market Activity in April 1989 (billions of U.S. dollars)[1]

Countries and items	Value of transactions per day
United Kingdom	$ 187[2]
United States	129[2]
Japan	115
Switzerland[3] [85%]	57
Singapore	55
Hong Kong	49
Australia	30
France[3] [95%]	26[2]
Canada	15
Netherlands	13[2]
Denmark[3] [90%]	13
Sweden	13
Belgium[3] [90%]	10
Italy[3] [75%]	10
Other countries[4]	22
Total	744
Adjustment for cross-border double-counting	−204
Total reported net turnover	540
Estimated gaps in reporting	100
Estimated global turnover	$ 640

[1]Value of transactions in currencies other than U.S. dollar converted to dollars at prevailing exchange rates. The figures for individual countries indicate turnover net of double-counting arising from local interbank business. The totals at the foot of the table are estimates of turnover net of double-counting arising from both local and cross-border interbank business.

[2]Based on estimates of domestic and cross-border interbank business arranged through brokers.

[3]No adjustment for less than full coverage; estimated market coverage is given in square brackets.

[4]Bahrain, Finland, Greece, Ireland, Norway, Portugal and Spain.

SOURCE: Bank for International Settlements (1990a).

[6]For a more detailed discussion of the foreign exchange market, see Chrystal (1984).

[7]Bank of England (1989).

[8]Federal Reserve Bank of New York (1989).

Table 3
Growth of Foreign Exchange Market Transactions, Foreign Trade and International Banking Activity

Countries	Value of foreign exchange transactions: percentage change between March 1986 to April 1989 net turnover	Exports and imports of goods and services: percentage change from I/1986 to I/1989
United Kingdom	108%	62%
United States	120	44
Japan	140	82
Canada	58	44
Total	116	56

SOURCE: Bank for International Settlements (1990a).

ment system. For a bank paying in a currency other than that of its home country, payment generally is made by a correspondent headquartered in the foreign country. A correspondent is a bank that holds deposits and provides services for other banks. The paying bank commonly sends a message over SWIFT, instructing its correspondent to make payment to the counterparty in the foreign exchange transaction.[9]

Suppose, for instance, that a bank headquartered in the United States must pay German marks to a counterparty to settle a foreign exchange transaction. The U.S. bank instructs its German correspondent to make payment to the counterparty (or the counterparty's German correspondent). The German correspondent debits the account of the U.S. bank denominated in marks and transfers the marks to the counterparty. Suppose a U.S. bank is obligated to pay dollars. It would send a message over CHIPS to make payment to the counterparty, either directly if it is a member of CHIPS, or through a correspondent in New York who is a member of CHIPS.[10]

THE RISKS INVOLVED IN SETTLING FOREIGN EXCHANGE TRANSACTIONS: AN ILLUSTRATION

Banks assume the risk that their counterparties will default on payments on their side of foreign exchange transactions. Effects on counterparties of default on settlement obligations depend on the financial condition of the bank that defaults. A solvent bank may default for a variety of reasons. Operating problems (for example, computer failure) may prevent them from executing their payment instructions. A solvent counterparty may not have funds in the proper currency on the value date, or simply may forget to send payment orders to settle some of their transactions.

Defaults by solvent banks on settlement obligations may have systemic effects, preventing other banks from settling their obligations. These banks may turn to their central banks for short-term loans denominated in the curren-

[9]SWIFT (Society for Worldwide Interbank Financial Telecommunication) is an electronic system, located in Brussels, Belgium, for sending messages among the world's major banks.

[10]See Bank for International Settlement (1990b) for a description of payments systems in various countries. CHIPS (Clearing House for Interbank Payments System) is an electronic payments system operated by the New York Clearing House Association. CHIPS participants (131 as of the end of 1990) exchange payment messages during each business day and settle for the net amounts at day-end with transfers of reserve balances at the Federal Reserve. See Federal Reserve Bank of New York (1991). A large share of CHIPS messages involve payment for the dollar side of foreign exchange transactions. Given that most foreign exchange transactions involve the U.S. dollar, CHIPS has a major role in the settlement of foreign exchange transactions. See Federal Reserve Bank of New York (1987).

Table 4

Payments in Settlement of Foreign Exchange Transactions under Gross Settlement and Bilateral Netting

Counterparties	Transaction number	Gross settlement: Direction of payment	Gross settlement: Units of currencies	Bilateral netting: Direction of payment	Bilateral netting: Units of currencies
Bank A and Bank B	1	Bank A to Bank B	£ 100	Bank A to Bank B	£ 50
		Bank B to Bank A	$175	Bank B to Bank A	$90
		(Profit of $10.00 for Bank A)		(Profit of $7.50 for Bank A)	
	2	Bank A to Bank B	$85		
		Bank B to Bank A	£ 50		
		(Profit of −$2.50 for Bank A)			
Bank A and Bank C	1	Bank A to Bank C	£ 100	Bank A to Bank C	$92.50
		Bank C to Bank A	$170	Bank C to Bank A	£ 50
		(Profit of $5.00 for Bank A)		(Profit of −$10.00 for Bank A)	
	2	Bank A to Bank C	$262.50		
		Bank C to Bank A	£ 150		
		(Profit of −$15.00 for Bank A)			
Bank B and Bank C	1	Bank B to Bank C	£ 150	Bank B to Bank C	£ 100
		Bank C to Bank B	$262.50	Bank C to Bank B	$177.50
		(Profit of $15.00 for Bank B)		(Profit of $12.50 for Bank B)	
	2	Bank B to Bank C	$85.00		
		Bank C to Bank B	£ 50		
		(Profit of −$2.50 for Bank B)			

cies necessary to settle their obligations. Thus, central banks have a collective interest in minimizing the chances of such liquidity problems.

Most liquidity problems are often only temporary. Bankruptcy and liquidation of a participant in the foreign exchange market, however, pose a more serious threat to individual counterparties and create the potential for systemic disruptions in the payment system (default by one bank causing default by others). Under a general definition of bankruptcy, the value of liabilities exceeds the value of assets. Some large bankrupt banks have been reorganized with assistance of their home governments. The reorganized banks continue to operate as going concerns, making payments in settlement of their obligations. Such reorganizations impose no losses on their counterparties.

In other cases, however, bankrupt banks cease to operate as going concerns. The courts appoint receivers to liquidate the bankrupt banks' assets and make payments to their creditors. The receivers may impose losses on other banks that were counterparties to foreign exchange transactions. Such losses depend on the legal principles followed by bankruptcy courts and the nature of netting agreements between counterparties.

The effects of the liquidation of a participant in the foreign exchange market on its counterparties are illustrated below. Legal assumptions are specified along the way as the example raises questions about the principles followed by bankruptcy courts. In each case in which a bank is assumed to go bankrupt, it is also assumed to be liquidated by a court-appointed receiver.

The Example

Suppose three banks (A, B and C) engage in foreign exchange transactions in two currencies: the U.S. dollar and the British pound. Each bank has foreign exchange transactions with the other two. Table 4 lists the transactions between the counterparties to be settled on the same value date. Each pair of banks has two transactions to settle. In one transaction, a bank pays dollars in exchange for pounds; in the other, a bank pays pounds in exchange for dollars.

The exchange rate on the value date is $1.65 per British pound. Transactions to be settled on the value date were negotiated a few days earlier when the exchange rate was higher: some transactions were negotiated with an exchange rate of $1.70; others, with an exchange rate of $1.75. Transactions are of varying size, creating imbalances in the flows of currencies between counterparties.

The example is designed to be as simple as possible and yet illustrate the risk involved in netting arrangements. There must be at least two transactions between a pair of banks if bilateral netting is to reduce the volume of payments and settlement risk. Three is the minimum number of banks for multilateral netting.

The Effects of Bilateral Netting on the Number and Value of Transactions

Figure 1 illustrates how bilateral netting affects the flows of currencies between Banks A and B in settling the transactions listed in table 4. Under gross settlement, banks make payments to each other to settle each transaction between them. To settle transaction number 1, Bank A pays £ 100 to Bank B, receiving $175 in turn. Since the exchange rate is $1.65 on the value date, this exchange of currencies yields a profit of $10 to Bank A. (Bank A receives $175, whereas the £ 100 paid by Bank A has a value of $165 on the value date). Bank A pays $85 to Bank B in settlement of transaction number 2, receiving £ 50. This exchange yields a loss of $2.50 for Bank A on the value date.

Banks A and B can economize on transactions by netting their payments flows. As illustrated in the bottom half of figure 1, Bank A could pay £ 50 to Bank B and receive $90 from Bank B. Bilateral netting reduces the number of payments from four to two and the value of payments, converted to dollars at the exchange rate of $1.65, from $507.50 to $172.50.

The Risk in Settling Foreign Exchange Transactions without a Netting Arrangement

To illustrate how netting arrangements affect risk, one must first understand the risk that banks assume without a netting agreement.

Legal Assumptions — This section specifies several assumptions about the legal principles that the bankruptcy court follows when banks settle their transactions without netting arrangements. While these principles are not applied in all cases, they are common and they simplify the analysis.

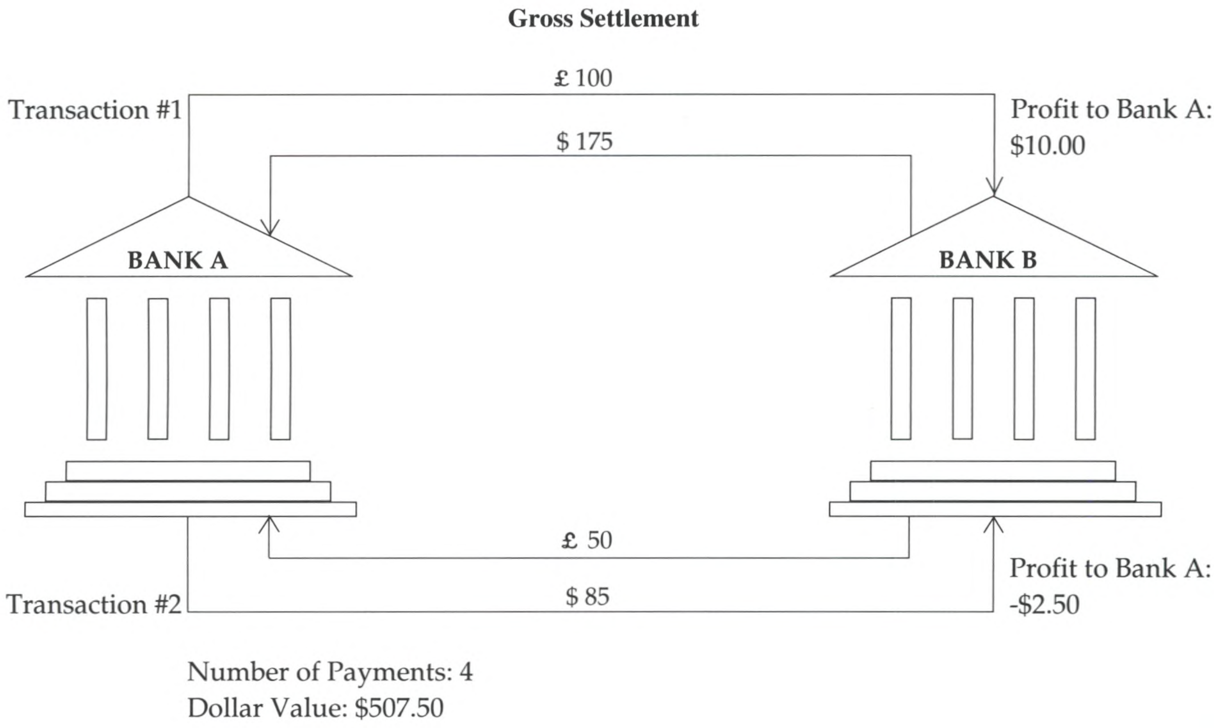
One assumption concerns the application of *legal rights of set-off* permitted by the court. Under the legal rights of set-off, the counterparty of a failed bank may settle its obligations with the receiver by paying the net amount of the transactions between them. If on net the failed bank owes a solvent counterparty, the counterparty is a general creditor of the failed bank for the net amount. Applying the rights of set-off to the foreign exchange transactions between a pair of banks yields the same loss to the solvent counterparty as it would under bilateral netting. Applying the legal rights of set-off, however, is uncertain and varies among the courts of different countries.[11] In this paper, rights of set-off are assumed not to apply in bankruptcy. Each transaction is treated separately, not linked to other transactions between the same parties.

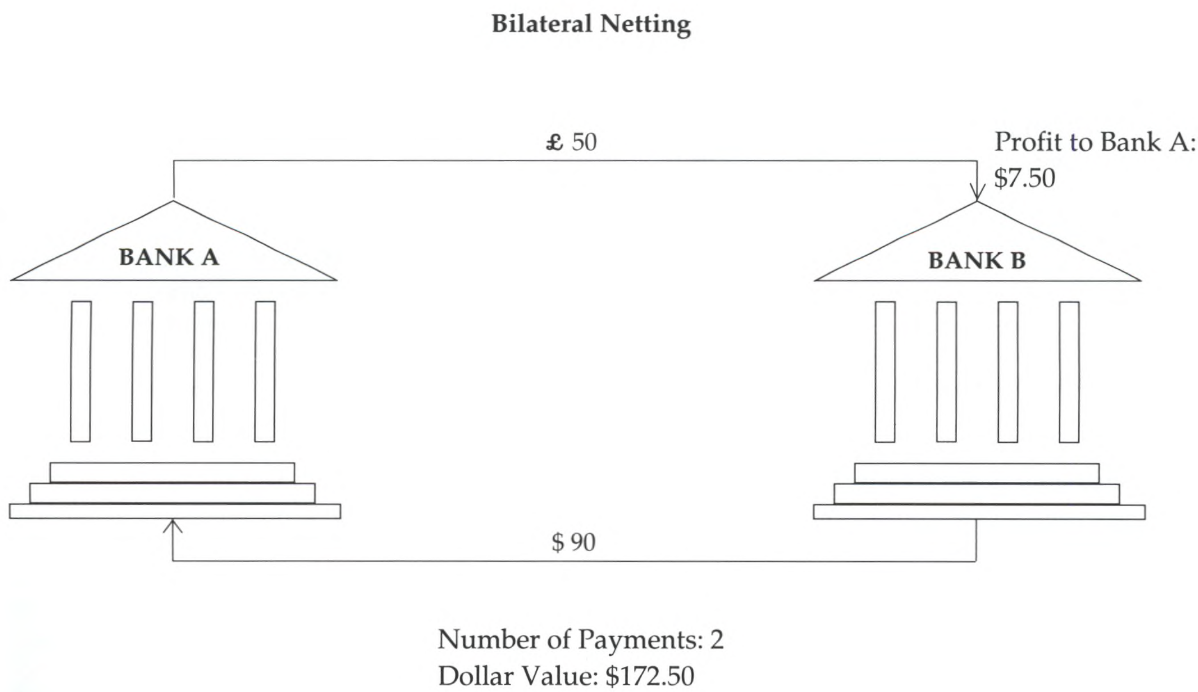
The court with jurisdiction in a bankruptcy case is assumed to appoint a receiver. In making payments to settle foreign exchange transactions or defaulting on transactions, the receiver acts to maximize the return to all creditors of the failed bank, without regard for the counterparties to foreign exchange transactions as a particular group of creditors.

