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ECONOMIC PERSPECTIVES

A review from the
Federal Reserve Bank
of Chicago

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Circuit breakers

These safety mechanisms are triggered by rapid or heavy market changes, and they can have unintentional effects on the financial system

James T. Moser

The "circuit breakers" that have gradually been added to financial markets since 1987 got their toughest test of the year yesterday. They passed.

—Wall Street Journal, July 24, 1990.

The limits "did exactly what they were supposed to do," he said.

—New York Times, July 24, 1990, quoting a trader.

Press reports describing the markets' encounter with circuit breakers on July 23, 1990, regarded them as successful. Their apparent criterion for success is the fact that the Dow Jones Industrial Average rose 60 points after encountering the circuit breaker. The experience from other markets suggests that circuit breakers do not usually produce dramatic price reversals. But, they do have effects. This article examines these effects.

Circuit breakers are mechanisms used by management to control activity in capacity-constrained systems. The term circuit breaker originates in electrical engineering to describe a pre-set switch that shuts down electrical activity in excess of a system's design capacity. The activation level of the breaker reflects an *ex ante* decision on the capability of the system.

Circuit breaker activation is inherently costly. The system engineer designing a circuit-breaker makes an *ex ante* choice between temporary loss of the use of the system and reductions in the likelihood of permanent damage to system integrity. Activation of a circuit breaker intentionally imposes costs that are expected to be less than losses realized by exceeding the system's capacity. Cost considerations naturally focus on the value the intended users can expect to obtain through their use of the system.

Activation of circuit breakers can also have unintentional costs. These have two sources. First, activation of circuit breakers can lead to unanticipated convenience losses. For example, system engineers may undervalue some activities lost when a circuit breaker is activated. Therefore, system users with a financial stake in its operation have incentives to increase system capacity by allowing increases in the activation levels of circuit breakers. It is these incentives that produce pressure to re-allocate financial resources toward increased investment in the system. Thus, when private interests are involved, the ability to re-allocate resources insures that unanticipated convenience losses will be infrequent and temporary.

Second, costs are also incurred when unplanned uses of the system are disrupted. System engineers focusing on anticipated uses will not incorporate the value of unanticipated uses into their circuit-breaker decisions. These value losses are recognized only when service interruption motivates increased investment by such users. When value losses fail to attract investment, system engineers are not moti-

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vated to include these losses in the circuit-breaker decision. I refer to these interests as *public*, to distinguish them from *private* interests that do lead to increased investment in the system.

In financial markets, the intended effect of circuit breakers is to halt trading when activity levels threaten market viability. Earlier circuit breaker policy was determined within the affected market by parties having private rather than public interests in the activation of circuit breakers. Exchanges, responding to these interests, developed three separate circuit breaker mechanisms. *Order-imbalance* circuit breakers are intended to protect the interests of market makers in specialist markets. *Volume-induced* circuit breakers are intended to protect the viability of back-office operations. *Price-change* circuit breakers are intended to bring excessive volatility under control.

Recent developments in financial markets have elevated the importance of public interests. Markets are increasingly characterized as inter-related. This inter-relatedness increases the importance of price information flowing between markets. This is particularly true between the stock markets and the markets for financial derivatives—options and futures.

Futures exchanges have developed standardized contracts for a variety of financial assets. Value changes in these contracts are closely linked to developments in their related asset markets. Thus, asset prices serve the public purpose of determining gains and losses in futures contracts. Futures exchanges and their customers have benefitted from the price information generated by asset markets. Activation of circuit breakers interrupts this information flow, decreasing the public value of the services rendered by asset markets.

Futures markets offer a distinct set of services including opportunities to manage risks and additional routes to price discovery. Circuit breakers activated in these markets similarly disrupt these services, lessening their value. The stock-index futures contract illustrates this. Prices for these futures contracts are for hypothetical baskets of stocks. Thus, a single quote determines the price of the futures basket, whereas in the asset market cash prices must be aggregated to produce a cash index. In addition, daily settlement in the futures market is in cash, greatly simplifying order processing. The simplicity of stock-index futures contracts produces an ideal instrument for institutions to manage systematic risk levels through simultaneous trading in asset markets and futures. Circuit breakers disrupt the normal synchronization of price changes between futures contracts and asset prices. This disruption amplifies the risk that gains realizable in one market may be unavailable to offset losses in the other market.

The current proliferation of derivative-asset markets with differing capacity constraints, combined with intensive intermarket trading, raises coordination issues that were less crucial in the past. Circuit breakers activated in one market now can affect several markets, not only the market in which they were activated. Thus, circuit breakers in financial markets can influence public interests. These public costs are realized in two ways. First, circuit breaker interruption of private markets serves to shift trading into markets that remain open. Such interruptions initiate a chain of events that ultimately generates demand for a lender of last-resort to supply liquidity to the financial system. Second, price-change circuit breakers shift credit risk to gaining positions that implicitly extend credit to loss positions. Their creditworthiness may decrease the quality of exchange guarantees of performance.

The next section describes the three types of circuit breakers. Then, I examine the history of circuit breaker activity. An analysis of the unintended result of price limits on liquidity demands and the quality of nonperformance guarantees follows.

Classification of circuit breakers

Circuit breakers are of three types. Each addresses a different design-capability issue. The first, the order-imbalance circuit breaker, occurs in specialist markets. Inequalities in the number of buy and sell orders are balanced by specialists trading for their own accounts. These trades maintain orderly markets by smoothing short-run order imbalances. Substantial order imbalances increase the risk born by specialists. This, in turn, jeopardizes orderly markets. The second type, volume-induced, occurs when order processing becomes uneconomic. At low volume, order processing does not meet costs. High volume impedes the ability of the exchange to effectively process orders. Markets close when either volume effect pushes trading costs to uneconomic levels. The third type, the price-triggered circuit breaker, closes markets when a given price level is reached. This last type originated in the futures markets. Such circuit breakers are called "price limits." Justifications of price limits are couched in terms of controlling "excessive" volatility.

Order-imbalance circuit breakers

Stock markets activate order-imbalance circuit breakers at the request of a specialist. The specialist asks for a suspension of trade in an individual stock when an order imbalance occurs. In these cases, suspension gives the specialist time to determine a market-clearing price based upon information obtained off the exchange floor. Following the price determination period, the market re-opens with the specialist taking a position at the newly determined price. The purpose of this circuit breaker is to protect the specialist from large losses.

Order imbalances were a problem in both the 1987 and 1989 breaks. In 1987, selling pressure at the October 19 opening prevented trading in 140 of the NYSE-listed stocks in the S&P 500 during the first half hour. In 1989, openings on October 16, 1989 were similarly delayed. (Most stocks were reported not opened during the first fifteen minutes of trading. Beginning 8:45 CT, stocks began opening and trading was reported at 9:15.) In both cases, the intended effect of the order-imbalance circuit breakers was to protect specialists from losses incurred by purchases in declining markets.

Activation of these circuit breakers have unintentional effects. Trading halts in individual stocks create uncertainty about the correct level of the aggregate indexes. This, in turn, tends to be reflected in the futures contract. As a result, the futures contract becomes more likely to encounter a price limit. (On October 16, 1989, it did hit the open limit—5 points down.) When a price limit is reached futures trading stops, shifting some trades to the stock exchange. These trades tend to aggravate any existing order-imbalance problems.