A final issue concerns the status of claims against a bankrupt bank that result from its default on foreign exchange transactions. Solvent counterparties are assumed to have the status of general creditors. In our example, losses are calculated under the assumption that general creditors receive nothing. All proceeds from the liquidation of assets go to creditors with more senior claims.

[11]Bank for International Settlements (1989), pp. 13-14.

Figure 1
Flow of Currencies Between Banks Under Gross Settlement and Bilateral Netting





These legal assumptions yield the maximum losses to counterparties. Thus, the losses calculated in particular cases can be viewed as the maximum, not necessarily the most likely, losses.

Timing of Bankruptcy and Size of Exposure — Suppose Banks A and B agree to settle their transactions as illustrated in the top half of figure 1, the gross settlement method. Suppose also that Bank A goes bankrupt before the four payments are executed on the value date. The possible loss to Bank B depends on the timing of the bankruptcy of Bank A.

In one situation, called *pre-settlement failure*, Bank A goes bankrupt before the value date, and Bank B knows about this event by the opening of business on the value date. In the other situation, called *settlement failure*, a bank makes payment on the value date for its side of foreign exchange transactions but does not receive payment from a counterparty.

One feature of the foreign exchange market that makes banks vulnerable to settlement failure is the difference in the time zones of central banks. The failure of the Herstatt Bank in 1974 illustrates the relationship between time zones and settlement failure. On June 26, 1974, German banking authorities closed Herstatt as of the close of business in Germany. Herstatt had received payment in marks during German banking hours for its foreign exchange transactions with that value date. It was closed, however, before the time for making payments in dollars in New York. Counterparties of Herstatt were left without the dollars they expected, after paying marks to Herstatt earlier in the day.[12]

Our example of settlement failure in this paper reflects the implications of differences in time zones. One bank is assumed to go bankrupt after the time for payments in pounds but before the time for making payments in dollars.

Pre-Settlement Failure — Suppose Bank A goes bankrupt before the value date. Without a netting agreement between Banks A and B, the legal obligations of each bank are those specified in the individual transactions between them. With an exchange rate of $1.65 on the value date, transaction number 1 is profitable to Bank A. The receiver of Bank A will pay £ 100 to Bank B to settle transaction number 1. Bank B is obligated to pay $175 to Bank A to settle this transaction. Since transaction number 2 is not profitable to Bank A on the value date, the receiver will default on transaction number 2. Bank B anticipated a profit of $2.50 on the value date from transaction number 2. Thus, the bankruptcy of Bank A imposes a loss of $2.50 on Bank B. Table 5 shows the loss to each bank due to the bankruptcy of its counterparty before the value date, under both gross settlement and netting arrangements.

Settlement Failure — Suppose Bank A goes bankrupt on the value date after payment in pounds but before payment in dollars. Bank A defaults on its payment of $85 to Bank B on the value date. Under gross settlement of transactions, however, Bank B is obligated to pay the $175 to Bank A. Bank B becomes a general creditor of Bank A for $85. The maximum loss to Bank B, as table 6 indicates, is $85.

Settlement failure can create liquidity problems for the counterparties of a failed bank. Suppose Bank B pays the $175 to Bank A before discovering that Bank A is bankrupt. The cash balances of Bank B denominated in dollars will be $85 below the level it had projected for the value date. Bank B might request a discount window loan from the Federal Reserve to cover the $85 shortfall in its reserve account.

How Bilateral Netting Affects the Losses in Settlement of Foreign Exchange Transactions

If Banks A and B engage in bilateral netting, the effects of the bankruptcy of Bank A on Bank B depend on whether paying the net amount discharges the obligations between counterparties.

Legal Assumptions — Under one type of agreement called *position netting*, two banks agree to net their payments to reduce transactions costs, but the agreement has no effect on their legal obligations. Under the legal assumptions in this paper, the position netting agreement would not prevent the receiver from making payments in settlement of some transactions but defaulting on others with the same counterparty. The bankruptcy court would treat the payment obligation of Banks A and B as though they had no netting agreement. The bankruptcy of one party has the same implica-

[12]Moore (1974).

Table 5

Bank Losses from Pre-Settlement Failure

Failure of	Losses to Bank A	Bank B	Bank C
Bank A			
Gross settlement		$ 2.50	$15.00
Bilateral netting		0.00	10.00
Multilateral netting		0.00	2.50
Bank B			
Gross settlement	$10.00		2.50
Bilateral netting	7.50		0.00
Multilateral netting	0.00		0.00
Bank C			
Gross settlement	5.00	15.00	
Bilateral netting	0.00	12.50	
Multilateral netting	0.00	2.50	

Table 6

Bank Losses from Settlement Failure

Failure of	Losses to Bank A	Bank B	Bank C
Bank A			
Gross settlement		$ 85.00	$262.50
Bilateral netting		0.00	92.50
Multilateral netting		0.00	2.50
Bank B			
Gross settlement	$175.00		85.00
Bilateral netting	90.00		0.00
Multilateral netting	0.00		0.00
Bank C			
Gross settlement	170.00	262.50	
Bilateral netting	0.00	177.50	
Multilateral netting	0.00	85.00	

tions for the counterparty as if they settled transactions using the gross settlement method.

Netting agreements that reduce this exposure to loss mandate that banks discharge their obligations by paying the net amount of the transactions between them. The legal language for such agreements is *netting by novation.* This paper assumes that bankruptcy courts recognize a contract for netting by novation as the only contract between counterparties for settlement of foreign exchange transactions.

A provision of bilateral netting contracts that reduces risk is called *closeout*, which becomes effective when a receiver or liquidator is appointed after a bank declares bankruptcy.[13] A netting agreement includes a formula that converts all outstanding transactions between a pair of counterparties, for all value dates, into one amount payable immediately. The closeout provision prohibits the receiver of a bankrupt bank from making payments in settlement for transactions with some value dates but defaulting on transactions with other value dates.[14] Bankruptcy courts are assumed to recognize closeout provisions as valid parts of netting arrangements.

Pre-settlement Failure — As the bottom half of figure 1 illustrates, the one contract between Banks A and B under netting by novation calls for Bank A to pay £ 50 and receive $90. At the exchange rate of $1.65 on the value date, this contract is profitable for Bank A. Thus, the receiver of Bank A would pay the £ 50 to Bank B to settle the contract. The bankruptcy of Bank A prior to the value date would impose no loss on Bank B, since Bank B had anticipated honoring its contract with Bank A before discovering that Bank A was bankrupt. In each case of pre-settlement failure illustrated in table 5, the losses are smaller under bilateral netting by novation than under gross settlement.

Settlement Failure — The bankruptcy of Bank A after payments in pounds but before payments in dollars imposes no loss on Bank B since, under the netting agreement, Bank A had no obligation to pay dollars to Bank B. As table 6 indicates, in settlement failure, the loss to a bank from the bankruptcy of its counterparty is

[13]Bank for International Settlements (1989), p. 13.

[14]One firm that offers legal advice and a communications network for bilateral netting by novation is FXNET. The netting contract drafted by FXNET includes netting by novation and closeout. See Bartko (1990). For further reference to FXNET, see Scarlata (1992), this *Review*. Plans for multilateral netting include similar closeout provisions in contracts between individual members and the clearing houses that would act as paying agents for the netting arrangements. See Duncan (1991). These closeout provisions limit the losses of solvent banks resulting from default by counterparties.

smaller under bilateral netting by novation than under gross settlement for each combination of failed bank and counterparty.

The Importance of the Legal Basis for Netting Agreements

The assumptions in this paper concerning the principles that bankruptcy courts follow yield the maximum reductions in losses from netting. These reductions in losses could be smaller under alternative assumptions.

The Lamfalussy Report indicates that bilateral netting could increase risk in settling foreign exchange transactions if netting arrangements do not have a sound legal basis. If netting "obscures the level of exposures, then netting arrangements have the potential to contribute to an increase in systemic risk."[15] The argument that bilateral netting may pose greater risks is based on assumptions about how banks that are active in the foreign exchange market set credit limits with counterparties. Banks with bilateral netting agreements may set credit limits with each other based on their net positions rather than the gross value of the underlying transactions between them. If a bankruptcy court requires payments by a solvent counterparty based on the value of the underlying transactions rather than the netting agreement, the exposure of the solvent counterparty would be larger than expected. This point indicates why the Lamfalussy Report emphasizes the legal basis for netting arrangements (table 1).

Multilateral Netting

Banks may be able to further reduce their transaction costs and their exposure to loss by engaging in multilateral netting. No multilateral netting arrangements are in operation at this time. This section examines the implications of a multilateral netting arrangement modeled after a draft of the plans of the ECHO NETTING system in London.[16]

Legal Assumptions — In the contract for multilateral netting, members of a netting arrangement establish a clearing house, which receives and pays out currencies in settlement of foreign exchange transactions. The clearing house is the counterparty for each transaction between members of the multilateral netting arrangement. Each member settles its legal obligations with the others by making payments to the clearing house. The clearing house assumes responsibility for paying all net amounts due to members, even if a member defaults on its payments to the clearing house.

The contract in a multilateral netting arrangement is assumed to include a closeout provision. If a member of the clearing house goes bankrupt, its receiver has only one decision to make about the foreign exchange transactions that the failed bank negotiated with other members: make the payments to settle the one contract with the clearing house or default.

Payments Flows and Loss Sharing — Figure 2 presents the payments between members of the netting arrangement and the clearing house, derived from payments that would be made under bilateral netting in table 4. The calculation of the numbers in figure 2 is illustrated for Bank A. Under bilateral netting, Bank A pays the other banks £ 50 (Bank B) and $92.50 (Bank C) and receives $90 (Bank B) and £ 50 (Bank C). Under multilateral netting, therefore, Bank A owes the clearing house $2.50 and the clearing house owes Bank A nothing on the value date. Figure 2 also indicates the payments between the clearing house and Banks B and C.

Any clearing house losses resulting from the default of a member are allocated to the other members in proportion to the losses they would have incurred under bilateral netting. This formula gives each member of the arrangement an incentive to avoid transactions with members it considers to be in danger of going bankrupt.

Pre-Settlement Failure — If Bank A goes bankrupt before the value date, its receiver will default on the payment of $2.50 to the clearing house. The loss of $2.50 is allocated to Bank C, since only Bank C would have a loss under bilateral netting.

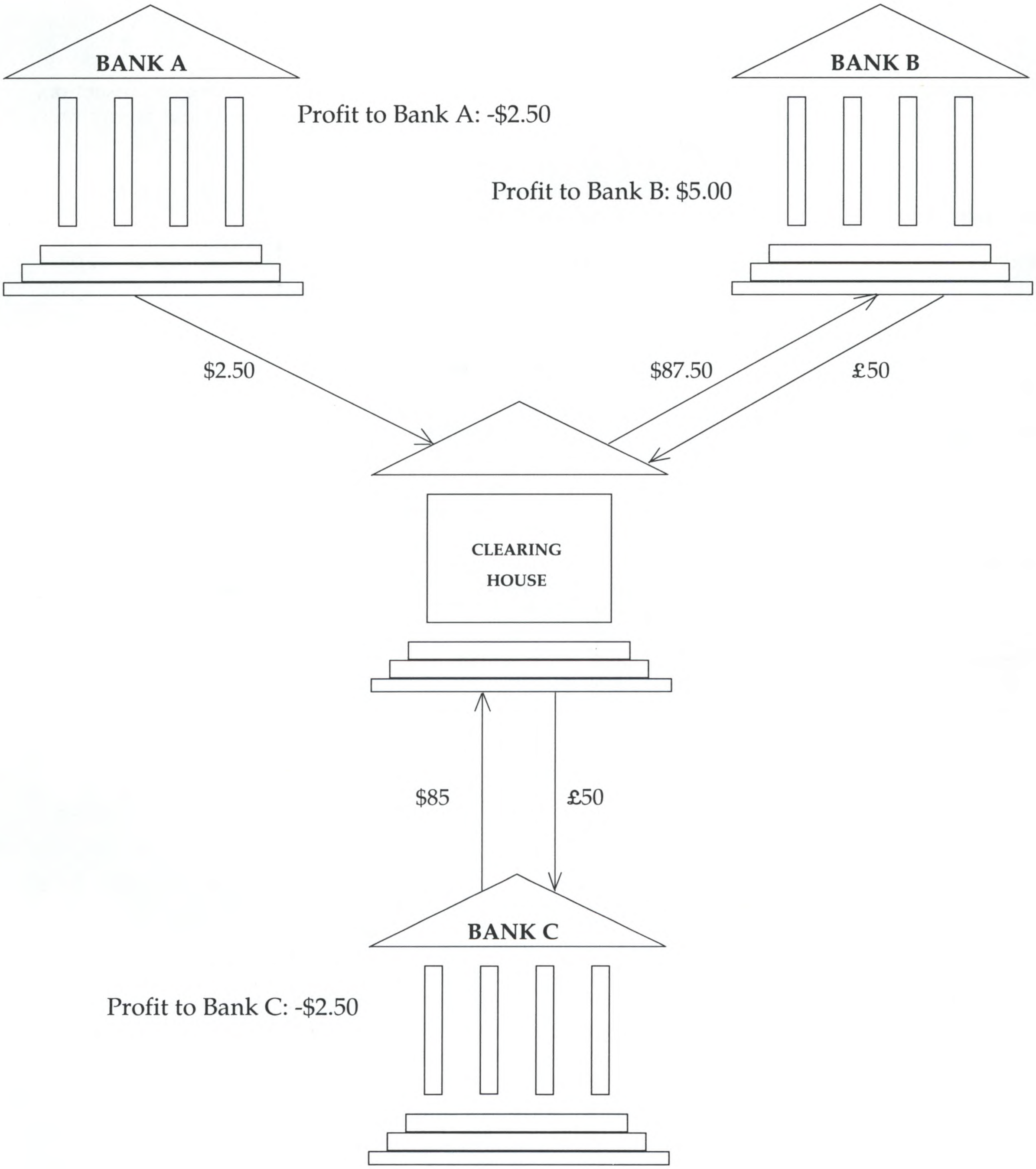
If Bank B goes bankrupt before the value date, its receiver will make the payment of £ 50 to settle the contract with the clearing house, since it yields a profit of $5 to Bank B. As table 5 indicates, the bankruptcy of Bank B before the value date imposes no loss on the other banks. The bankruptcy of Bank C imposes a loss of $2.50 on Bank B. In each case in table 5, the

[15] Bank for International Settlements (1990c), p. 3.

[16] Duncan (1991).

Figure 2

Payments Between Members of a Multilateral Netting Arrangement and the Clearing House



Number of Payments: 5
Dollar Value: $340

A Glossary of Terms

Bilateral netting — An arrangement between two parties in which they exchange only the net units of the currencies specified in the transactions between them, rather than the currencies for each transaction individually.

Clearing house — An institution established by a group of banks to facilitate the settlement of obligations among themselves. Each bank settles its obligations with the others by making payment to the clearing house for the net amount owed the other members.

Counterparty — The other party in a transaction. In a foreign exchange transaction, one party agrees to make payment in one currency and its counterparty agrees to pay in another currency.

Foreign exchange transaction — An agreement by two parties (generally large banks) to exchange currencies on a given date.

Gross settlement — A method of making payments between a pair of parties in which each party makes a separate payment in settlement of each transaction between them.

Legal rights of set-off — Under bankruptcy law, a right to net obligations with a bankrupt counterparty.

Multilateral netting — An arrangement between three or more parties in which each member makes payments to a clearing house for the net payments due to the other members and receives from the clearing house the net amounts due from the other members.

Netting — An arrangement by which parties with more than one transaction to settle on a given date exchange only the net amounts of the transactions between them.

Netting by novation — The replacement of two existing contracts between two parties for delivery of a specified currency on the same date by a single net contract for that date, so that the original contracts are satisfied and discarded.

Position netting — The netting of payment obligations between two or more parties which neither satisfies nor discharges the original obligations that were netted.

Pre-settlement failure — Bankruptcy of a bank prior to the value date of transactions with a counterparty.

Settlement — Completion of a payment between two parties discharging an obligation.

Settlement failure — Default by a bank on payment in one currency after the bank and its counterparty had made payments in the other currency.

Systemic risk — The risk that the inability of one institution within a payment system to meet its obligations when due will cause other participants to be unable to meet their obligations when due.

Value date — The date on which banks exchange currencies in settlement of a foreign exchange transaction.

loss under multilateral netting is either zero or smaller than under bilateral netting.

Settlement Failure — Suppose Bank A goes bankrupt after the payment of pounds but before the payment of dollars. The loss to be borne by members of the clearing house is $2.50, the payment obligation of Bank A. This loss is imposed on Bank C, which would have a loss of $92.50 under bilateral netting (table 6).

Bank B has no obligation to pay dollars to the clearing house. Thus, the bankruptcy of Bank B after the payment of pounds but before the payment of dollars imposes no losses on other members of the clearing house. The bankruptcy of Bank C after payment in pounds imposes a loss of $85 on Bank B. The loss in each case under multilateral netting in table 6 is either zero or less than the loss under bilateral netting.[17]

Liquidity Requirements of the Clearing House

One of the concerns central bankers have about multilateral netting is whether the clearing house would have access to sufficient liquidity to make payments to other members if one of them defaults. The Lamfalussy Report indicates that a clearing house should "be capable of ensuring the timely completion of daily settlements in the event of an inability to settle by the participant with the largest single net-debit position." In figure 2, Banks A and C each have net debit positions of $2.50. The clearing house would need access to at least $2.50 to meet the minimum liquidity requirement of the Lamfalussy Report. This requirement is a cost of operating the clearing house, either as the opportunity cost of liquid assets held by the clearing house or the cost of credit lines. Bilateral netting, in contrast, involves no such costs.

CONCLUSIONS

Banks assume risk in settling foreign exchange transactions. This paper examines the implications of netting by using a hypothetical example. The example shows how netting schemes can reduce the size of losses to counterparties when a bank goes bankrupt and is liquidated.

A committee of central bankers from the major developed countries recently examined the implications of netting arrangements for risk. The committee's report indicates that netting arrangements may either increase or decrease risk, depending on whether they meet certain minimum standards listed in the report.

Bilateral netting could reduce the loss when a counterparty defaults, if the bankruptcy court would recognize the payment of the net amount between the counterparties as a settlement of the transactions between them. It could increase risk in settlement of foreign exchange transactions, however, if counterparties set credit limits based on their net exposures but the court requires payment in settlement for each underlying transaction between counterparties.

Multilateral netting can reduce the losses resulting from default even more than bilateral netting, if the clearing house created to settle transactions has access to the liquid assets necessary to complete the settlement. Lack of sufficient liquidity for the clearing house could create a major disruption in the operation of the payment system.

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[17]The generality of the result that netting reduces losses to solvent counterparties can be investigated by simulating the losses resulting from default in an example with more banks and more transactions and with some terms of the transactions chosen at random. Our simulation includes 10 banks. Each has 10 transactions to settle with each of the other nine banks. The size of the transactions and exchange rates are chosen at random. The multilateral netting arrangement uses the loss-sharing formula described above. Each of the 10 banks is assumed to go bankrupt, imposing losses on nine counterparties. In each of the 90 cases of losses to counterparties, losses are smaller under bilateral netting than under the gross settlement method, and losses under multilateral netting are either zero or smaller than under bilateral netting.

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Institutional Developments in the Globalization of Securities and Futures Markets

FINANCIAL TRANSACTIONS such as the buying and selling of securities, commodities, foreign exchange and bonds, have increasingly involved individuals and firms from different countries. For example, a Japanese resident might purchase U.S. dollars with Japanese yen (a foreign exchange transaction) to buy shares of IBM on the New York Stock Exchange (a securities transaction). To accommodate such transactions, futures and securities exchanges have expanded the services they offer their users, adding numerous financial instruments, engaging in cooperative efforts across exchanges and introducing computer-based technologies.

The globalization of world markets provides significant benefits, including greater opportunities for investors to diversify risk, and access to broader markets for demanders of funds. International trading in financial instruments, however, does pose risks, some of which can be mitigated by coordination between global financial markets.

This paper describes recent institutional developments in the globalization of financial markets and discusses the advantages and disadvantages of these innovations. The paper opens with a brief overview of the various transnational developments that are occurring in world securities and commodities markets. It then addresses both the benefits of expanding financial markets and the costs that accompany the move. Risk factors and standardization of procedures are highlighted as issues of concern as financial centers globalize. The paper closes with a discussion of the Group of Thirty proposal for the coordination of clearing and settlement in world securities markets.

INTERNATIONAL DEVELOPMENTS IN FINANCIAL AND COMMODITY MARKETS

The trend toward internationalization of financial markets can be illustrated by highlighting the rapid increases in transactions in a few markets. For example, cross-country activity, when measured as the volume of foreign transactions in securities of U.S. firms (aggregate purchases and sales), grew from $75.3 billion in 1980 to $361.4 billion in 1990.[1] Similarly, U.S. transactions in securities of foreign firms (aggregate purchases and sales) grew from $17.85 billion to $253.4 billion between 1980 and 1990.[2] In futures and options markets, 20 new exchanges

[1] Abken (1991), p. 3.

[2] Ibid.

were established worldwide between 1985 and 1989, bringing the total to 72.[3] Likewise, nearly 40 million futures and options contracts were traded worldwide in 1988, an increase of approximately 186 percent since 1983.[4] Eurodollar interest rate futures saw an especially large change, increasing almost 70 percent annually between 1983 and 1988.[5]

Illustrations of Globalization

The globalization of financial and commodity markets involves numerous activities and institutional developments that facilitate access to foreign markets, whether by a trader or a security. One of these activities is the cross-listing of securities in several countries. Cross-listing simply means, for example, that a firm in the United States lists its stocks on a London exchange. In 1990, the International Stock Exchange (ISE) of London had one of the highest percentages (23 percent) of foreign company stock listings.[6]

Another trend is cross-country hedging and portfolio diversification. A U.S. trader, for example, can diversify a portfolio composed of U.S. stocks by buying stocks of a U.K. firm in London through a London broker. Globalization can also mean holding membership in another country's exchanges. For example, after "The Big Bang" of 1986 in London, many U.S. securities firms and banks applied to buy seats on London exchanges.[7]

A third trend in the internationalization of financial markets is called "passing the book," whereby control of trading is passed between traders at exchanges around the globe. This enables 24-hour trading of a financial instrument. An example of this would be a U.S. investment firm trading from New York during U.S. and Japanese hours and from its London desk during U.K. hours. The more common practice of passing the position book between time zones is actually to transfer the handling instructions between traders. An example is a New York currency trader who instructs the trader at his Singapore office to track the price of a currency during evening hours in New York. When the market reaches a particular price, the Singapore trader will buy or sell, depending on instructions from New York.

One trend that does not involve actual trading is the underwriting of corporate securities through offices outside the home country. An underwriter is a firm that buys an issue of securities from a company, then resells it to investors. For the company issuing the securities, underwriting provides a guarantee that a certain amount of money will be derived from the sale of the securities that can be used for capital expenditure. A large stock issue may have underwriters from several countries, for example, to compensate for a country whose capital market does not have the depth to handle large securities offerings.[8] The distribution of underwriters across several countries provides the issuing firm with a wider access to funding.[9] Investors, on the other hand, obtain a broader selection of securities.

Developments in Automated Trading Systems

More recently, the development of automated trading has received substantial attention. Automated or electronic trading systems allow agents to make trades via computer, without the "open outcry" or pit auction system.[10] Interestingly, the development of much of the current automation is an extension of technological innovations originally developed for domestic markets. It is clear, however, that this automation has af-

[3]Baer, Evanoff and Pavel (1991), p. 11.

[4]Ibid.

[5]Eurodollar deposits are dollar-denominated deposits outside the United States. Eurodollar interest rate futures contracts are futures contracts on the interest rates on these deposits. The figures are from Baer, Evanoff and Pavel (1991), p. 11.

[6]For the New York Stock Exchange, the figure was 3.7 percent. U.S. Congress, Office of Technology Assessment (1990), p. 29.

[7]The Big Bang was a deregulation effort for British financial markets which began on October 27, 1986. Examples of changes to the London equity markets are the end of fixed commission rates; barriers between order-taking brokers and risk-taking market makers were broken down; and, the self-regulating Securities and Investment Board (SIB) was established. The SIB is a non-governmental version of the Securities and Exchange Commission (SEC) in the United States. Khoury (1990), p. 129.

[8]Depth means that there are enough buyers and sellers in a market that a large transaction will not affect the price.

[9]An example is the privatization of French companies in 1986, where the value of these newly privatized companies was approximately $30 billion, but the total value of listings on the Paris Bourse was only about $80 billion. U.S. Congress, Office of Technology Assessment (1990), p. 34.

[10]Open outcry occurs on an organized exchange when orders between buyers and sellers are traded between third parties in anonymity. The buyer/seller enters into a contract with the exchange or its representative clearinghouse.

fected the globalization of financial markets considerably.

The National Association of Securities Dealers Automated Quotations (Nasdaq) was one of the earliest developments in financial market computerization, beginning in 1971. Nasdaq provides computer listings of price information for several thousand companies. By 1982, the National Association of Securities Dealers (NASD) had produced the National Market System, which provided investors with information as sales were completed, and by 1991, had developed the Private Offerings, Resales, and Trading through Automated Linkages (PORTAL) system.[11] From a computer terminal, PORTAL enables users to trade in unregistered domestic and foreign debt and equity securities.[12]

Nasdaq has established computer telephone linkage as well as automated trade execution and international clearing and settlement with the International Stock Exchange of London and the Stock Exchange of Singapore. Nasdaq has since become a significant market for the listing of foreign securities, trading approximately $6 billion in foreign securities as of 1991, up from the $2.6 billion in 1985.[13] Thus, Nasdaq provides the cross-listing of securities, together with the rapid trade execution of an automated system.

The growth of international trading has also affected futures and options exchanges in the United States. The fact that traders could access instruments and overseas markets after normal U.S. trading hours had ended, provided a motivation for many of the extended-hour and 24-hour trading initiatives (see shaded insert for examples of extended trading hours and table 1 for automated trading systems).

A significant portion of U.S. financial instruments, futures and options is traded at exchanges throughout the world. That is, foreigners do not have to use the Chicago Mercantile Exchange to trade Eurodollar contracts, a CME staple. For example, in 1989, a third of the trade in contracts offered by the CME originated outside of North America.[14] In 1989, 10 percent of the CME's daily volume was transacted overnight in an overseas exchange while the CME was closed.[15] Furthermore, in 1985, the CME and Chicago Board of Trade together accounted for 83 percent of all futures volume. By 1990, the figure had fallen to 55 percent.[16] The attempt to regain market share instigated such CME expansions as extended trading hours and automated trading systems.

Perhaps the most ambitious project in automated trading is Globex, an attempt to create a 24-hour trading market originally proposed in 1987 by the CME.[17] Globex is an electronic trade execution system whereby traders enter buy and sell orders that are matched automatically according to price and time priority.[18] Originating as a strictly off-hours trading system, the purpose of Globex is to enable continued active trading beyond the CME's regular trading hours. The CME intends to use Globex to access markets after its own close of business and regain some of the market share lost to foreign exchanges.

POTENTIAL GAINS AND RISKS OF INTERNATIONALIZATION

The significant changes accompanying the internationalization of financial trading systems allow for the realization of substantial gains; at the same time, globalization also exacerbates the risks already present in financial trading. The most significant of these gains and risks are described below.

Benefits of Globalization

One of the most important areas of progress is the speed with which information is processed and disseminated to market participants. Increased flow of market data provides greater

[11]PORTAL uses a book entry settlement system with no physical delivery, eliminating the problem of unmatched trades. PORTAL is currently the only fully automated clearing and settlement system in the United States. Clearing and settlement issues, book entry and matching trades will be discussed in more detail later in the text.

[12]Unregistered securities are not registered with the Securities and Exchange Commission (SEC). They are issued in a limited volume or by small companies.

[13]See Nasdaq (1991), p. 16, for the 1991 figure, and NASD (1991), p. 15, for the 1985 figure.

[14]Hansell (1989), p. 187.

[15]Ibid.

[16]Chesler-Marsh (1991), p. 33.

[17]The Chicago Board of Trade has since become a participant with the CME in the Globex project.

[18]For detailed reading on automated trading systems, see Domowitz (1990).

"After-Hours" Trading

The following is a listing of some of the developments in trading after regular operating hours.

New York Stock Exchange

Has two after-hours trading sessions, beginning June 13, 1991. One 45-minute, order-matching session and a one-hour-and-15-minute session for crossing baskets of stocks.

American Stock Exchange

Plans for an after-hours session between 4:15 p.m. and 5 p.m. where buyers and sellers can trade at regular session's closing price. Currently, talks with Reuters Holdings PLC, the Chicago Board Options Exchange and the Cincinnati Stock Exchange for a global after-hours trading system for stocks and their options and derivatives such as stock-index warrants.

Nasdaq

Has filed with the SEC to start trading on Nasdaq International at 3:30 a.m. EDT.

Midwest Stock Exchange

Will not have its own after-hours session, but will fill customer orders based on after-hours activity on the New York Stock Exchange.

Pacific Stock Exchange

Has filed plans with the SEC to extend trading in listed stocks in a regular auction market lasting until 4:50 p.m. EDT. Currently, PSE closes at 4:30 p.m. EDT. Will match buy and sell orders in a 5 p.m. EDT session at the NYSE closing price.

Philadelphia Stock Exchange

Trades currency options and futures for 20.5 hours a day. Has filed plans with the SEC for an after-hours order matching system similar to the Big Board. Also plans to fill customer orders based on after-hours activity on the Big Board.

Boston Stock Exchange

Will not have its own session, but will fill customer orders based on after-hours activity on the Big Board.

Chicago Board Options Exchange

Has no current plans to trade stock options before or after normal trading hours. Involved with Amex in electronic system.

Instinet

An electronic trading system owned by Reuters Holdings, operates up to 16 hours a day.

[1]"Big Board After-Hours Trading" (1991).

accessibility to foreign markets. In turn, the larger the number of participants using a market, the greater the liquidity of the market and, thus, its desirability for investors.[19]

The level of market activity and the transmission of data on prices, market supply and demand conditions are a few examples of information relevant to traders. Yet, this information technology has less to do with improving the efficiency of forecasting techniques than it does to shaving seconds off the receipt of up-to-the-minute market events. Information like the announcement of a commodity quota or a corporate merger provides the impetus for the rapid decision-making that characterizes financial trading.