Volume-induced circuit breakers

The cost-effectiveness of order processing depends on the level of trading volume. At low trading levels, breakeven costs are not met. The determination of exchange trading hours recognizes that the fixed costs of operations must be covered by revenues generated from trading activities. Exchanges schedule closings based on expectations that additions to these fixed costs will not be adequately compensated. Thus, daily closes can be construed as activation of a circuit breaker.

Trading volume can surpass the ability of exchange back offices to process the paperwork required to document executed trades. When this happens, the effectiveness of order processing is reduced, producing additional costs as the need for correcting orders rises. These costs are expected to rise with trading volume. With these additional costs, exchange operations can become uneconomic and the exchange closes.

In 1968, the stock exchanges instituted a temporary four-day week during the last half of the year, closing on Wednesdays to increase the time available to process paperwork. Heavy volume in the period prior to the four-day week had led to increases in errors executing orders. These midweek closings insured that each five-trading-day delivery period included at least one nontrading day, allowing the back offices to catch up.

More recently, heavy volume appears to have complicated the order-matching activity of the specialists. Stock trading volume during the 1987 price break surpassed the ability of specialists to match orders. As a result, executions were not timely and the ticker lagged current trades. Changes instituted after 1987 substantially increased the capacity of the exchange to process orders to an estimated one billion shares daily. However, the trading suspensions that resulted from the volume on October 13, 1989, suggest a lower capacity. At the rate of trading in the last hour of October 13, daily volume would have been just over 703 million shares. Volume on October 16, 1989, the heaviest day of trading since October 1987, was 416 million shares. After processing the overhang from the previous Friday (most stocks were trading by 10:15), stock trading proceeded smoothly all day.

Price-limit circuit breakers

In futures markets, price limits restrict trading to a band of prices generally symmetrical above and below the previous trading day's settlement price.[1] The stated goals of circuit breaker policies have historically been to control volatility. More recently, price limits on stock index contracts have been set to coordinate price movements in the cash and futures markets. Price limits serve as market-closing rules because:

1) short trades (sales of futures contracts) are not offered on up-limit days—the market clearing price is higher; and

2) long trades (buying futures contracts) are not offered on down-limit days—the market clearing price is lower.

Historically, the rules committees of the futures exchanges incorporated price limits into trading rules in response to threatened regulatory intervention. That pattern suggests that price-triggered circuit breakers would not exist without potential regulatory intervention.

Past circuit breaker experience

This history of the price-limit form of circuit breaker demonstrates that price limits appear to resolve ''political'' volatility.[2] The imposition of price limits, an apparent impediment to the price discovery purpose of futures exchanges, coincides with threats to the independence of the exchanges. Rather than face increased regulatory oversight and lose their ability to resolve disputes internally, the exchanges accommodated pressures for regulation by self-imposing price limits.

Early history of price limits

The earliest occurrence of a price limit in futures trading was at the Dojima exchange in Japan during the early 18th century. Settlement in the *koku* ''small futures'' contract for rice was determined by the average of the previous three days' forward-closing prices. If this price deviated by more than a fixed amount from the cash price for rice, all contracts were either reversed out or delivered. This effectively discontinued trading in the contract by eliminating all futures positions. Also, the futures price was tied to the cash market, avoiding the potential criticism that futures trading caused problems in cash markets. Imposition of the rule came during a time when rice markets were described as ''deteriorating.'' Deteriorating markets are often characterized by price volatility.

The first instance of a price limit rule in the United States came during the First World War. On February 1, 1917, Germany announced that its submarines would sink all ships found in the major Atlantic shipping lanes. Cotton prices for May delivery on the New York Cotton Exchange closed down by a record of over five cents a pound. By the following Monday, however, the market had recovered to within one and one-half cents of the earlier price. In subsequent weeks, futures prices continued to be extremely volatile. The threat of attacks on shipping continued to run down prices as traders feared lost access to the European markets. Cotton prices rose as markets responded to news of potentially large purchases of cotton for military uniforms. Congress responded by supplying flat-rate three percent war loss insurance—a substantial discount from the then-current Lloyd's of London quote of ten percent. Cotton prices reached an all-time high following the introduction of this subsidized insurance.

The futures exchanges trading cotton responded to this volatility in two ways. On June 20, 1917, the British Board of Trade closed down cotton futures trading and the New York Cotton Exchange increased margin requirements. Separately, the U.S. government requested a price limit on the cotton contract. On August 22, 1917, a three-cent price limit was imposed. This limit remained in effect for the duration of the war. Interestingly, there is no record of a limit day during this period.

Also during the First World War, the Food Administration froze prices on wheat to prevent profiteering in that commodity. This action closed down trading in wheat futures at the Chicago Board of Trade. However, other grain prices were not frozen and their corresponding futures contracts traded freely. Since these grains are partially substitutable for wheat, government policy regarding wheat induced volatility in other grains. Futures prices for these commodities reflected this volatility, attracting the attention of the Food Administration. As a result of this scrutiny, the Board of Trade instituted a two-cent per day price limit on the oat contract and the New York Mercantile Exchange introduced a three-cent per day price limit on soy bean oil contracts. These price limits were removed once trading in wheat futures resumed after the war.

Price limits were formalized in 1925 at the Chicago Board of Trade. The 1925 Annual Report reported a modification to all contracts allowing the Board of Directors to set price-change limits of five percent of the preceding day's average closing price, following a ten-hour notice period. (For comparison, a five percent limit on wheat in today's wheat contract comes to 18.9 cents per bushel. The present limit is twenty cents per bushel.) Determination of an emergency was left to the Board. Nevertheless, price limits retained their temporary character, to be used only in emergency situations.

Direct federal intervention in agricultural markets during peace time began in the early 1930s under the authority of the Agricultural Adjustment Act. The Federal Farm Board, attempting to maintain prices in spite of large supplies of wheat, opened long futures contracts in May 1931 and 1932 wheat. Uncertainty about government policy (including complaints that officials were manipulating prices in their own interests) increased the frequency of emergency use of price limits.

(A recent proposal by Robert Heller makes similar use of futures markets. He argues the current policy of supplying liquidity during a market break disrupts monetary policy. Instead he suggests the Fed supply liquidity directly by taking long futures positions. His use of futures contracts is reasoned from the same basis as the Federal Farm Board policy of six decades ago—both approaches avoid the problem of the federal government holding and disposing of assets. The experience of the 1930s suggests that careful consideration should be given to the problem of contract expiration.)[3]

Passage of the National Industrial Recovery Act in July 1933 opened the way for trade associations to enforce price stabilization agreements, with the federal government acting both as architect and enforcing partner. Application for these partnerships was made through the National Recovery Administration (NRA) with the agreements chartered through Executive Orders by President Franklin Roosevelt. The agreements came in the form of codes for fair competition.

Grain price volatility continued to be high after the Farm Board ceased its price manipulations. The drought of the period and uncertainty about government policy were contributing factors. This high volatility led to Department of Agriculture pressure in July 1933 for a fair-trade agreement among the grain exchanges. Pressure on the exchanges to comply came in the form of a proposal by the Agricultural Adjustment Administration and the Grain Futures Administration that would have empowered the Secretary of Agriculture to modify and enforce trading rules at the futures exchanges. The proposed authority included limits on individual trading, limits on daily price changes, and margin setting. The futures exchanges complied with the request and Executive Order No. 6648, entitled "Code of Fair Competition for Grain Exchanges and Members Thereof", was signed by President Roosevelt on March 20, 1934. The agreement, implemented the next day, included price limits which could not be exceeded, but did permit exchanges to set limits below the prescribed maximums.

The Supreme Court ruling in the Schechter Poultry Corporation case on May 27, 1935, declared the NRA codes unconstitutional. Following the Schechter decision, Congressional hearings began on the Commodity Exchange Act to broaden the scope of federal regulatory powers over the futures exchanges. These powers had previously been lodged within the Grain Futures Administration. Congressional discussion indicated the proposed Act would institutionalize the defunct NRA codes.

To thwart increased regulation, the Chicago Board of Trade incorporated permanent price limits on all its contracts. (At the same time, the Board of Trade also eliminated trading of options on futures, then called "priviledges [sic]." These were also targeted in Congressional hearings.) The action began the use of price limits as a standard contract feature. The Commodity Exchange Act later passed specifying only regulatory review, rather than expanded powers, over contract details—including price limits.

Circuit breakers in the 1980s

In 1982, futures contracts on stock indexes were introduced. The initial contracts, keeping with standard practice, were introduced with price limits. However, for the first time since the 1930s, these limits were dropped on objections from New York stock trading interests. In late 1984, price limits were dropped on all International Monetary Market contracts for foreign exchange.

The movement away from price limits continued until the market break of October 1987, when price limits were instituted on the S&P 500 contract. Three of the six commissions studying issues of the market break recommended significant regulatory changes. With regard to price limits the recommendations differ substantially. The Brady Commission recommended coordinated trading halts. While no specific method was proposed, the Commission indicated that price limits should be considered among the possible mechanisms. The NYSE "Katzenbach" study group said that price limits will not resolve market break issues. Their proposals focused on increasing the cost of trading to prevent speculation. They specifically proposed requiring delivery of stocks on stock-index futures contracts--increasing the cost of trading futures. The SEC study recommended against price limits on stock-index contracts. The SEC proposal suggested optional delivery of stock on index contracts, again increasing the cost of trading futures.

After the 1987 break, price limits were imposed on stock-index futures. The stated reason for these limits was to synchronize futures and cash prices. In 1988, the S&P 500 contract traded with a level-determined price limit. At levels below 275, the limit was 15 index points ($7500 per contract); between 275.05 and 325, the limit was 20 index points ($10,000 per contract); and, above 325, the limit was 25 index points ($12,500 per contract). Initial margins on these contracts were $15,000, twice the pre-break amount. In addition, a five-point limit was established at market opening. On reaching an opening limit, trading is suspended for two minutes and reopened at a new opening level. The opening limit rule holds only for the first ten minutes of trading.

The 1987 market break also led to introduction of price-triggered circuit breakers on the New York Stock Exchange. After a fall of 25 points in the Dow Jones Industrial Average (DJIA), the Sidecar program re-prioritized orders, giving priority to small (less that one million dollars) orders. After a decline of 250 points in the DJIA, the stock market would be closed for one hour. After a 400-point decline in the DJIA, the stock market would be closed for two hours. In addition, the DOT (Designated Order Turnaround) program would be shut down after a 50-point decline in the DJIA.

The mini-crash of October 1989

Recalling that the intent of these circuit breakers is to synchronize cash and futures markets, the events of October 13, 1989, provide a gauge for the usefulness of circuit breaker mechanisms. The evidence suggests that price limits did not synchronize these markets and may have routed dynamic-hedge trades into the stock market.

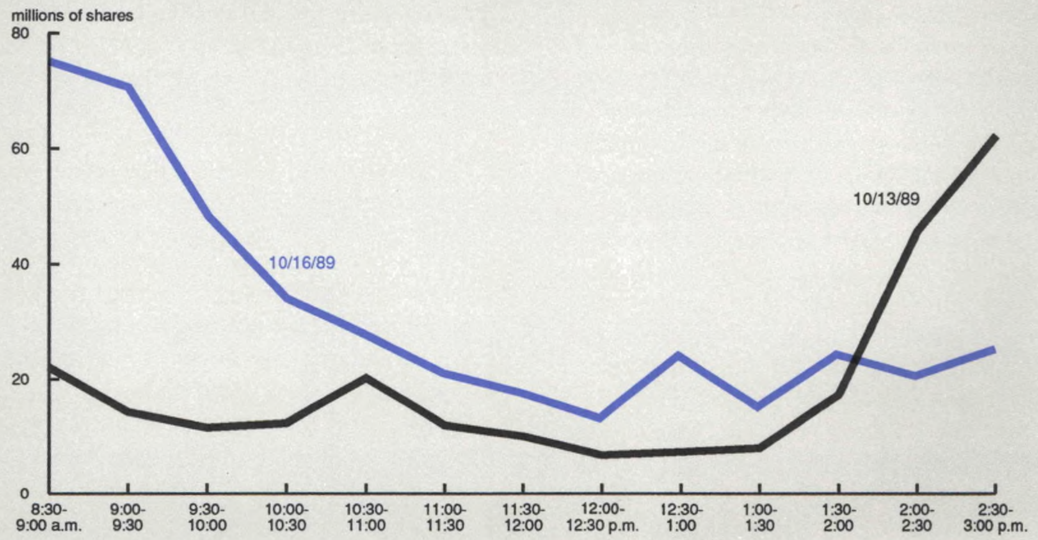
At 1:43 (CDT) negotiators announced the failure of financing for the proposed UAL buyout. The announcement sent the stock and index-futures markets into a steep decline. At 2:00 the DJIA was down 55 points. This corresponds to a 7.3 point drop in the S&P. Seven minutes later, the S&P futures contract hit its limit—12 points down. With futures trading suspended, the DJIA at 2:30 was down 114.76 points or roughly 15.3 S&P points. At 2:30, the futures contract reopened, but closed again fifteen minutes later—down 30 points. At the close of trading (3:00), the DJIA was down 190 points, or 25.3 S&P points. Quotes from the stock market clearly lagged behind those from the futures market. The circuit breakers do not appear to have kept prices in line.

Trading volume was affected by the circuit breakers. Figure 1 shows NYSE volume for half-hour intervals for 10/13/89 and 10/16/89. Volume at 1:30 on 10/13 was 125.52 million shares for the day, or 12.55 million shares per half-hour interval. The market response to the UAL announcement in the 1:30-2:00 interval increased volume to 17.48 million shares, or 39 percent above the average prior to 1:30 but still less than two of the previous half-hour intervals.

At 2:07 CDT futures trading was suspended for the remainder of the half-hour period. Minutes later Chicago Board Options Exchange (CBOE) closed without re-opening. Volume during that period was 45.86 million shares, 265 percent above the average and more than twice the busiest previous period. During the last half-hour of trading, volume was 396 percent above the average—nearly

FIGURE 1

Stock volume levels: October 1989



four times the busiest period before 1:30. This trading might be explained as a response to new information and, therefore, independent of the incidence of circuit breakers but evidence in the Index futures pit suggests more was involved.