Access to foreign stocks provides investors with opportunities for diversification; investors need information about the foreign firm (for example, its financial stability or successful management), however, in order to make an investment decision. The rapid rise of information technolo-

[19]Liquidity is the depth of the market (for example, securities or futures) and its ability to absorb sudden shifts in supply and demand without excessive price fluctuation.

gy increases the familiarity of foreign corporations and their operations. This spread of information reduces one of the traditional obstacles to foreign investment and opens up both savings and investment opportunities for firms and individuals. The payoff is a more efficient allocation of capital and, thus, a stimulus to production and real output.

Likewise, the advent of almost immediate transfer of information around the globe reduces the informational discrepancies between market participants. Arbitrageurs, of course, attempt to profit from price discrepancies. The more people have access to the same information, however, the more likely price discrepancies will be spotted and acted upon. The divergence of prices from their no-arbitrage relationship (which provides profit potentials), will be quickly arbitraged away as both the quantity and speed of information transfer is enhanced.[20]

Another benefit of internationalization is access to markets otherwise inaccessible. As mentioned earlier, the Chicago Mercantile Exchange will be accessible after regular trading hours through Globex. Not only will U.S. traders now be able to operate after U.S. trading hours, but foreign traders can also use Globex to operate during their own regular trading hours. New markets enable investors to introduce diversity into their portfolios in both the type of instrument and the country from which it is issued. Just as computerized systems, such as Globex, facilitate diversification and accessibility, so too can other methods, such as cross-exchange listings and cross-memberships.

Risks in Globalization

Trading in financial assets, whether done domestically or across national boundaries, involves risk. Some of these risks are more important in an international setting than a strictly domestic setting. They occur primarily at various stages of the clearing and settlement process. Unlike risks commonly associated with price uncertainty, the risks in clearing and settlement procedures involve uncertainty about the timely payment of funds and the transfer of assets in financial trades.

An example of a typical securities transaction can provide a clear illustration. Once a securities trade is executed, the member firms involved submit the trade information for confirmation to the clearing agent. The trade is then compared and matched by computer for accuracy and the information on the trade is sent to the relevant members on either the day of the trade or the day after. If both parties concur with the conditions of the trade, the trade is ready for settlement. At present, settlement in securities occurs five days after the trade in the United States.

Using this example, the next section will briefly discuss the concepts and institutions in clearing and settlement procedures before introducing the specific risks of globalization.

Clearing and Settlement Procedures

"Clearing" a trade involves the confirmation of the type and quantity of the financial instrument being traded, the transaction date and price, and the identification of the buyer and seller. "Settlement" means the fulfillment of the obligations of the transaction. In equities and bonds, for example, settlement means payment to the seller and delivery of the security certificate or transfer of ownership to the buyer.

The clearing and settlement process depends on the institutions that facilitate transactions. Commodities and securities exchanges provide the facilities for traders to conduct their business, establish and enforce trading rules, collect and distribute market and economic information about prices, and provide an institutional framework for arbitrating and settling disputes.

Another institution—the clearinghouse—compares trades between parties and can remove risk from the settlement process.[21] A clearinghouse places itself between the buyer and seller, ensuring that the buyer receives the instrument purchased and the seller receives payment. That is, by becoming the counterparty to all trades, the clearinghouse guarantees every trade. Each participant has a net obligation with the clearinghouse to buy or sell the security

[20]An example of a no-arbitrage condition is that the difference between the cash and futures price of a storable commodity, at any point in time, should reflect carrying costs of storing the commodity until maturity. If the price differential exceeds carrying costs, then there exists an incentive to enter the market, that is, to buy today and sell at the higher futures price.

[21]Trade comparison involves confirming and matching the terms of the trade to ensure accuracy.

Table 1
Automated Trading Systems

System[1]	Sponsor	Purpose	Instruments
Access	New York Mercantile Exchange (NYMEX)	Computerized screen trading system to automatically match trade on a first-in-first-out basis. Allows traders to select a standing bid or offer (but are blind to the counterparty chosen).	Energy futures and futures-options for crude oil, heating oil, gasoline, propane and natural gas.
Automated Pit Trading (APT)	London International Financial Futures Exchange (LIFFE)	Intended to extend trading hours to cover European trading day. Its aim is to copy the life of the trading floor on to a computer screen.	FT-SE 100 index futures and most of LIFFE's main contracts.
EJV (Electronic Joint Venture)	Collaboration between First Boston, Goldman Sachs, Morgan Stanley, Salomon Brothers, Shearson Lehman and Citibank	Trading system that allows dealers to buy and sell securities electronically using voice-activated computer technology. Also provides price and analytic services.	Currently restricted to Treasury bills and notes with maturity of less than three years. Once established, it expects to extend coverage to all maturities.
Euroquote	European Community (EC) national stock exchanges	A European-wide share trading system. Will combine price information from 12 EC exchanges into an electronic feed for subscribers. Eventually, may become a full trading system and integrate Euroquote with a settlement system to decrease the cost and difficulties of settling cross-country transactions. (This proposal has since been abandoned by the chairmen of Europe's national stock exchanges.)	EC stocks
Globex	Chicago Mercantile Exchange (CME), Reuters and Chicago Board of Trade (CBOT)	An automated trading system with anonymous buy and sell orders that are matched by price and time. (See text for details.)	Traded instruments will be introduced in three separate waves: 1) financial futures and options, e.g., Eurodollar futures, futures and options on Eurodollar currencies—Deutschemark, yen, pound sterling, Canadian and Australian dollars, Swiss franc, LIBOR, and U.S. Treasury bond and note futures and options; 2) equity-related products; and 3) agriculture-related futures.

Table 1 (continued)
Automated Trading Systems

System[1]	Sponsor	Purpose	Instruments
Quotron System Inc.	Current testing of the prototype involves The Bank of America, Barclays Bank, Chase Manhattan Bank, Chemical Bank, Citibank, Credit Suisse, Lloyds Bank, Midland Bank, Morgan Guaranty, National Westminster, Swiss Bank Corp. and Union Bank of Switzerland.	Joint project to develop a computer system that automatically matches and executes foreign exchange trades.	Trades in foreign exchange.
Swiss Options and Financial Futures Exchange (SOFFEX)	Owned by Switzerland's three leading stock exchanges and five largest banks.	Fully automated trading and clearing system, where quotes and orders are recorded, sorted and matched automatically. The computer screen is composed of five segments, each with different types of information and automatically updated throughout the day.	Futures and options on the 13 underlying stocks and the Swiss Market Index (SMI), a basket of Switzerland's 24 leading stocks.

[1]Of these systems, only LIFFE's APT system and SOFFEX are currently in operation.

NOTE: For a more extensive survey of automated systems, see Peter A. Abken, "Globalization of Stock, Futures, and Options Markets," Federal Reserve Bank of Atlanta *Economic Review* (July/August 1991).

based on her net position with other participants in the clearinghouse.

A third institution—the depository—is an organization (not necessarily part of an exchange) that holds stocks and bonds for safekeeping on behalf of their owners. It has a computerized accounting system to record and transfer ownership of securities between participants by integrating a book-entry system with a money transfer system.[22]

The procedures for clearing and settlement vary across countries. At present, there are three common methods of clearing and settlement. Each involves various combinations of the three central institutions involved in futures and securities markets.

The first model is exemplified by the United Kingdom's equities market. In this model, there is neither a central depository nor a separate clearinghouse. Instead, the stock exchange itself is responsible for trade matching and confirmation as well as providing a location for the delivery and receipt of securities and payments between traders.[23]

The second model, exemplified by Germany's Deutscher Kassenverein depository system, has no independent clearinghouse, but does have a centralized depository and a stock exchange that provides the matching and confirmation of transactions. Once matched and confirmed, the trade information is sent to the depository for settlement.[24]

[22]A book-entry system means a credit or debit to a customer's account will transfer securities between buyer and seller. A money transfer system transfers the funds between the parties to the trade, such as a wire transfer.

[23]U.S. Congress, Office of Technology Assessment (1990), p. 58.

[24]Ibid.

The third model, as seen in the U.S. equities market, contains all three institutions: a stock market, a central depository and an independent clearinghouse. For example, the National Securities Clearing Corporation (NSCC), which processes 95 percent of all equities trades in the United States, is jointly owned by the New York Stock Exchange, the American Stock Exchange, and NASD.[25] The majority of the securities for NSCC members, in turn, are held by the Depository Trust Company. The stock market and clearinghouse together match and confirm transactions. The clearinghouse also places itself between counterparties to trades, then passes trade information to the depository.[26]

Risks in Clearing and Settlement

Credit (or counterparty) risk occurs when one side of the transaction does not settle in full, either when due or on a later date. The existence of counterparty risk, which is of minimal significance in many U.S. markets because of a clearinghouse, can be critical in an international transaction. The clearinghouse, generally well capitalized, guarantees that all trades will be honored. In many international transactions, however, no clearinghouse exists. Thus, a trader lacks information about the counterparty's reliability. Varying regulations on foreign trading may make it even more difficult to ascertain the safeguards available to a trader in that market.

Closely related to credit risk is liquidity risk, which is the risk that trades will not be settled at the appointed time, but at some undetermined time thereafter.[27] At settlement, counterparties are exposed to both credit and liquidity risks. Liquidity risk occurs because settlement may not occur on the specified date; credit risk occurs because the other party may not deliver at all. Thus, at settlement, the parties may not know whether the problem will be one of liquidity or credit. The settlement of international trades can exacerbate the problem of simultaneously exchanging securities for payment because of time zone differences.[28]

Another risk, replacement cost risk, occurs when the price of the security changes between trade and settlement. When one party has defaulted and the price of the instrument changes, then one of the parties involved would be adversely affected by the price change and suffer a loss in replacing the transaction. In foreign markets, the potential for adverse changes in the exchange rate can exacerbate this risk.

Operational risk occurs because of the possible failure of computer systems, telecommunications or institutionalized procedures during trading. Given the heavy reliance on technology in accessing financial markets abroad, this issue is extremely important in determining the success or failure of new trading systems. The precautions taken by the CME for its Globex system—an important part of its initial proposal to the Commodity Futures Trading Commission, a government regulator of futures exchanges—are a good example of this.[29]

Yet another risk, especially worrisome to regulators, is systemic risk. Systemic risk occurs when credit risks stemming from operational or financial problems result in agents exiting the market, which, in turn, threatens the industry. The inability of one financial institution to make its payments can cause other participants to be unable to meet their financial obligations in a timely manner. In the banking sector, this is typified as a run from deposits to currency. In futures and options, it occurs when agents no longer trade through standard channels like an exchange. For example, if members of an exchange begin trading elsewhere, the financial stability of the exchange is threatened as members withdraw their financial collateral.[30]

[25]U.S. Congress, Office of Technology Assessment (1990), p. 81.

[26]For related readings on clearance and settlement systems, see the monographs prepared by the Payment System Studies Staff of the Federal Reserve Bank of New York in the references to this paper.

[27]A temporary inability to convert assets into cash is often associated with liquidity risk while bankruptcy of a counterparty is associated with credit risk. For a more detailed description, see Federal Reserve Bank of New York (February 1989).

[28]For further reading on market risks, see Baer and Evanoff (1990).

[29]Examples of CME precautions include measures to prevent unauthorized individuals from accessing the system, such as four different identification codes; termination of a computer operator's session if nonstandard instructions are entered; and, in the failure of the central computer, recovery would involve automatic switchover to a back-up mainframe, taking approximately 60-90 seconds. See CFTC (1989), pp. 125-32.

[30]For further reading on systemic risks, see OECD (1991).

GLOBAL COORDINATION

The October 1987 stock market crash, with worldwide repercussions, revealed weaknesses in the clearing and settlement system. Many feared that the default of a major market player could threaten the financial systems of many countries. This prompted world financial leaders to work toward global coordination. The clearing and settlement of trades was considered one of the most crucial aspects of this coordination.

In 1989, the Group of Thirty issued a report, *Clearing and Settlement Systems in the World's Securities Markets.*[31] Based on its examination, five critical deficiencies in the clearing and settlement systems across countries were identified:

[1] Absence of compatible trade confirmation and matching systems for both domestic and international trades;

[2] Varying settlement periods across the different markets;

[3] Absence of delivery versus payment in some markets;

[4] Absence of standardized trade guarantees;

[5] Absence of book entry processing for settlement of securities transactions in several markets.

Trade Confirmation and Matching

Trade confirmation and matching, also known as trade comparison, is the process of confirming and matching the terms of a trade to ensure accuracy (for example, the issue, price, quantity and counterparties) and is usually done by a clearinghouse (although sometimes by an exchange or by the parties themselves, in the forward foreign exchange market). If not confirmed and matched, a chain reaction of failed trades is possible as subsequent trades are made on the assumption that earlier trades will be successfully completed.

Rapid trade comparison shortens the amount of time between when the trade is made and when it is successfully matched. This reduces credit risk by reducing the amount of time an agent has to opt for defaulting on a trade. In the international context, delays of hours in a domestic market may result in a delay of days for international trades. Requiring all investors to obtain membership in a trade comparison system and achieving a compatible system across international markets can reduce the delays and credit risks involved in diverse systems.

Settlement Periods

The second deficiency is unequal settlement periods, which can increase settlement risk and potential default. Settlement risk occurs when there are gaps in the timing of payments and receipts on settlement date.[32] The harm of different settlement periods is that, as mentioned earlier, traders or investors who are active participants in the market make later trades contingent on the assumption of the successful settlement of earlier trades. Hence, the harm is twofold—the default of an earlier counterparty and the dependence on this trade that could jeopardize subsequent trades. As with many trade issues that require timeliness, delays in settlement can be exacerbated if spread across different trading hours and time zones.

While this is costly in a domestic market, the investment of a U.S. agent dealing in international markets can be even more costly because it is also subject to the economic conditions of foreign countries and exchange rates. Adverse changes in the exchange rate can turn a minor loss into a significant one in the presence of currency risk. Thus, for agents moving between international markets, an uncertain settlement period combined with an uncertain exchange rate can increase financial losses.

The growing volume of trades has led to a number of techniques where, to reduce the number of settlement transactions, trades are not processed one at a time. "Netting" is a system whereby transactions are aggregated, so that debit and credit positions offset each other, leaving a participant with one final position in the market of owing or being owed. Netting greatly increases the liquidity of the market and the trader's flexibility because, rather than posting collateral for every trade, the trader is responsible only for the net settlement debit.[33]

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[31]The Group of Thirty is a private sector organization that takes its membership from financial sectors such as exchanges, banks and investment houses.

[32]Settlement risk encompasses both liquidity risk and credit risk.

[33]Board of Governors of the Federal Reserve System and the Federal Reserve Bank of New York (1990), p. 40.

There are three main choices for a netting system. The first is bilateral netting, whereby all trades in the same security and between the same parties to the trade are netted to one final delivery versus payment (DVP).[34] For example, if Ralph sells 100 shares of British Mohair to Sam, then buys back 75 shares of British Mohair from Sam, the net position is that Ralph must deliver 25 shares to Sam. This is the narrowest of the three netting options.

The second is multilateral netting (or daily netting), which, unlike bilateral netting, allows for different counterparties in the netting scheme. In this instance, all trades in the same security are netted to a final debit or credit position for each participant.