After limits were hit in the S&P 500 pit for the second time, a limited number of sell orders were executed at the limit price despite the disadvantageous price obtained there. Further, at the official 3:15 close of index trading, 2,000 sell orders worth $330 million were said to be outstanding. The pattern of selling in the Index pit indicates that traders were searching for reliable executions. The closest available substitute to selling stock-index futures is the sale of stock holdings. Thus, the substantial increase in stock volume can be related to the incidence of the CME circuit breaker. (See Figure 2).

The consequence of the volume increase may have been an increased difficulty in keeping up with the flow of orders. Heavy selling after 1:30 CDT produced suspensions in ten stocks with seven not re-opening. This suggests that stock markets were unable to handle the increased volume.

Finally, the evidence from the 1989 price break reveals three weaknesses. First, volume increases after price limits were encountered suggest these circuit breakers routed trades from the futures markets to the stock markets. This is a serious concern. There is good evidence from the 1987 break that order imbalances are positively correlated with price changes. Policies tending to exacerbate the order-imbalance problem are likely to increase price volatility during price swings encountered in the future. Second, both the price lags reflected in the DJIA and the suspensions in stock trading indicate that the circuit breakers did not keep prices in line. Third, taking the $330 million overhang in the futures market to be intended to cover stock positions of institutional traders, at least one-third of a billion dollars went unhedged.

New circuit breakers in place

After the 1989 market break, price limits were revised. The following describes current limit procedures for the S&P contract. The five-point opening limit is retained. After the opening interval and at all levels of the index, current levels are: On a 12-point drop in the index prior to 2:30 PM (Central Time), trading is suspended for thirty minutes; on a 20-point drop in the index prior to 1:30 PM, trading is suspended for one hour; on a 30-point change (up or down), trading is suspended until 50 percent of S&P stocks (by capitalized value) are open for trading.

The NYSE also revised its circuit breakers to restrain program trading. After a 30-point drop in the DJIA, incoming orders are routed into the Sidecar for fifteen minutes. After a 75-point drop trading orders are Sidecar'd for thirty minutes. In addition, the CME rejects incoming S&P 500 contract orders after a 12-point drop in the S&P.

The emphasis on drops clarifies the purpose of recent price-linked, circuit-breaker policies. They do not resolve cash flow problems for the futures exchanges—else limits would be imposed on the upside as well. Nor do they control volatility—for the same reason. They do shield the futures exchanges from the criticism that futures trading pulls down stock prices.

Circuit breakers and the market for liquidity

Liquidity is the relative ease of matching buy and sell orders at recently observed prices. Sellers can always obtain liquidity by lowering offers to sell. The difference between the price they obtain and the previously observed prices they expected can be construed as the cost of liquidity. Buyers recognize that for some assets these costs may be high. Thus, their offers to buy incorporate the risk of encountering a high liquidity cost on the eventual sale of the asset. Buyers respond by adjusting bids downward.

Markets respond by organizing to keep liquidity costs low. They accomplish this through efficient matching of buy and sell orders backed up by methods to handle any order imbalances that may arise.

The market-making activity

Market making refers to the activity of matching buy and sell orders. In specialist markets such as the stock exchanges, orders to buy or sell arrive at a central post, are matched up by a specialist, and are posted as transactions. The specialist's order book is unbalanced when the number of buy and sell orders at the most recent price are unequal. When these order imbalances occur, exchange rules require the specialist to trade for his own position—buying in a declining market or selling in a rising market. Since these trades are aimed at re-balancing the order book, they may be loss trades for the specialist; that is, buying above the correct market price in a declining market or selling below in a rising market. These trades produce a balance of buy and sell orders and fulfill the specialist's responsibility of maintaining an orderly market. To facilitate this role, dealers have exchange-required capitalization and minimum inventories for their stock listings.

Under an interest-rate targeting policy, the Fed acts as a marketmaker in markets directly linked to reserve assets. Reserve policy effects credit levels so that a stable monetary policy depends on a stable market for reserves. To maintain this stability, the Fed acts as a specialist in reserves—both buying and selling to prevent order imbalances.

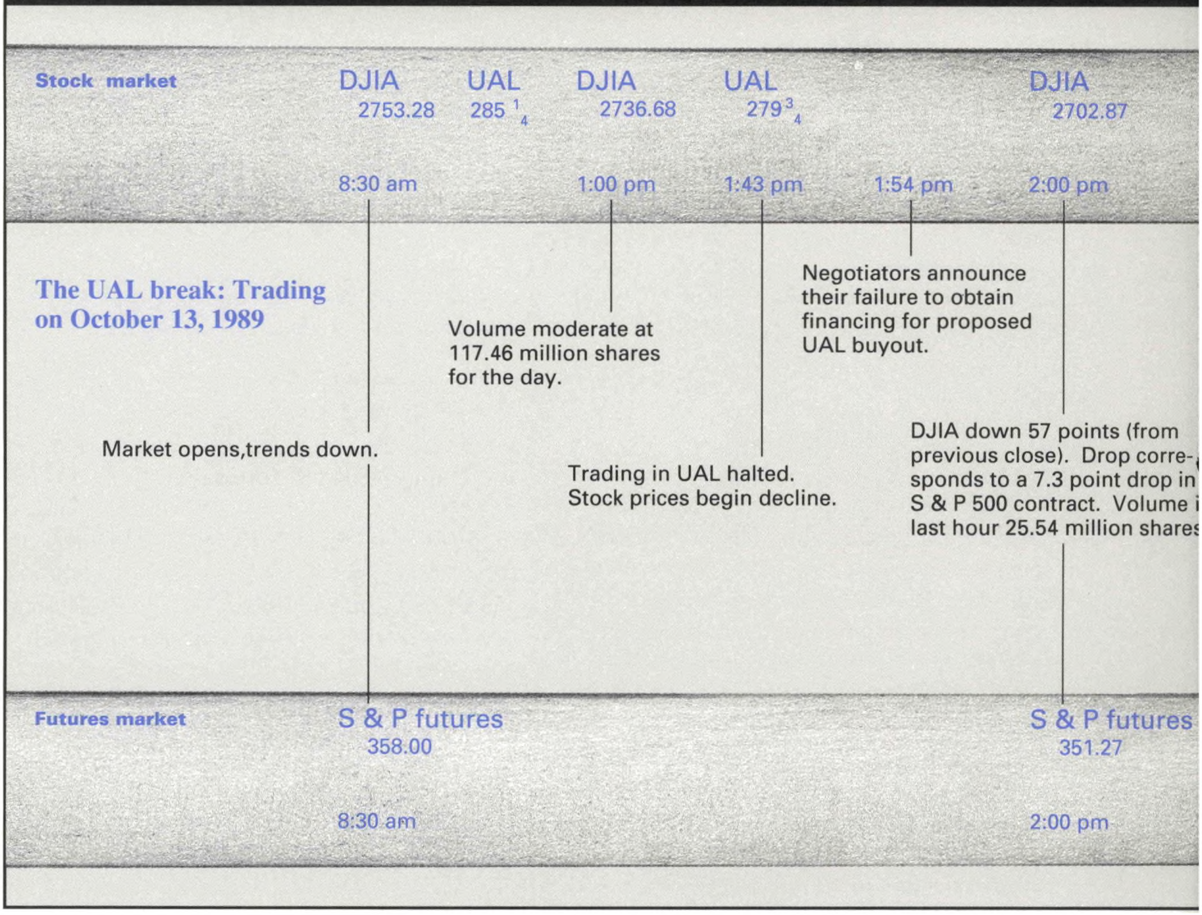
Links between financial markets

The Federal Reserve is affected by circuit breakers because markets for stocks, bonds, and futures contracts are fundamentally linked through the payments system and the market for reserves. To see this, consider the problem faced by the specialist after a steep decline in stock prices. In the process of buying stock to maintain an orderly market, losses have been encountered. In addition, inventories of stock, generally purchased on margin, have been marked down and require additional financing. Summing the financing needs of many specialists after declines of the magnitude experienced during the breaks of 1987 and 1989, one will generally observe a large increase in the demand for loanable funds. Institutions supplying funds to specialists respond by selling short-term Treasury securities to meet reserve requirements. Thus, the demand shock in the loanable funds market tends to destabilize markets for Treasury securities—orders to sell Treasury securities exceed buy orders.

Shocks to the loanable funds market are also felt as the margin accounts of mark-to-market assets are adjusted. Dynamic hedge trades in a declining market increase demand for Treasury securities placed in the initial margin accounts of long and short futures positions. Long and short positions marked to market add further shocks as losing positions sell Treasuries to generate funds required to cover calls for variation margin and winning positions invest cash balances in Treasuries. Over a period of time these shocks will net out. Nevertheless, lack of synchronicity induces short-term swings in the supply of liquidity.

Combining with these separate effects, stock-market specialists encountering losses from their market-making activities are seek-

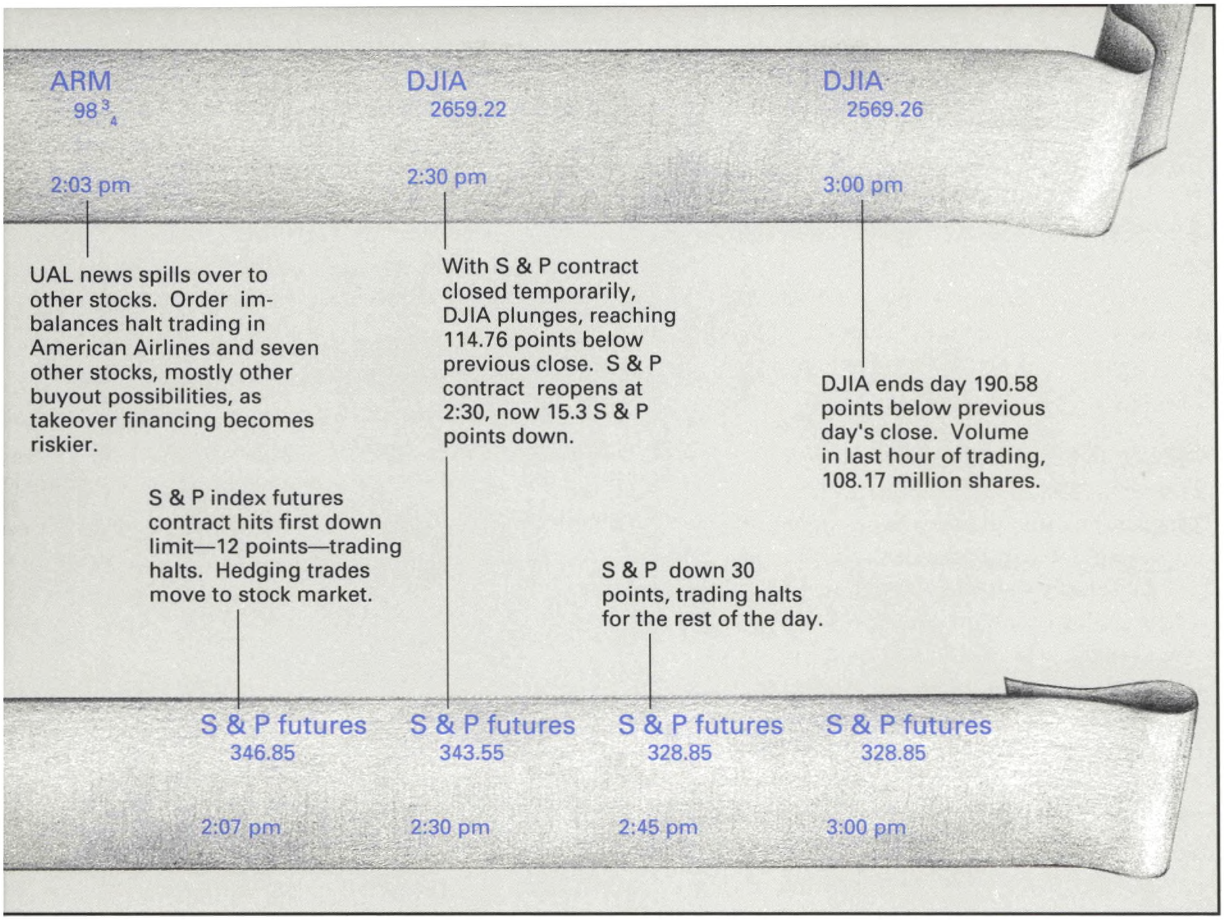
FIGURE 2



ing funds in a market subjected to volatile levels of liquidity. In its capacity as reserve specialist, the Federal Reserve supports liquidity by maintaining a balance between buy and sell orders for reserves and Treasury securities. This activity prevents short-run order imbalances from wringing liquidity from the system. The credit-demand shock from specialists' needs for funds are supported as the Fed adds reserves to the system.

Importantly, Fed policy must first distinguish between the real and monetary components of these shocks in the market for reserves. Facilitating the liquidity demands of a financial shock need not have real effects. Liquidity can be increased through purchases of Treasuries. Once the short-term credit needs of the payments system subside, reserve levels can then be reduced. These financial shocks can be identified by sharp market declines accompanied by volume and order-balancing problems. The timing of this credit accommodation requires consideration. Circuit breakers interfere with trades needed to generate liquidity. The appropriate time for the Fed to begin the supply of liquidity is at the point when trading halts create an imbalance of buy and sell orders for reserves and Treasury securities.

Policy considerations for mixed real-monetary shocks differ. In these events, the Fed must consider both the need for credit accommodation through its order-matching activity and its monetary policy which is implemented through reserve-level choices. For example, liquidity operations after the 1987 break produced significant decreases in short-term rates. Reserves were left in the system after October 1987, giving permanence to the October liquidity operations. The 1989 break was followed by reports that the Fed would supply liquidity as in 1987. These reports were later disavowed. However, open market operations on October 16, 1989, did effect a modest temporary increase in the reserve base.



In terms of the effect on credit markets, the expectation of increased credit availability is key. Interest rates fell on October 16, evidencing market anticipation of increased purchases of Treasuries. Interest rates rose shortly afterwards as the Fed's response and its disclaimers became known.

Identification of a real component to a shock suggests consideration of a less temporary adjustment to the reserve level. Accommodation of temporary liquidity needs facilitates the allocation of capital. Failure to accommodate liquidity tends to hinder the reallocation of capital, delaying recovery from the real shock. Once temporary liquidity needs are met, reserve policy should then focus on real, relatively permanent aspects.