The last option is continuous net settlement, whereby all trades in a particular security are pooled by issue to a final debit or credit position for the day and any unsettled trades are carried over and offset against the next day's trades. In practice, the clearing corporation substitutes as the counterparty to the trade in continuous net settlement.

The type of netting system implemented depends on the volume of the market. Establishing a multilateral or continuous net settlement system is a costly procedure, requiring a risk-sharing arrangement among members, a clearing corporation (as with continuous net settlement) and powerful computer systems to handle the volume of trades. The costs of such a system may exceed the costs of operating with only a bilateral system. This is especially true in low-volume markets where bilateral netting can be a feasible and less costly alternative. A proposal for a multilateral netting system in the high-volume foreign exchange market was examined in 1988 by members of FXNET, a bilateral netting system.[35] Representatives of leading international banks, responding to FXNET's questionnaire, felt that a major benefit would be to reduce processing costs.[36]

This is especially relevant in markets expanding their foreign membership. If netting is desirable because it reduces the number of trades to process, it becomes even more so as markets service no longer just domestic, but a growing number of foreign clients. In the FXNET questionnaire, respondents stated that, "Cross-border aspects of multilateral netting should be considered early in the process, as they will be more important than with bilateral netting."[37] With the addition of cross-border traders increasing the transactions volume a market handles, a netting system would simplify the repeated payments that would be introduced.

Whichever netting system is chosen, the desirable settlement time frame is a rolling settlement system. In such a system, trades settle on all business days of the week, scheduled the same number of days after the trade.[38] Thus, the presence of a standardized settlement period and a netting system is a crucial aspect to moving between international markets with security of settlement.

Delivery Vs. Payment

The third finding by the Group of Thirty is the absence of delivery versus payment (DVP) in some markets. DVP is a two-sided payment system that simultaneously debits or credits the cash account of one member and makes the corresponding entry on the securities side of the transaction. This reduces the settlement risk that occurs when there is a discrepancy between the timing of payments and receipts on settlement date.

The Group of Thirty, arguing the need for prompt two-sided payments, has recommended interim procedures: risk can be reduced by delivering securities only against a certified check or by employing a mechanism whereby delivery and payment are done simultaneously although through different systems. In either case, net settlement of cash and securities is completed by the end of the day.

Even without a formalized DVP, methods can be developed to minimize settlement risk by having both parties to a trade settle their accounts simultaneously. With markets in different time zones and, thus, different operating hours, allowing each side of a trade to settle at a differ-

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[34]DVP is a payment system whereby the debits and credits of a trade are applied to the parties' accounts simultaneously.

[35]For further reading on the netting of foreign exchange transactions, see Gilbert (1992).

[36]Minutes of FXNET Multilateral Netting Steering Committee, (1989).

[37]Ibid.

[38]The Group of Thirty recommends the implementation of a rolling settling system by 1992 so that final settlement occurs three days after the trade.

ent time could result in a next-day payment, not one within the hours of the first settlement.

Standardized Trade Guarantees

The fourth deficiency is the absence of standardized trade guarantees. A trade guarantee ensures that all compared or netted trades will be settled, based on the conditions on which they were compared, even in the event of counterparty default. To assure trade guarantees, each member of the comparison and netting systems assumes the default risk of the system.

A standard method of providing a guarantee is to establish a general clearing fund based on member contributions. When a default occurs, the losses are first extracted from the defaulting party's clearing fund contribution. If that contribution does not meet the full amount of the loss, the remainder is charged against the clearing corporation's general clearing fund.

The international environment adds an extra facet to these guarantees. Since membership is becoming increasingly international, a major financial loss can strain the capacity of the corporation to handle the failure immediately. Obtaining permission for access to additional funding, for example, could cause unnecessary delays. Thus, the maintenance of additional sources of funds, like member deposits or access to bank lines, becomes crucial in an international setting. To ensure the integrity of the corporation and, thus, the market, trade guarantees provide a measure of security and stability in the face of potential failures.

Book Entry Processing

The last issue to be addressed in global coordination is the absence of book entry processing for settling securities transactions in several markets. Before addressing book entry, however, other institutions surrounding this process should be introduced.

The first of these is a central securities depository (CSD).[39] The primary activity of a CSD is to immobilize and dematerialize securities so that they can be processed in the more efficient book entry method. Immobilization of securities means that the physical documents (for example, share certificates) are stored at the depository, eliminating their actual movement when ownership changes. Dematerialization means that no physical securities with title of ownership are issued. Securities exist solely as computer records.

Transfers of certificates are done by book entry, where a simple credit and a balancing debit to customers' computerized accounts on the books of the CSD will transfer securities from one account to another. Immobilization and dematerialization replace the more risky and time-consuming process of transferring the securities in paper form whenever a transaction is made. Transfers of stocks trade-by-trade introduce a needless complication to the clearing and settlement system, which becomes even more complicated if it involves delivering them to investors worldwide.

Recommendations by the Group of Thirty

The Group of Thirty has proposed nine recommendations found in table 2 to correct the preceding five deficiencies. The status of the Group of Thirty recommendations are listed in table 3. This table depicts the extent to which 21 countries have made progress on these recommendations. While the United States has accomplished more than most of the countries surveyed, the fact that so many countries have not finalized these policies, and may not by 1992, has implications for the eventual timetable of global coordination.[40]

Currently, there is no well-defined regulatory structure for the global marketplace. While regulatory authorities exist in specific countries—for example, the Securities and Exchange Commission has the regulatory authority, oversight and arbitration of securities disputes in the U.S. stock market—the international arena has no similar agency to govern global financial relations. In its absence, voluntary coordination of clearing and settlement systems can help reduce the risks that lead to defaults, failures and potential disputes between legal and regulatory authorities. Thus, there are potential gains if

[39]The strict definition of a CSD requires that a country should have only one depository. In practice, however, more than one may exist. This type of system can be effective as long as there is linkage between the entities to coordinate trade information. The United States has several depositories.

[40]In addition to the Group of Thirty proposal, other groups, such as the Working Group on Financial Markets have studied clearing and settlement issues.

Table 2

Group of Thirty Recommendations

The following are nine recommendations put forth by the Group of Thirty to correct the deficiencies it finds in the coordination of clearing and settlement systems.[1] The numbers in brackets are the relevant deficiencies presented in the section, Global Coordination, that these recommendations address.

- By 1990, all comparisons of trades between direct market participants (i.e., brokers, broker/dealers and other exchange members) should be accomplished by T+1, (the first day after the trade). [1]
- Indirect market participants (such as institutional investors or any trading counterparties that are not broker/dealers) should, by 1992, be members of a trade comparison system that achieves positive affirmation of trade details. [1]
- Each country should have an effective and fully developed central securities depository, organized and managed to encourage the broadest possible industry participation (directly and indirectly) by 1992. [3, 5]
- Each country should study its market volume and participation to determine whether a trade netting system would be beneficial in terms of reducing risk and promoting efficiency. If a netting system would be appropriate, it should be implemented by 1992. [2]
- Delivery versus payment (DVP) should be employed as the method for settling all securities transactions. A DVP system should be in place by 1992. [3, 5]
- Payments associated with the settlement of securities transactions and the servicing of securities portfolios should be made consistent across all instruments and markets by adopting the "same day" funds convention. [2]
- A "Rolling Settlement" system should be adopted by all markets. Final settlement should occur on T+3 by 1992. As an interim target, final settlement should occur on T+5 by 1990 at the latest, save only where it hinders the achievement of T+3 by 1992. [2]
- Securities lending and borrowing should be encouraged as a method of expediting the settlement of securities transactions. Existing regulatory and taxation barriers that inhibit the practice of lending securities should be removed by 1990.[2] [4]
- Each country should adopt the standard for securities messages developed by the International Organization for Standardization [ISO Standard 7775]. In particular, countries should adopt the ISIN numbering system for securities issues as defined in the ISO Standard 6166, at least for cross-border transactions. These standards should be universally applied by 1992.

[1]Group of Thirty (March 1989).

[2]For information on securities lending, see Paul C. Lipson, Bradley K. Sabel, and Frank Keane, "Securities Lending" (Federal Reserve Bank of New York, August 1989).

the clearing and settlement systems operating in domestic markets are coordinated among global financial markets.

CONCLUDING REMARKS

This discussion has attempted to present an overview of issues that are currently of interest in the globalization of financial markets. The linkage among international markets is of interest both to private investors and to national governments, who desire stable domestic and international financial sectors.

International competition among financial markets is growing rapidly and has produced benefits such as new financial instruments, new markets and extended trading hours. These changes, however, are not without costs. Domestic rules and regulation are not sufficient safeguards for a system that operates in an increasingly international environment. Financial and governmental communities are addressing the need to integrate international expansion to facilitate the continued safe and profitable growth of financial instruments and the important functions these markets serve. It is clear that much work remains.

Table 3

Current Status of the Group of Thirty's Recommendations for International Settlement—Equities

Recommendation No. Country	1 Comparison on T+1[1]	2 Comparison System	3 Institutional Securities Depository	4 Central Securities Netting	5 Delivery versus Payment	6 Rolling Settlement on T+5[2]	7 Same-Day Funds	8 ISO/ISM	9 Securities Lending
Australia	Yes	No	No	No	Yes	Open	No	No	Yes
Austria	Yes	No	Yes	No	No	Weekly	Yes	No	No
Belgium	No	No	Yes	No	Yes	Fortnightly	Yes	No	Yes
Canada	Yes	Yes	Yes	Yes	Yes	T+5	Yes	No	Yes
Denmark	Yes	No	No	No	Yes	T+3	Yes	No	Yes
Finland	Yes	No	No	No	Yes	T+5	No	No	No
France	Yes	No	Yes	No	No	Monthly	Yes	No	Yes
Germany	Yes	No	Yes	No	Yes	T+2	Yes	No	No
Hong Kong	Yes	No	No	No	Yes	T+1	No	No	Limited
Italy	Yes	No	Yes	No	Yes	Monthly	Yes	No	Limited
Japan	Yes	No	No	Yes	Yes	T+3	No	No	Yes
Korea	No	No	Yes	No	Yes	T+2	No	No	No
Netherlands	Yes	No	Yes	Yes	Yes	T+5	No	No	Yes
Norway	Yes	No	No	No	Yes	T+6	Yes	No	No
Singapore	Yes	No	No	No	Yes	T+5	No	No	Yes
Spain	Yes	No	No	No	No	Weekly	No	No	Limited
Sweden	Yes	No	Yes	No	Yes	T+5	No	No	Yes
Switzerland	Yes	No	Yes	No	Yes	T+3	Yes	No	Yes
Thailand	Yes	No	Yes	Yes	Yes	T+4	Yes	No	No
United Kingdom	Yes	Yes	No	Yes	No	Fortnightly	No	No	Limited
United States	Yes	Yes	Yes	Yes	Yes	T+5	No	No	Yes

SOURCE: Updated by the Office of Technology Assessment, July 1990, from *A Comparative View: The Group of Thirty's Recommendations and the Current U.S. National Clearance and Settlement System* (Morgan Stanley & Co., June 1989).

[1]T+1 means the first day after the trade.

[2]T+5 means five days after the trade.

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Data Envelopment Analysis and Commercial Bank Performance: A Primer With Applications to Missouri Banks

COMMERCIAL BANKS PLAY a vital role in the economy for two reasons: they provide a major source of financial intermediation and their checkable deposit liabilities represent the bulk of the nation's money stock. Evaluating their overall performance and monitoring their financial condition is important to depositors, owners, potential investors, managers and, of course, regulators.

Currently, financial ratios are often used to measure the overall financial soundness of a bank and the quality of its management. Bank regulators, for example, use financial ratios to help evaluate a bank's performance as part of the CAMEL system.[1] Evaluating the economic performance of banks, however, is a complicated process. Often a number of criteria such as profits, liquidity, asset quality, attitude toward risk, and management strategies must be considered. The changing nature of the banking industry has made such evaluations even more difficult, increasing the need for more flexible alternative forms of financial analysis.

This paper describes a particular methodology called Data Envelopment Analysis (DEA), that has been used previously to analyze the relative efficiencies of industrial firms, universities, hospitals, military operations, baseball players and, more recently, commercial banks.[2] The use of DEA is demonstrated by evaluating the management of 60 Missouri commercial banks for the period from 1984 to 1990.[3]

[1]For more details, see Booker (1983), Korobow (1983) and Putnam (1983).

[2]The name DEA is attributed to Charnes, Cooper and Rhodes (1978), for the development of DEA, see Charnes, et al.(1985) and Charnes, et al. (1978); for some applications of DEA, see Banker, et al. (1984), Charnes, et al. (1990) and Sherman and Gold (1985).

[3]Although there is vast literature analyzing competition and performance in the U.S. banking industry (e.g., Gilbert (1984), Ehlen (1983), Korobow (1983), Putnam (1983), Wall (1983) and Watro (1989)), actual banking efficiency has received limited attention. Recently, a few publications have used DEA or a similar approach to study the technical and scale efficiencies of commercial banks (e.g., Sherman and Gold (1985), Charnes et al. (1990), Rangan et al. (1988), Aly et al. (1990), and Elyasiani and Mehdian (1990)).

DATA ENVELOPMENT ANALYSIS: SOME BASICS

DEA represents a mathematical programming methodology that can be applied to assess the efficiency of a variety of institutions using a variety of data. This section provides an intuitive explanation of the DEA approach. A formal mathematical presentation of DEA is described in appendix A; a slightly different nonparametric approach is described in appendix B.

The DEA Standard for Efficiency

DEA is based on a concept of efficiency that is widely used in engineering and the natural sciences. Engineering efficiency is defined as the ratio of the amount of work performed by a machine to the amount of energy consumed in the process. Since machines must be operated according to the law of conservation of energy, their efficiency ratios are always less than or equal to unity.

This concept of engineering efficiency is not immediately applicable to economic production because the value of output is expected to exceed the value of inputs due to the "value added" in production. Nevertheless, under certain circumstances, an economic efficiency standard—similar to the engineering standard—can be defined and used to compare the *relative* efficiencies of economic entities. For example, a firm can be said to be efficient relative to another if it produces either the same level of output with fewer inputs or more output with the same or fewer inputs. A single firm is considered "technically efficient" if it cannot increase any output or reduce any input without reducing other outputs or increasing other inputs.[4] Consequently, this concept of technical efficiency is similar to the engineering concept. The somewhat broader concept of "economic efficiency," on the other hand, is achieved when firms find the combination of inputs that enable them to produce the desired level of output at minimum cost.[5]

DEA and Technical Efficiency

The discussion of the DEA approach will be undertaken in the context of technical efficiency in the microeconomic theory of production. In microeconomics, the production possibility set consists of the feasible input and output combinations that arise from available production technology. The production function (or production transformation as it is called in the case of multiple outputs) is a mathematical expression for a process that transforms inputs into output. In so doing, it defines the frontier of the production possibility set. For example, consider the well-known Cobb-Douglas production function:

(1) $$Y = AK^{a}L^{(1-a)},$$

where Y is the maximum output for given quantities of two inputs: capital (K) and labor (L). Even if all firms produce the same good (Y) with the same technology defined by equation 1, they may still use different combinations of labor and capital to produce different levels of output. Nonetheless, all firms whose input-output combinations lie on the surface (frontier) of the production relationship defined by equation 1 are said to be technologically efficient. Similarly, firms with input-output combinations located inside the frontier are technologically inefficient.