Effect of circuit breakers

Circuit breakers alter the effect of a market move on credit markets by altering cash flows. Trading halts have three effects on the flow of funds.

First, amounts marked to market based on prices recorded when trading was halted do not reflect market values—short positions record less gain in a price decline, long positions record less loss. Provided trading halts are synchronized across markets, amounts marked to market for related securities are similar causing no excess demand for loanable funds. Unsynchronized trading halts, on the other hand, tend to produce asymmetry in that losses and gains on related assets are unequal. The liquidity needs produced by losses incurred in one market cannot be covered by recognition of gains in related markets. Thus, nonsynchronized trading halts increase the demand for loanable funds and shift liquidity trades into those markets which remain open. This places greater stress on these markets.

Consider, for example, a specialist hedging his equity position with a short futures position in an index contract. A trading halt in the index futures contract can result in equity losses exceeding gains on futures. In an unrestricted market, the futures position, in this example, would generate needed cash to cover the financing needs of the stock position. A halt in futures trading reduces the flow of funds to the specialist, increasing dependance on borrowed funds. Inventory financing needs that cannot be met with gains from the futures contract must be covered by increased borrowing.

Second, positions not marked to market are affected like marked-to-market accounts. The difference is one of form, not result. Gains and losses on stocks or options are realized by unwinding the position. Circuit breakers halt trading and prevent unwinding of contracts. This restricts access to invested balances required to cover losses, realized elsewhere, increasing the demand for credit.

For example, traders holding UAL on 10/13 attempted to sell out after the 1:43 announcement. The halt in trading of that stock initiated a search for close substitutes for UAL stock. The nearest substitutes were other takeover stocks and transportations, particularly airlines. Order books for these stocks quickly became unbalanced. Three Big Board stocks halted trading temporarily: USAir Group, Delta Air Lines, and Philips Industries. Seven Big Board stocks halted and remained closed for the day: UAL, AMR, BankAmerica, Walt Disney, Capital Cities/ABC, Philip Morris, and Pacific Telesis. Sales again shifted; first to index futures, then to a broad range of stocks after the 15-point limit halted futures trading.

These first two effects of price limits derive from restrictions on investor access to liquidity. During market breaks when liquidity is most valuable, circuit breakers reduce the number of routes available for private resolution of liquidity needs. This tends to increase demand for a source of last resort to supply liquidity—a role many expect to be taken up by the Fed.

A third effect derives from responses to price uncertainty as clearinghouses re-consider prudential margin levels. The trade halt produced by a circuit breaker creates uncertainty about the market's actual volatility. Since margin levels are determined in response to estimates of price volatility, risk-averse clearinghouses are forced to estimate margin needs on a worst-case basis. This will tend to increase the margin levels required by prudent clearinghouses. Recognizing that further losses to customer accounts may be substantial, initial and variation margin levels are increased to prevent losses from spilling over from customer accounts into clearing-member accounts. This effect tends to decrease the supply of loanable funds by increasing use of Treasury securities to meet margin obligations.

Credit risk due to loss financing

The previous comments on circuit breakers emphasize problems induced by disruption to the flow of funds. Circuit breakers can also be viewed as shifting credit risk. Failure to record the full loss amount in a marked-to-market account implicitly extends an interest-free loan for a portion of the loss amount to the losing position. The amount of this loan is the difference between the amount marked to the settlement price and the amount marked to the true market price. The loan is extended to losing positions from gaining positions.

The amount of credit extended by these loans can be considerable. To illustrate, I will use the October 1989 market break. Taking the true futures price to be roughly the 10/16/89 opening, the true settlement price for the 117, 202 December contracts outstanding should have been 323.85. The difference between the actual settlement of 328.85 and the estimate of the true settlement is 5 S&P points. The amount of credit implicitly extended to short positions over the weekend of 10/14-10/15 was, therefore, \$58.6 million or 3.3 percent of the value marked to market on 10/13.[4]

To gauge the risk to the financial system, we need to recall that futures clearinghouses provide performance guarantees for contracts trading on their affiliated exchanges. The quality of these guarantees depends on the amount of potential loss relative to equity. As potential losses increase relative to a fixed level of equity, the possibility of default rises, diminishing the quality of any guarantees. Book equity balances for the CME at the end of 1988 were \$79.3 million. The \$58.6 million implicitly lent to short positions is 73.9 percent of book equity.

The full implication for contract performance guarantees is not known. Threats to these guarantees will tend to shift trading away from the futures markets as the perceived quality of the guarantees declines. This tends to increase the credit needs of specialists operating in stock markets, requiring increases in reserves to meet these demands. Thus, the significance of the credit balance implied by price limits bears investigation. The policy issue is the viability of contract performance guarantees provided by the futures exchanges.

Conclusion

This article examines the effects of circuit breakers on the stability of the financial markets. Circuit breakers are classified into three types based on capacity issues: volume-triggered circuit breakers halt trading when volume exceeds order-processing capacity; order-imbalance circuit breakers halt trading when orders to buy or sell threaten the viability of the specialist; and price-limit circuit breakers halt trading when price changes are regarded as excessive. The history of price limits suggests they are introduced when futures exchanges are threatened with greater regulatory oversight.

This paper argues that circuit breakers reduce access to markets. This reduces the ability of markets to resolve needs for liquidity. Second, price limits extend credit to loss positions in futures and options markets. Since clearinghouses guarantee contract performance, these guarantees may be threatened by large credit balances.

On several recent occasions, circuit breakers have proved of some value in market crises. But it must be remembered that their value is not costless, nor their benefits without limit.

FOOTNOTES

[1]A notable exception to price-limit symmetry is found in the stock-index contracts. These are discussed in the next section.

[2]This term is from Joseph A. Grundfest, Commissioner of the Securities and Exchange Commission.

[3]The Heller proposal is in Heller, R., "Have the Fed Support Stock Market, Too," *Wall Street Journal*, October 27, 1989, p. A14. An analysis of the 1930s experience is in Moser, James T., "Public Policy Intervention Through Futures Market Operations," forthcoming in the *Journal of Futures Markets*.

[4] The 10/16 open price is probably too high. Opening contract prices on that date encountered the CME open limit of five points, preventing realization of a lower price on the S&P contract. Thus, our estimate may significantly underestimate the amount of credit extended.

Highway capacity and economic growth

The quality and quantity of highway transportation systems have a direct bearing on economic growth—good roads are good business

David A. Aschauer

To the commuter struggling along the clogged freeways of southern California, this statistic must seem unlikely: *the average auto commute in Los Angeles County took only 22 minutes in 1985.* Even more unlikely: *that time was shorter than 1980's average, 23.7 minutes.* After decades of increasing traffic and looming gridlock, how could these daily pilgrimages have become shorter?

One answer is suggested by Peter Gordon, Associate Dean of the School of Urban and Regional Planning at the University of Southern California. Gordon and his colleague, Harry Richardson, say that the highly developed freeway system in the Los Angeles area has allowed business and industry to further decentralize, often locating (or relocating) along the freeway system. It is this shift that has helped to shorten the commuter trips.

Four minutes or so a day per worker may not seem like much. But it adds up to nearly two full working days a year per worker, in a working-age population of some 5.4 million. And industry's intelligent use of the freeway system has other benefits, such as shorter delivery and pick-up times.

The concepts and empirical evidence contained in this article support the idea that transportation infrastructure plays an important role in the process of regional economic growth. While it is common for economists to argue that investment is a key determinant of productivity growth and economic development, it is often the case that the particular investment chosen for analysis is quite limited in scope. Indeed, public investment in infrastructure capital—streets and highways, mass transit, airports, water and sewer systems, and the like—is typically left out of growth discussions, at least at the level of national, aggregate analysis.[1]

Only a relatively small number of studies have sought to establish the importance of infrastructure investment to private sector productivity and income growth. In a series of papers, I have developed a framework (Aschauer 1988, 1989a, 1989b, 1989c) with three basic empirical implications: 1) That infrastructure capital carries a positive marginal product in a private-sector neoclassical production technology; 2) That infrastructure capital is complementary to private capital and is capable of enhancing the marginal product of private capital; and 3) That infrastructure investment is likely to spur private investment in plant and equipment. The empirical results contained in those papers are in broad conformity with the underlying framework.

Holz-Eakin (1989) and Munnell (1990) come to nearly the same conclusions using slightly different empirical approaches or sample periods. Similarly, Garcia-Mila and McGuire (1987) establish a contemporaneous, positive link between the stock of highways and per capita output. Based on the results of

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these studies, one might be convinced that by ignoring public capital stocks the relationship between investment and economic growth is misspecified and potentially underestimated.

Still, legitimate questions may be raised about the results in the aforementioned papers. For instance, the estimates in Aschauer (1989a) seem to suggest a marginal productivity of public capital in private production which is "too high." The elasticity of private sector output with respect to public capital is approximately the same as that with respect to private capital while the public capital stock is approximately one-half the size of the private capital stock. This implies a marginal product of public capital which is approximately twice as large as that of private capital. Perhaps, it may be argued, the correlation between the public capital stock and private sector productivity is merely evidence of economic causation running in the reverse direction—from productivity through per capita output and, in turn, through tax revenues to the demand for public capital.

This article develops an alternative estimation strategy in order to establish the direction of causation from highway investment to economic growth. Specifically, this article searches for a connection between the level of highway capacity and the growth rate of per capita output. The following section lays out the conceptual approach. The next section contains a description of the data and a discussion of empirical results. The article concludes by offering some suggestions for future research.

Conceptual issues

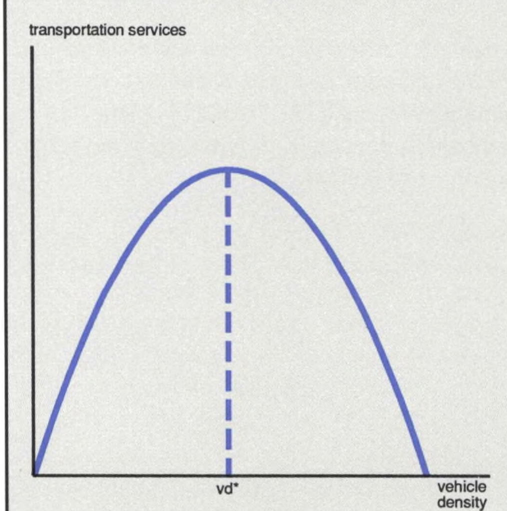
The conceptual analysis centers on the linkages among highway capacity and the production of transportation services, private sector investment, and economic growth. Transportation services are taken to be ''produced'' by a simple neoclassical technology

$$1)\quad t_j = f(\underset{?}{vd_j}, \underset{+}{hi_j})$$

where t_j = transportation services (measured as a flow of vehicles per time period) in a particular locale j; vd_j = vehicle density (measured as vehicles per mile of highway); and hi_j = highway capacity (measured as miles of highway). The production technology is characterized by a positive marginal product of highway capacity regardless of the level of vehicle density; additions to the highway stock reduce travel time and, thus, increase traffic flow and the associated transportation services. The production technology can exhibit a positive, a flat, or a negative marginal product of density, however, depending upon whether density is below, at, or above a certain critical level, vd^*, which is typically termed the ''bottleneck point'' for the highway stock.[2] The production function is depicted as the fundamental diagram of traffic in Figure 1. For a given level of highway capacity, the production of transportation services increases with vehicle density up to the bottleneck point, and declines with further increases in density.[3] A number of empirical studies, such as Fare, Grosskopf, and Yoon (1982), have confirmed this relationship for isolated locales.

FIGURE 1

Fundamental diagram of traffic



This article links the level of highway capacity to a measure of economic growth across localities. I argue that the return to productive activity (apart from transportation services) in any place is positively related to the level of transportation services, measured as a flow of vehicles per time period. Thus, I postulate the rate of return function

$$2)\quad r_j = r(\underset{+}{t_j}) = r(\underset{?}{vd_j}, \underset{+}{hi_j})$$

so that the return from production, r, in locale j depends on the degree to which the highway stock is congested and on the magnitude of the highway stock.

The level of capital accumulation in a particular locale, in turn, is dependent upon the gap between the return to productive activity, r_j, and the economy-wide cost of capital which we denote p. Hence, we have

3) $Dk_j = g(r_j - p)$

where Dk_j = the growth rate of the physical capital stock per person in locale j.

Finally, non-transportation output per person is assumed to be related to the accumulated capital stock per head according to a Cobb-Douglas production function augmented by a common rate of exogenous technological growth and a "catch-up" factor whereby total factor productivity in any given local is allowed to converge on that of other, leading locales. Following Dowdrick and Nguyen (1989), this allows us to write the growth rate of per capita output in the form

4) $Dy_j = a_0 + a_1 {*} y_j(0) + a_2 {*} Dk_j$

where $y_j(0)$ is the initial level of output in locality j; and where $a_1 < 0$, and $a_2 > 0$. Combining Equations (2), (3), and (4) yields the growth relationship between output, vehicle density, and highway capacity

5) $Dy_j = y(\underset{-}{y_j(0)}, \underset{?}{vd_j}, \underset{+}{hi_j})$

so that output growth will be negatively related to the initial level of output; positively or negatively related to vehicle density (depending on whether vehicle density has passed the bottleneck point); and positively related to highway capacity.

The logic of this approach is quite simple. An increase in the stock of highways for a given locale generates a higher return to local, productive activity by raising the level of transportation services available to producers. This higher return to production, in turn, stimulates private investment in these productive facilities. The increased investment carries with it higher growth in output and income for the particular locale.[4]

Increased productivity, of course, is not the only possible mechanism by which infrastructure in general, or highways in particular, might affect the rate of economic growth. Murphy, Shleifer, and Vishny (1989) suggest that investment in infrastructure (in this case, a railroad) may result in lower production costs to a number of economic sectors. These "external effects" of the investment allow for a multiplicity of equilibria, so that infrastructure spending can generate a "big push" to a higher level of output.[5]

In a recent paper, Romer (1989a) constructs a model in which technological change evolves endogenously as the result of profit maximizing investment behavior by imperfectly competitive firms. Knowledge is only partly excludable so that the aggregate production function for final goods exhibits increasing returns to scale. This nonconvexity in the production set allows for steady-state growth in per capita income. Romer shows how market power is necessary for the growth in knowledge to be a result of a response to market incentives; without imperfect competition, total output is less than would be required in payment of all inputs according to their marginal productivities. From the perspective of the current article, the key result of his model is that the rate of growth of a particular economy depends directly on the degree to which it is integrated with other economies. Such integration allows access to a larger stock of human capital which, in turn, raises investment in knowledge or technological improvement and boosts growth.