DEA provides a similar notion of efficiency. The principal difference is that the DEA production frontier is not determined by some specific equation like that shown in equation 1; instead, it is generated from the actual data for the evaluated firms (which in DEA terminology are typically called decision-making units or DMUs).[6] Consequently, the DEA efficiency score for a specific firm is not defined by an absolute standard like equation 1. Rather, it is defined *relative* to the other firms under consideration. And, similar to engineering efficiency measures, DEA establishes a "benchmark" efficiency score of unity that no individual firm's score can exceed. Consequently, efficient firms receive efficiency scores of unity, while inefficient firms receive DEA scores of less than unity.

[4]See Koopmans (1951).

[5]This is also named "allocative efficiency" because a profit maximizing firm must allocate its resources such that the technical rate of substitution is equal to the ratio of the prices of the resources. Theoretical considerations of allocative efficiency can be found in the articles by Banker (1984) and Banker and Maindiratta (1988).

[6]It is common to estimate production functions using regression analysis. When cross-section data are used, the estimated production function represents the average behavior of firms in the sample. Hence, the estimated production function depends upon the data for both efficient and inefficient firms. By imposing suitable constraints, these statistical procedures can be modified to orient the estimates toward frontiers. In this manner, the frontier of the production set can be estimated econometrically.

In microeconomic analysis, efficient production is defined by technological relationships with the assumption that firms are operated efficiently. Whether or not firms have access to the same technology, it is assumed that they operate on the frontier of their relevant production possibilities set; hence, they are technically efficient by definition. As a result, much of microeconomic theory ignores issues concerning technological inefficiencies.

DEA assumes that all firms face the same *unspecified* technology which defines their production possibilities set. The objective of DEA is to determine which firms operate on their efficiency frontier and which firms do not. That is, DEA partitions the inputs and outputs of all firms into efficient and inefficient combinations. The efficient input-output combinations yield an implicit production frontier against which each firm's input and output combination is evaluated. If the firm's input-output combination lies on the DEA frontier, the firm might be considered efficient; if the firm's input-output combination lies inside the DEA frontier, the firm is considered inefficient.

An advantage of DEA is that it uses actual sample data to derive the efficiency frontier against which each firm in the sample can be evaluated.[7] As a result, no explicit functional form for the production function has to be specified in advance. Instead, the production frontier is generated by a mathematical programming algorithm which also calculates the optimal DEA efficiency score for each firm.

To illustrate the relationship between DEA and economic production in its simplest form, consider the example shown in figure 1, in which firms use a single input to produce a single output. In this example, there are six firms whose inputs are denoted as x_i and whose outputs are denoted as y_i $(i = 1,2,...,6)$; their input-output combinations are labeled by F_S $(s = 1,2,...,6)$. While the production frontier is generated by the input-output combinations for the firms labeled F_1, F_3, F_5 and F_6, the efficient portion of the production frontier is shown by the connected line segments. F_2 and F_4 are clearly DEA inefficient because they lie inside the frontier; F_6 is DEA inefficient because the same output can be produced with less input.

The Importance of Facets in DEA

"Facets" are an important concept used to evaluate a firm's efficiency in DEA. The efficiency measure in DEA is concerned with whether a firm can increase its output using the same inputs or produce the same output with fewer inputs. Consequently, only part of the entire efficiency frontier is relevant when evaluating the efficiency of a specific firm. The relevant portion of the efficiency frontier is called a facet. For example, in figure 1, only the facet from F_1 to F_3 is relevant for evaluating the efficiency of the firm designated by F_2. Similarly, only the facet from F_3 to F_5 is used to evaluate the firm denoted by F_4.[8]

The use of facets with DEA enables analysts to identify inefficient firms and, through comparison with efficient firms on relevant facets, to suggest ways in which the inefficient firms might improve their performance. As illustrated in figure 1, F_2 can become efficient by rising to some point on the F_1-F_3 facet. In particular, it could move to A by simply using less input, to B by producing more output or to C by both reducing input and increasing output. Of course, in this example, the analysis is obvious and the recommendation trivial. In more complicated, multiple input-multiple output cases, however, the appropriate efficiency recommendations would be much more difficult to discover without the DEA methodology.[9]

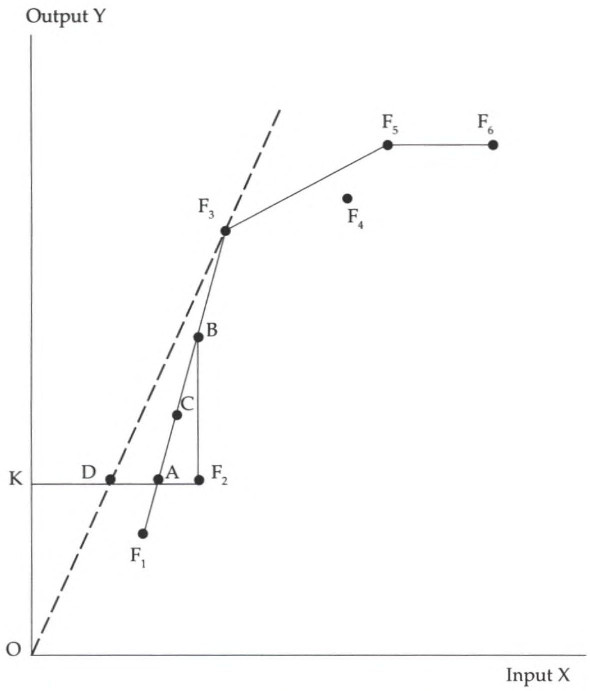
[7]DEA has two theoretical properties that are especially useful for its implementation. One is that the DEA model is mathematically related to a multi-objective optimization problem in which all inputs and outputs are defined as multiple objectives such that all inputs are minimized and all outputs are maximized simultaneously under the technology constraints. Thus, DEA-efficient DMUs represent Pareto optimal solutions to the multi-objective optimization problem, while the Pareto optimal solution does not necessarily imply DEA efficiency.

Another important property is that DEA efficiency scores are independent of the units in which inputs and outputs are measured, as long as these units are the same for all DMUs. These characteristics make the DEA methodology highly flexible. The only constraint set originally in the CCR model is that the values of inputs and outputs must be strictly *positive*. This constraint, however, has been abandoned in the new additive DEA formulation. As a consequence, the additive DEA model is used to compute reservation prices for new and disappearing commodities in the construction of price indexes by Lovell and Zieschang (1990).

[8]In a multiple dimensional space, the efficiency frontier forms a polyhedron. In geometry, a portion of the surface of a polyhedron is called a facet; this is why the same term is used in DEA. These facets have important implications in empirical studies, such as identification of competitors and strategic groups in an industry. See Day, Lewin, Salazar and Li (1989).

[9]For alternative measures of efficiency, see appendix B.

Figure 1
Production Frontier and Efficiency Subset



Scale Efficiency

In addition to measuring technological efficiency, DEA also provides information about scale efficiencies in production. Because the measure of scale efficiency in DEA analysis varies from model to model, care must be exercised. The scale efficiency measured for the DEA model used in this study, however, corresponds fairly closely to the microeconomic definition of economics of scale in the classical theory of production.[10]

To illustrate, consider the F_1-F_3 facet in figure 2. Firms located on this facet exhibit increasing returns to scale because a proportionate rise in their input and output places them inside the production frontier. A proportionate decrease in their input and output is impossible because it would move them outside of the frontier. This is illustrated by a ray from the origin that passes through the F_1-F_3 facet at F'_2.

Firms located on the F_3-F_5 facet exhibit decreasing returns to scale because a proportionate decrease in their input and output places them inside the production frontier. A proportionate increase in their input and output is impossible because it would move them outside of the frontier.

Constant returns to scale occur if all proportionate increases *or* decreases in inputs and outputs move the firm either along or above the production frontier. In figure 2, for example, F_3 exhibits constant returns to scale because proportionate increases or decreases would place it outside the production frontier.

Since the facets are generated by efficient firms, the scale efficiency of these firms is determined by the properties of their particular facet. Scale efficiencies for inefficient firms are determined by their respective reference facets as well. Thus, F_2 and F_4 in figure 1 exhibit increasing and decreasing returns to scale, respectively.

DEA and Economic Efficiency

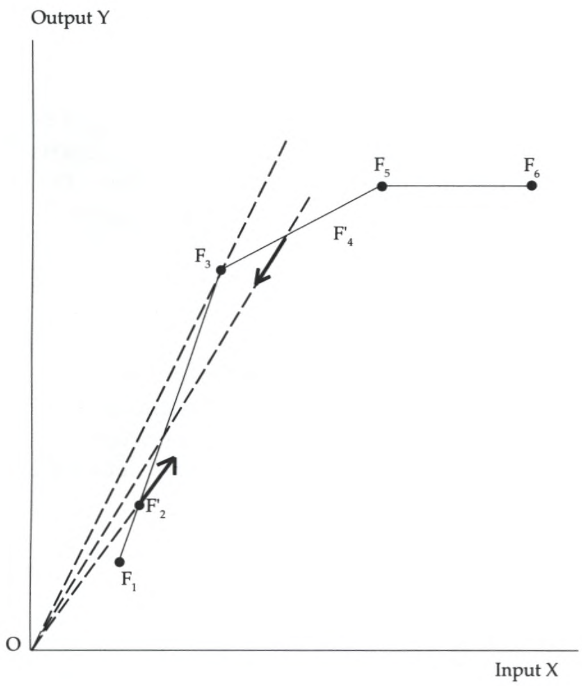
While the discussion of DEA in the context of technological efficiency of production is useful for illustrative purposes, it is far too narrow and limiting. DEA is frequently applied to questions and data that transcend the narrow focus of technical efficiency in production. For example, DEA is frequently applied to financial data when addressing questions of economic efficiency. In this regard, its application is somewhat more problematic. For example, when firms face different marginal costs of production due to regional or local wage differentials, one firm may appear inefficient relative to another. Given the potential differences in relative costs that a firm may face, however, it might be equally efficient. Alternatively, differences that appear to be due to economic inefficiencies may in fact be due to cost differences directly attributable to the nonhomogeneity of products. Because of problems like these, DEA must be applied judiciously.

DEA Window Analysis

To this point, the discussion of DEA has been concerned with evaluating the relative efficiency of different firms at the same time. Those who use DEA, however, frequently employ a type of sensitivity analysis called "window analysis." The performance of one firm or its reference firms

[10]See Fare, Grosskopf and Lovell (1985). Different DEA models employ different measures of scale efficiency. See appendixes A and B for details.

Figure 2
An Illustration of Scale Efficiencies



may be particularly "good" or "bad" at a given time because of factors that are external to the firm's relative efficiency. In addition, the number of firms that can be analyzed using the DEA model is virtually unlimited. Therefore, data on firms in different periods can be incorporated into the analysis by simply treating them as if they represent different firms. In this way, a given firm at a given time can compare its performance at different times and with the performance of other firms at the same *and* at different times. Through a sequence of such "windows," the sensitivity of a firm's efficiency score can be derived for a particular year according to changing conditions and a changing set of reference firms.[11] A firm that is DEA efficient in a given year, regardless of the window, is likely to be truly efficient relative to other firms. Conversely, a firm that is only DEA efficient in a particular window may be efficient solely because of extraneous circumstances.

In addition, window analysis provides some evidence of the short-run evolution of efficiency for a firm over time. Of course, comparisons of DEA efficiency scores over extended periods may be misleading (or worse) because of significant changes in technology and the underlying economic structure.

APPLYING DEA TO BANKING: AN EVALUATION OF 60 MISSOURI COMMERCIAL BANKS

To demonstrate DEA's use, it is applied to evaluate relative efficiency in banking. Financial data for 60 of the largest Missouri commercial banks for 1984 (determined by their total assets in 1990) are used. Initially, the relative efficiency of these banks is examined using two alternative DEA models: the CCR model and the additive DEA model. A discussion of these alternative DEA models appears in appendix A. In extending the discussion and analysis, however, we focus solely on the CCR model.

Measuring Inputs and Outputs

Perhaps the most important step in using DEA to examine the relative efficiency of any type of firm is the selection of appropriate inputs and outputs. This is partially true for banks because there is considerable disagreement over the appropriate inputs and outputs for banks. Previous applications of DEA to banks generally have adopted one of two approaches to justify their choice of inputs and outputs.[12]

The first "intermediary approach" views banks as financial intermediaries whose primary business is to borrow funds from depositors and lend those funds to others for profit. In these studies, the banks' outputs are loans (measured in dollars) and their inputs are the various costs of these funds (including interest expense, labor, capital and operating costs).

A second approach views banks as institutions that use capital and labor to produce loans and deposit account services. In these studies, the banks' outputs are their accounts and transactions, while their inputs are their labor, capital and operating costs; the banks' interest expenses are excluded in these studies.

[11]This is called "panel data analysis" in econometrics.

[12]Some studies have adopted the simple rule that if it produces revenue, it is an output; if it requires a net expenditure, it is an input. For example, see Hancock (1989).

Our analysis of 60 Missouri banks uses a variant of the intermediary approach. The banks' outputs are interest income (IC), non-interest income (NIC) and total loans (TL). Interest income includes interest and fee income on loans, income from lease-financing receivables, interest and dividend income on securities, and other income. Non-interest income includes service charges on deposit accounts, income from fiduciary activities and other non-interest income. Total loans consist of loans and leases net of unearned income. These outputs represent the banks' revenues and major business activities.

The banks' inputs are interest expenses (IE), non-interest expenses (NIE), transaction deposits (TD), and non-transaction deposits (NTD). Interest expenses include expenses for federal funds and the purchase and sale of securities, and the interest on demand notes and other borrowed money. Non-interest expenses include salaries, expenses associated with premises and fixed assets, taxes and other expenses. Bank deposits are disaggregated into transaction and non-transaction deposits because they have different turnover and cost structures. These inputs represent measures for the banks' labor, capital and operating costs. Deposits and funds purchased (measured by their interest expense) are the source of loanable funds to be invested in assets.[13]

Evaluation of Missouri Bank Management Performance in 1984

The DEA scores and returns to scale measures resulting from applying the CCR and additive DEA models are presented in table 1.[14] Although the overall results are similar across the two models, there are minor differences in the individual efficiency scores that may provide information about the relative efficiency of these banks.

The two models differ fundamentally in their definition of the efficiency frontier. In particular, the CCR model assumes constant returns to scale, while the additive model allows for the possibility of constant (C), increasing (I) or decreasing (D) returns. Because of this, banks that are efficient in the CCR model must also be efficient in the additive model. As table 1 illustrates for our Missouri banks, the converse, however, is not true.

The overall efficiency score is composed of "pure" technical and "scale" efficiencies. In the CCR model, a firm which is technologically efficient also uses the most efficient scale of operation. In the additive model, however, the score represents only "pure" technical efficiency. By comparing the results of the CCR and additive models, we can see that while five of our Missouri banks were technologically efficient, they were not operating at the most efficient scale of operation. The reader is cautioned, however, that this analysis excludes a number of factors (such as demographic characteristics of the markets in which they operate) that may be important in determining the most economically efficient scale of operation.

Since the efficiency scores are defined differently in the CCR and the additive DEA models, it is not possible to generate a measure of scale inefficiency using the results in table 1. Nevertheless, the fact that the efficiency scores from the two models are quite similar suggests that the scale inefficiency is not a major source of overall inefficiency for these banks. It appears that the inefficient banks simply used too many inputs or produced too few outputs rather than chose the incorrect scale for production.[15]

A Further Analysis of the CCR Model

An illustration of the use of DEA analysis can be obtained by considering the data for the bank with the lowest efficiency score, bank 59. The results for this bank are summarized in table 2. The reference banks making up the facet to which bank 59 is compared and "lambda," a measure of the relative importance of each reference bank in the facet, are given. The table shows that three reference banks compose the facet for bank 59. Banks 51 and 39 play the major role and the other bank is relatively unimportant.

[13] This is controversial, however. Some researchers specify deposits as outputs, arguing that treating deposits as inputs makes banks that depend on purchased money look artificially efficient (see Berg et al., 1990).

[14] The results from solving the DEA model also include information about DEA scale efficiencies, the efficient projection on the efficiency frontier, slack variables s_r^+ and s_i^- and the dual variables μ_r and ν_i. The "dual" variables represent "shadow prices" for each input and output. That is, they represent the marginal effects of the input and output variables on the bank's DEA efficiency score. See appendix A for details.

[15] Similar results of insignificant scale-inefficiency of U.S. banks have been reported by Aly et al. (1990).

Table 1

Overall Performance of 60 Missouri Commercial Banks Evaluated by the CCR and Additive DEA Models (1984)

	Efficiency Ratio				Efficiency Ratio		
Bank no.	CCR model	Additive model	Type of scale[1]	Bank no.	CCR model	Additive model	Type of scale[1]
1	.8545	.8825	D	31	.8568	.9310	D
2	.9228	1.0000	I	32	.9305	.9537	D
3	.9033	.9129	I	33	.8509	.8642	D
4	.8588	.9498	I	34	.8392	.9554	I
5	1.0000	1.0000	C	35	.8596	.8986	I
6	.8766	.9042	I	36	1.0000	1.0000	C
7	.8709	.9144	I	37	.8712	.9813	I
8	.8841	.9323	I	38	.8707	.9150	I
9	.8735	.9857	I	39	1.0000	1.0000	C
10	.8115	.9116	I	40	1.0000	1.0000	C
11	.9086	.9856	I	41	.8500	.9453	I
12	.7852	.8388	I	42	.8867	.9656	I
13	.8338	.9927	I	43	.8220	.8965	I
14	.9739	.9024	I	44	.8254	.9069	I
15	.8937	.9829	I	45	1.0000	1.0000	C
16	.8292	.8492	I	46	.9124	.9889	I
17	.8705	.8211	I	47	1.0000	1.0000	C
18	.9684	.9783	I	48	1.0000	1.0000	C
19	.8439	1.0000	D	49	.9507	.9890	I
20	.9527	.9930	I	50	1.0000	1.0000	C
21	.9746	1.0000	I	51	1.0000	1.0000	C
22	.8681	.8888	I	52	1.0000	1.0000	C
23	.9744	.9642	I	53	.8992	.9705	I
24	.9003	.9646	I	54	.9443	1.0000	I
25	1.0000	1.0000	C	55	.9303	.9931	I
26	.8714	.8406	I	56	.8889	1.0000	D
27	1.0000	1.0000	C	57	.8434	.9338	I
28	1.0000	1.0000	C	58	1.0000	1.0000	C
29	.8753	.9351	I	59	.7600	.7824	I
30	.9003	.9319	D	60	.8614	.9541	I

Scale efficiency is measured by the CCR model.
C = constant returns to scale
I = increasing returns to scale
D = decreasing returns to scale
[1]Determined by the CCR model.

The value measure in the first column in the lower half of the table gives the value of the outputs and the inputs for bank 59 in 1984. The second column gives the value measure that bank 59 would have to achieve in order to be DEA efficient. The difference between these numbers is presented in the third column.[16] Bank 59 should increase its total loans by 143 percent and its non-interest income by 6 percent. Bank 59 should reduce its four inputs by 26.6 percent of interest expenses and by 24 percent of the other inputs.

Table 2 also presents a measure for bank 59 denoted as the "dual." This measure is important because the ratio of the duals for outputs and inputs shows the tradeoff of increments or decrements in inputs and outputs to DEA efficiency. This is with the assumption that the bank is free to vary all of its inputs and outputs. The fact that the dual for NIE is large relative to the others suggests that the biggest efficiency gains for bank 59 will come from decreasing non-interest expenses. A similar analysis can be conducted for each ineffi-

[16]In the case of outputs, this difference is a measure of "slack." In the case of inputs, however, the slack variable is more complicated.

cient bank to determine its reference banks and the way in which it can become DEA efficient.

A Window Analysis

The available data cover a seven-year span from 1984 through 1990. A three-year period was chosen to allow five windows. The windows and the periods they cover are as follows:

window 1	1984	1985	1986				
window 2		1985	1986	1987			
window 3			1986	1987	1988		
window 4				1987	1988	1989	
window 5					1988	1989	1990

In each window, the number of banks is tripled because each bank at a different year is treated as an independent firm. Repeating the procedure discussed above for each window, information about the evolutions of DEA efficiencies of every bank during the seven-year period was obtained. Table 3 lists the DEA scores of three banks by year in each window. The average of the 15 DEA efficiency scores is presented in the column denoted "mean." The column labeled GD indicates the greatest difference in a bank's DEA scores *in the same year* but in different windows. The column labeled TGD denotes the greatest difference in a bank's DEA scores for the entire period.

A bank can receive a different DEA efficiency score for the same year in different windows. This variation in the DEA scores of each bank reflects both the performance of that bank over time as well as that of other banks. The distribution of banks by their average efficiency over the five windows is presented in table 4.

Bank 48 was the only one that was efficient for every year in every window over the 1984-90 period. Its average efficiency of 1.00 indicates that bank 48 was a superb bank in the sample DEA evaluation.

Bank 41, on the other hand, began in the first window with scores of 0.84 in 1984, 0.85 in 1985 and 0.89 in 1986. In the second window, bank 41 had scores of 0.86 in 1985, 0.90 in 1986 and 0.94 in 1987. Although all of its efficiency scores fluctu-

Table 2
Detailed Results for Bank 59

Efficiency Score = .7600
Facet 51 39 27
Lambda = .315 .188 .037

Outputs	Value measures	Value if efficient	Difference	Dual
IC	9,627.0	9,627.0	.0	.7895E-04
NIC	350.0	371.9	21.9	.1000E-08
TL	22,442.0	54,599.8	32,157.8	.3704E-10
Inputs				
IE	7,887.0	5,784.3	2,102.7	.4762E-09
NIE	2,182.0	1,658.4	523.6	.2277E-03
TD	19,915.0	15,136.0	4,779.0	.2780E-05
NTD	77,005.0	58,526.1	18,478.9	.5815E-05

Table 3
DEA Window Analysis

	Efficiency Scores							Summary Measures		
Bank	YR84	YR85	YR86	YR87	YR88	YR89	YR90	MEAN	GD	TGD
48	1.00	1.00	1.00					1.00	0.00	0.00
		1.00	1.00	1.00						
			1.00	1.00	1.00					
				1.00	1.00	1.00				
					1.00	1.00	1.00			
41	0.84	0.85	0.89					0.92	0.05	0.14
		0.86	0.90	0.94						
			0.90	0.94	0.91					
				0.96	0.94	0.96				
					0.96	0.98	0.98			
59	0.76	0.68	0.60					0.68	0.04	0.18
		0.70	0.60	0.63						
			0.59	0.63	0.67					
				0.65	0.70	0.75				
					0.71	0.76	0.77			

Table 4

Distribution of Average DEA Scores (1984-1990)

Model	Five-year average DEA score	Number of banks
CCR	1.00	1
	0.98 — 0.99	8
	0.96 — 0.97	4
	0.93 — 0.95	13
	0.91 — 0.92	7
	0.90	3
	0.88 — 0.89	4
	0.86 — 0.87	10
	0.83 — 0.85	5
	0.80 — 0.82	3
	0.79	1
	0.68	1

ated slightly in the other three windows, they tended to increase. With a gradual improvement in its DEA efficiency over the seven years, bank 41 was almost fully efficient in the last year, with a DEA score of 0.98. However, its average-efficiency score of 0.92 does not put it among the top 13 banks for the period.

In contrast to the banks previously discussed, bank 59 displayed relatively erratic and inefficient behavior over the entire seven-year period. Its average DEA score of 0.68 was the lowest of the 60 Missouri banks analyzed.

The window analysis enables us to identify the best and the worst banks in a relative sense, as well as the most stable and most variable banks in terms of their seven-year average DEA scores.

CONCLUDING REMARKS

The DEA methodology discussed in this article has the potential to provide crucial information about banks' financial conditions and management performance for the benefit of bank regulators, managers and bank stock investors. The DEA framework is extremely general, permitting multiple criteria for evaluation purposes. Moreover, DEA requires only data on the quantity of inputs and outputs; no price data are necessary. This is especially appealing in the analysis of banking because of the difficulties inherent in defining and measuring the prices of banks' inputs and outputs.

In addition, the DEA method is highly flexible. In particular, the selection of inputs and outputs has considerably fewer limitations than alternative econometric approaches. Nevertheless, if the analysis is to be useful, care must be exercised in the selection of inputs and outputs.

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Appendix A
A Comparison of the CCR

The CCR Ratio Model

The most important characteristics of the DEA methodology can be presented with the CCR Ratio Model. Consider a general situation where n decision making units, DMUs, convert the *same* m inputs into the *same* s outputs. The quantities of these outputs can be different for each DMU. In more precise notation, the j-th DMU uses a m-dimensional input vector, x_{ij} $(i = 1,2,\ldots,m)$, to produce an s-dimensional output vector, y_{rj} $(r = 1,2,\ldots, s)$. The particular DMU being evaluated is identified by subscript 0; all others are denoted by subscript j. The following optimization problem is formed for each DMU:

$$\text{Max } h_0 = \sum_{r=1}^{s} u_r y_{r0} \Big/ \sum_{i=1}^{m} v_i x_{i0}$$

subject to the constraints:

$$\sum_{r=1}^{s} u_r y_{rj} \Big/ \sum_{i=1}^{m} v_i x_{ij} \leq 1,\ u_r \geq 0,\ v_i \geq 0$$

for $i = 1,2,\ldots, m$; $r = 1,2,\ldots, s$; $j = 1,2,\ldots, n$.

where the output weights denoted by u_r $(r = 1,2,\ldots,s)$ and the input weights denoted by v_i $(i = 1,2,\ldots,m)$ are required to be non-negative (i.e., $u_r, v_i \geq 0$ for $r = 1, 2, \ldots, s$; $i = 1, 2, \ldots, m$). The "virtual output" is the sum $(\sum_{r=1}^{s} u_r y_{rj})$ and the "virtual input" is the sum $(\sum_{i=1}^{m} v_i x_{ij})$. The objective function is defined by h_0, that is, the ratio of virtual output to virtual input. The solution is a set of optimal input and output weights. The maximum of the objective function is the DEA efficiency score assigned to DMU_0. The first set of inequality constraints guarantees that the efficiency ratios of other DMUs (computed by using the same weights u_r and v_i) are not greater than unity. The remaining inequality constraints simply require all input and output weights to be positive. Since every DMU can be DMU_0, this optimization problem is well-defined for every DMU. Because the weights (v_i, u_r) and the observations of inputs and outputs (x_{ij}, y_{rj}) are all positive and the constraints must be satisfied by DMU_0, the maximum value of h_0 can only be a positive number less than or equal to unity. If the efficiency score $h_0 = 1$, DMU_0 satisfies the necessary condition to be DEA efficient; otherwise, it is DEA inefficient.

The above problem cannot be solved as stated because of difficulties associated with nonlinear (fractional) mathematical programming. Charnes and Cooper, however, have developed a mathematical transformation (the so-called "CC transformation") which converts the above nonlinear programming problem into a linear one. Existing duality theory and simplex algorithms in linear programming are used to solve the transformed problem.[1]

For a linear programming problem, there exists a pair of expressions which are "dual" to each other. The CCR ratio model is formed by problem 1 and problem 2 below:

Problem 1:

$$\text{Min } h_0 = \theta_0 - \varepsilon\left(\sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+\right)$$

subject to

$$\theta_0 x_{i0} - \sum_{j=1}^{n} x_{ij}\lambda_j - s_i^- = 0,$$

$$\sum_{j=1}^{n} y_{rj}\lambda_j - s_r^+ = y_{r0},\ \lambda_j \geq 0,\ s_i^- \geq 0,\ s_r^+ \geq 0,$$

for $i = 1,.., m$; $r = 1,.., s$; $j = 1,.., n$.

Problem 2:

$$\text{Max } Y_0 = \sum_{r=1}^{s} \mu_r y_{r0}$$

subject to

$$\sum_{i=1}^{m} \nu_i x_{i0} = 1,\ \sum_{r=1}^{s} \mu_r y_{rj} - \sum_{i=1}^{m} \nu_i x_{ij} \leq 0,$$

$$\mu_r \geq \varepsilon,\ \nu_i \geq \varepsilon$$

for $i = 1,.., m$; $r = 1,.., s$; $j = 1,.., n$.

As before, the subscript 0 represents the DMU being evaluated, x_{ij} denotes input i, y_{rj} denotes output r of DMU_j, and μ_r and ν_i represent the weights for outputs and inputs, respectively. An arbitrarily small positive number, ε, is introduced to ensure that all of the observed inputs and outputs have positive values or shadow prices and that the optimal value h_0 is not affected by the values assigned to the so-called "slack variables" (s_r^+ or s_i^-).[2]

The main conclusions from the CCR model are summarized as follows:

1. The optimal values of s_r^+, s_i^-, and λ_j via problem 1 must be positive. The following inequalities should then be satisfied:

$$y_{r0} \leq \sum_{j=1}^{n} y_{rj}\lambda_j \text{ and } \theta_0 x_{i0} \geq \sum_{j=1}^{n} X_{ij}\lambda_j,$$

for $r = 1, ..., s$; $i = 1, ..., m$.

2. Technical efficiency will be achieved if, and only if, all of the following conditions are satisfied:

$$\theta_0 = 1 \text{ and } s_r^+ = 0,\ s_i^- = 0$$

for $i = 1,.., m$; $r = 1,.., s$.

The condition $\theta_0 = 1$ ensures that DMU_0 is located on the production frontier; the conditions $s_r^+ = 0$ and $s_i^- = 0$ exclude situations such as F_6 in figure 1 of the text.

3. The constant returns to scale condition for DMU_0 occurs if $\sum_{j=1}^{n} \lambda_j = 1$, otherwise, $\sum_{j=1}^{n} \lambda_j > 1$ implies decreasing returns to scale; $\sum_{j=1}^{n} \lambda_j < 1$ implies increasing returns to scale.

4. An adjustment can be made in order to move (or project) inefficient DMU_0 onto the efficiency frontier. The projection (x^*, y^*) in the CCR model is formed by the following formulas:

$$x_{i0}^* = \theta_0 x_{i0} - s_i^- \quad i = 1, .., m$$

$$y_{r0}^* = y_{r0} + s_r^+ \quad r = 1, .., s.$$

The differences ($x_{i0} - x_{i0}^*$), $i = 1,.., m$, represent amounts of inputs to be reduced; ($y_{r0}^* - y_{r0}$), $r = 1,..,s$, represent the amounts of outputs to be increased in order to move DMU_0 onto the efficiency frontier. Hence, these differences can provide diagnostic information about the inefficiency of DMU_0.

[1]This also opens the way for many different DEA models which are refined, more flexible or more convenient for computations. These DEA models (BCC model, additive DEA model, cone ratio DEA model, CCW model) and their mathematical characteristics are beyond this paper.

[2]For the ϵ-Method, see Zukhovitskiy et al. (1966), pp. 46-51.

5. Problem 1 is defined as the "primal" problem while problem 2 is the "dual." The dual variables have the economic interpretation of "shadow prices." The value of ν_i indicates the marginal effect of input x_{i0} on the DEA efficiency score. The value of μ_r indicates the marginal effect of output y_r on the DEA efficiency score. A comparison of these dual variables provides information on the relative importance of inputs and outputs in the DEA evaluation.

6. In the CCR model, problem 1 (or problem 2) is solved for each DMU. Theoretically, there is no limitation on how many DMUs can enter the DEA model. Hence, the DEA model can perform an efficiency diagnosis for many DMUs.

Why is this approach referred to as data envelopment analysis? The two inequalities in conclusion 1,

$$y_{r0} \leq \sum_{j=1}^{n} y_{rj}\lambda_j \text{ and } \theta_0 x_{i0} \geq \sum_{j=1}^{n} x_{ij}\lambda_j,$$

for $r = 1, \ldots, s;\ i = 1, \ldots, m$

are constraints to be satisfied for the optimal solution. The first inequality implies that the output of DMU_0 should not exceed the linear combination of all observed output y_{rj}; thus, the optimal solutions will create a hyperplane to envelop the output of DMU_0 from above. Similarly, the second constraint can be interpreted such that the optimal solutions create another hyperplane which envelops the input of DMU_0 from below. Since both outputs and inputs of the DMU evaluated are enveloped from above and below, the name DEA exactly matches the geometric interpretation of the procedure.

To see how this works, assume that there is a group of DMUs that produces the same outputs using the same inputs, but in varying amounts. In ranking their efficiencies of DMUs, DEA assigns weights to the outputs and inputs of each DMU. These weights are neither predetermined nor based on prior information or preferences of the decision makers. Instead, each DMU receives a set of "optimal" weights that are determined by solving the above mathematical programming problem. This procedure generates a DEA efficiency score for the DMU evaluated based on the solution value for the input and output weights. A set of constraints guarantees that no DMU, including the one evaluated, can obtain an efficiency score that exceeds unity. In this way, DEA derives a measure of the relative efficiency rating for each DMU in the cases of multiple input and output.

The Additive Model

Among DEA models, the additive model has been important in applications. The additive model can be formalized as the following two problems, which are dual to each other.[3]

Problem 3:

$$\text{Max} \sum_{i=1}^{m} s_i^- / |x_{i0}| + \sum_{r=1}^{s} s_r^+ / |y_{r0}|$$

subject to

$$x_{i0} - \sum_{j=1}^{n} x_{ij}\lambda_j - s_i^- = 0,\ \sum_{j=1}^{n} y_{rj}\lambda_j - s_r^+ = y_{r0},$$

$$\sum_{j=1}^{n} \lambda_j = 1,\ \lambda_j \geq 0,\ s_i^- \geq 0,\ s_r^+ \geq 0,$$

for $i = 1,.., m;\ r = 1,.., s;\ j = 1,.., n.$

Problem 4:

$$\text{Min} \sum_{r=1}^{s} \mu_r y_{r0} + \sum_{i=1}^{m} \nu_i x_{i0} + u_0$$

subject to:

$$\sum_{r=1}^{s} \mu_r y_{rj} + \sum_{i=1}^{m} \nu_i x_{ij} + u_0 \geq 0,$$

$$\nu_i \geq 1 / |x_{i0}|,\ \mu_r \leq 1 / |y_{r0}|,$$

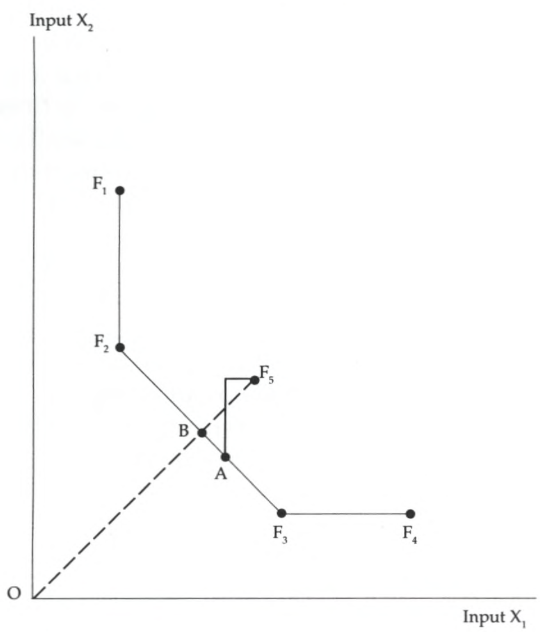
for $i = 1,.., m;\ r = 1,.., s;\ j = 1,.., n.$

Compared with the CCR model, the additive model has introduced another constraint $\sum_{j=1}^{n} \lambda_j = 1$ and a new variable u_0. The new constraint in problem 3 ensures that the efficiency frontier is constructed by the convex combinations of original data points rather than a convex cone as in the CCR model. The new variable u_0 in problem 4 is used to identify returns to scale. The other variables in the additive model have interpretations similar to the CCR model.

In addition, there is a difference in the way the additive model and the CCR ratio model locate the efficient reference point on the facet. In figure A.1, an output isoquant consists of input combinations for five firms (F_1, F_2, F_3, F_4 and F_5) in the case of one-output (y) and two-input (x_1 and x_2). Point F_5 represents an inefficient DMU which uses more of x_1 and x_2 to produce the same amount of output as

[3]See Charnes et al. (1985).

Figure A.1
The Difference Between CCR and Additive DEA Models



its efficient reference DMUs, F_2 and F_3. By the CCR ratio model, the efficiency score is determined via a value h_0, which can be interpreted in terms of the ray from the origin to F_5. That is, h_0 is expressed by the length of the ray from the origin to the intersection point B divided by the length from the origin to F_5. In the additive model, however, the reference efficient point on facet F_2-F_3 is denoted by A, which is determined by maximizing the sum of the slacks, $s_1 + s_2$. Geometrically, the slack variables are expressed by the horizontal line starting from F_5 and the vertical line extending to the facet F_2-F_3. Point A is selected such that the sum of the lengths of the horizontal and vertical lines are maximized. The DEA efficiency score in the additive model that we used is computed by the following formula:

$$\left(\sum_{i=1}^{m} x^{*}_{i0} + \sum_{r=1}^{s} y^{*}_{r0}\right) / \left(\sum_{i=1}^{m} x_{i0} + \sum_{r=1}^{s} y_{r0} + \sum_{r=1}^{s} 2s_r^{+}\right).$$

where x^{*}_{i0} and y^{*}_{r0} are corresponding inputs and outputs of the efficient reference point, such as point A.

The DEA scale efficiency in the additive model is identified by a variable u_0 in problem 4 in accordance with the following criteria:

If $u_0 = 0$, DMU_0 has constant returns to scale; otherwise,

$u_0 > 0$ implies decreasing returns to scale;
$u_0 < 0$ implies increasing returns to scale.

The value of variable u_0 is part of an optimal solution of the additive model and is produced by the computer code such that facet rate $= -u_0$.

Appendix B
Data Envelopment Analysis: An Alternative Approach

In measuring and evaluating technical and scale efficiencies there are two basic approaches: the DEA technique developed by Charnes, Cooper and others in operations research and the approach developed by Farrell, Fare and Grosskopf, among others, in economics.[1] The latter approach is based upon a set of axioms on production technology to define the concept of efficiency. Some connections of the two approaches have been investigated by Banker, Charnes and Cooper (1984) and by Fare and Hunsaker (1986).

Both approaches share the characteristics that there is no need to specify a production function or cost function and to estimate the parameters. Therefore, they are nonparametric, nonstochastic techniques that can be used to construct a multiproduct frontier relative to which the efficiency measures of the entities in the sample are calculated. Because the frontier in these approaches is generated by data and all observations are enveloped by the frontier, both approaches can be viewed as Data Envelopment

[1]See Fare and Hunsaker (1986); Fare, Grosskopf and Lovell (1985).

Analysis. In this appendix, some of the differences and similarities among the CCR and the additive models and the Farrell or Russell models are discussed.

The choice of efficiency reference on the relevant frontier is a major difference among these DEA models. In the Farrell or Russell models, three measures of technical efficiency can be defined: input, output and graph efficiency measures.

Using the input efficiency measure, the observed output vector is fixed and the search for efficient reference is constrained to proportionally reducing inputs until the efficient frontier is reached. The "ratio of contraction," as it is called, is the ratio of the particular input to be efficient to the current level of inputs (in the Farrell input model).

Using the output efficiency measure, the observed input vector is fixed and the outputs proportionally expanded until the efficient frontier is reached. The "stretch ratio" of the output, as it is called, is the ratio of efficient output to the current level of output (in the Farrell output model).

For the graph efficiency measure, both input and output vectors are varied. Inputs are reduced and outputs are expanded, both proportionally, with the input ratio reciprocal to the output ratio.

In the case of figure 1 in the text, A is the reference point for the input efficiency measure, B is the reference point for the output efficiency measure and C might be the reference point for the graph efficiency measure. These three efficiency measures can be classified as radial because proportional changes of inputs and/or outputs are used in defining them.

To illustrate the input efficiency measure, ray OF_3 in figure 1 of the text is used to represent the optimal scale that would be generated by long-run competitive equilibrium. The overall input efficiency measure is defined with respect to the ray OF_3, while the input pure technical efficiency is defined with respect to the line segment connecting F_1, F_3 and F_5. The measure of input overall technical efficiency, KD/KF_2, can be decomposed into the measure of pure technical input efficiency given by the ratio KA/KF_2 and the measure of input scale efficiency given by the ratio KD/KA. When the scale efficiency equals unity, the constant returns to scale occur; otherwise non-increasing or varying returns to scale hold.

It is clear from these examples that, in general, these radial efficiency measures will be different. Moreover, there is nothing to guarantee that a firm that is output efficient by this measure is also input efficient or vice versa. For example, the firm denoted by F_6 in figure 1 of the text is output efficient by the output efficiency measure, but is not input efficient (see Fare, Grosskopf and Lovell (1985)). However, the Farrell input efficiency measure is reciprocal to the Farrell output efficiency measure, if and only if, the technology is homogeneous degree one. Because this condition is satisfied by constant returns to scale technology, the Farrell input and output efficiency measures are "identical" in this case. For models with other technologies, simple relationships between input and output efficiency measures do not hold.

An improvement of the Farrell or Russell models over the others is the use of non-radial efficiency measures. The use of proportional changes of inputs and/or outputs in searching for efficient reference is abandoned.

Moreover, different piecewise linear technology can be accommodated in both Farrell and Russell models to meet the needs of various users. For example, to measure scale efficiency we can use constant returns to scale, non-increasing returns to scale or varying returns to scale technologies. These technology constraints can be easily imposed by corresponding restrictions on the "intensity parameters" in the Farrell or Russell models.

In the CCR or additive DEA model discussed in appendix A, however, only one efficiency measure is defined: the CCR model uses the radial measure of efficiency while the additive model uses the non-radial measure.

Geometrically, the efficiency frontier with constant returns to scale technology is a convex cone, but it is a convex hull in cases of both non-increasing and varying returns to scale. In general, these constraints on technology form a chain such that one efficiency frontier is enveloped by another. Consequently, the associated efficiency measures are compatible and nested.[2]

[2]See Grosskopf (1986).

As is presented in appendix A, the CCR model has a convex cone efficiency frontier that implies technology with constant returns to scale. The additive model uses a convex hull as its efficiency frontier that is associated with the varying returns to scale. Even though the efficiency frontier of the additive model is enveloped by the efficiency frontier of the CCR model, the efficiency scores given by both models are not compatible because one uses a radial measure while the other uses a non-radial measure. The efficiency ratio of the CCR model is identical to the Farrell input efficiency measure (or reciprocal output efficiency measure) with constant returns to scale technology. Although both additive and Russell models define non-radial efficiency measures, the definitions are not identical. Hence, the efficiency measures given by these models are not compatible.

With our 1984 data of 60 Missouri commercial banks, we used the Farrell model with input and output efficiency measures and different technology constraints. The overall technical efficiencies and scale efficiencies are presented in table B.1. The reported results are based upon the input measure of efficiency.

Comparing table B.1 with table 1 in the text, we can see that the CCR model and the Farrell input model give identical technical efficiency measures and classification of returns to scale. Farrell input scale efficiency measures in table B.1 indicate that the scale inefficiency was not a major source of technical inefficiency in this group of banks. For a few of the banks in the sample, however, the scale inefficiency might be a problem.

Table B.1

Farrell Technical and Scale Efficiencies of 60 Missouri Commercial Banks (Input Efficiency Measure)

Bank no.	Efficiency measure	Scale measure	Type of scale[1]	Bank no.	Efficiency measure	Scale measure	Type of scale[1]
1	.8545	.8556	D	31	.8568	.9813	D
2	.9228	.9228	I	32	.9305	.9964	D
3	.9033	.9177	I	33	.8509	.8777	D
4	.8588	.9852	I	34	.8392	.9738	I
5	1.0000	1.0000	C	35	.8596	.9849	I
6	.8766	.9983	I	36	1.0000	1.0000	C
7	.8709	.9308	I	37	.8712	.9870	I
8	.8841	.9980	I	38	.8707	.9316	I
9	.8735	.9731	I	39	1.0000	1.0000	C
10	.8115	.9943	I	40	1.0000	1.0000	C
11	.9086	.9962	I	41	.8500	.9853	I
12	.7852	.9740	I	42	.8867	.9637	I
13	.8338	.9572	I	43	.8220	.9836	I
14	.9739	.9994	I	44	.8254	.9887	I
15	.8937	.9550	I	45	1.0000	1.0000	C
16	.8292	.9938	I	46	.9124	.9769	I
17	.8705	.9714	I	47	1.0000	1.0000	C
18	.9684	.9939	I	48	1.0000	1.0000	C
19	.8439	.8439	D	49	.9507	.9983	I
20	.9527	.9867	I	50	1.0000	1.0000	C
21	.9746	.9747	I	51	1.0000	1.0000	C
22	.8681	.9306	I	52	1.0000	1.0000	C
23	.9744	.9843	I	53	.8992	.9758	I
24	.9003	.9877	I	54	.9443	.9443	I
25	1.0000	1.0000	C	55	.9303	.9762	I
26	.8714	.9930	I	56	.8889	.8889	D
27	1.0000	1.0000	C	57	.8434	.9427	I
28	1.0000	1.0000	C	58	1.0000	1.0000	C
29	.8753	.9622	I	59	.7600	.9565	I
30	.9003	.9538	D	60	.8614	.9830	I

Where C = constant returns to scale
I = increasing returns to scale
D = decreasing returns to scale
[1]Determined by the Farrell input measure.

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