Sokoloff (1989) offers support for the Romer model. Sokoloff utilizes 19th century United States county-level data to show that the introduction of water transportation (canal construction or river dredging) sparked a sharply higher rate of patenting in those counties adjacent to the transportation system. Presumably, such counties displayed a higher rate of economic growth as well. Clearly, one could argue that similar effects would be expected from the development or improvement of a highway transportation system.

In a model that also admits the possibility of increasing returns to scale, and steady-state growth in per capita income, Barro (1989a) shows how the rate of economic growth can be affected by the size of a government sector. A larger government raises economic growth to the extent that it raises the marginal productivity of private capital but lowers economic growth to the extent that the associated higher rate of taxation discourages productive activity. In a companion empirical paper, Barro (1989b) presents evidence that suggests that governments optimize in their choice of the size of the government sector relative to the economy. In particular, he finds that economic growth is inversely related to "unproductive" government activity (such as government consumptions spending) and weakly positively related to "productive" government activity (such as nonmilitary public investment).

Data and empirical results

In this article, I use data on real per capita income growth and measures of highway capacity and quality across the contiguous forty-eight states during the period 1960 to 1985. As the focus of the study is on the longer term relationship between the transportation infrastructure and economic growth, the data on per capita income growth are sample averages of underlying annual observations. The basic highway capacity variable is measured as the total existing road mileage, inclusive of urban and rural roadway, in a given state relative to the square mileage of the state over the period 1960 to 1985.

The separate importance of the urban and rural road systems to per capita income growth will also be investigated. In these data, urban refers to census places with a minimum population of 5,000. The basic highway quality variable is the percent of highway mileage of deficient quality in 1982; such road surface carries a Present Serviceability Rating (PSR) of 2.5 or less for interstate highways and of 2.0 or less for other categories of roadway (other arterial and collector roads).[6]

In order to assess the degree to which the transportation system is congested, a highway usage variable must be employed. The variable chosen for that purpose in this article is vehicle density, expressed as total vehicle registrations (cars, trucks, and motorcycles) per highway mile over the period 1960 to 1985. Of course, this measure of vehicle density will be inaccurate to the extent that vehicles registered in a particular state are operated in other states.

The basic relationship to be investigated is a linearized version of Equation (5):

$$6)\quad Dy_j = b_0 + b_1{*}y_j(0) + b_2{*}vd_j + b_3{*}hi_j + b_4{*}pq_j + c_i{*}d_i + e$$

where Dy_j = per capita income growth in state j; $y_j(0)$ = initial (1960) level of per capita income (in logarithms), vd_j = logarithm of vehicle density; hi_j = logarithm of highway capacity; pq_j = pavement quality; and d_i = dummy variables for the Northeast, Midwest, and West regions of the United States as defined by the Census Bureau.

As the primary focus of this article is on the relationship between highway capacity and economic activity, the above equation is estimated without explicit consideration of the separate effects of vehicle density and pavement quality. Table 1 contains results of estimating this simpler equation by ordinary least squares (OLS) and weighted least squares (WLS) methods. Column 1 reports OLS results including all regional dummy variables. As is shown, there is a significant tendency for states' economies to converge toward a common level of per capita income. Specifically, the coefficient estimate of –1.38 on initial income implies that a one-standard-deviation reduction in the initial level of the logarithm of per capita income results in a faster rate of income growth of .28 percentage point during the period 1960 to 1985. Notably, the central proposition of this article—that economies with a superior surface transportation infrastructure will benefit through higher productivity and per capita income growth—achieves empirical confirmation. The coefficient estimate of .22 on the highway capacity variable indicates that a one-standard-deviation increase in the logarithm of highway capacity induces a .13 of a percentage point increase in the growth rate of per capita income.

The finding that the stock of highways is an important contributor to economic growth parallels the results of recent empirical research by Romer (1989b). Romer focuses on the importance of human capital—measured by the level of literacy of the population—for economic growth across countries. In regressions similar to those in Table 1, he finds a significant positive relationship between human capital and per capita output growth. He also finds that human capital is positively correlated with private investment in plant and equipment. According to the conceptual analysis above, a similar connection between highways and investment would be expected.

The results in Column 1 of Table 1 indicate that, apart from initial per capita income

TABLE 1

Per capita income growth and highway capacity
(Dependent variable: Dy_j)

	1	2	3	4	5	6	7	8	9	10
method	**OLS**	**OLS**	**OLS**	**OLS**	**WLS**	**WLS**	**WLS**	**WLS**	**WLS**	**WLS**
					sq. rt. of y(0)	sq. rt. of y(0)	level of y(0)	level of y(0)	log of y(0)	log of y(0)
constant	–6.53	–6.92	–6.94	–7.69	–7.18	–7.94	–7.47	–8.19	–6.84	–7.61
	1.53	1.10	1.45	1.08	1.15	1.08	1.20	1.09	1.09	1.08
$y_j(0)$	–1.38	–1.44	–1.48	–1.59	–1.49	–1.64	–1.54	–1.69	–1.43	–1.58
	.25	.19	.24	.18	.20	.19	.21	.19	.18	.18
hi_j	.22	.26	.27	.30	.26	.30	.25	.31	.26	.30
	.10	.06	.09	.06	.06	.06	.06	.06	.06	.06
pq_j	--	--	–009	–009	--	–010	--	–011	--	–008
			.004	.003		.003		.003		.003
mw	–27	–25	–37	–31	–26	–32	–26	–33	–25	–31
	.11	.08	.11	.08	.08	.08	.08	.08	.09	.08
ne	<.01	--	–07	--						
	.13		.12							
w	–0.8	--	–11	--						
	.15		.14							
R^2	.61	.63	.66	.67	.39	.49	.32	.46	.69	.73
SER	.26	.25	.24	.24	.26	.23	.26	.23	.25	.24

Variable definitions in appendix.

and highway capacity, only the Midwest region has a growth rate of per capita income statistically different from that of the South, which is used as a benchmark in this Table. Column 2 reestimates the basic equation, dropping the Northeast and West regional dummy variables. As was to be expected, the adjusted coefficient of determination improves marginally upon this alteration and only minor impacts on the individual coefficient estimates can be discerned.

Column 3 includes a measure of pavement quality in the regression equation to determine the separate effect of pavement quality on productivity and income growth. Here, a one-percentage-point erosion in pavement quality induces a reduction of per capita income growth equal to .009 of a percentage point per year. The point estimates of the coefficients on initial income and on highway capacity are left relatively undisturbed and, as before, the Northeast and West regional dummies are statistically insignificant. Column 4 eliminates the latter dummy variables and exhibits nearly the same results for the remaining coefficients.

As estimation is being undertaken over a cross-section of states, there is some presumption that the error structure may not be homoskedastic. Accordingly, Table 1 also contains the results of various generalized least-squares estimations using a variety of weighting series. Columns 5 and 6 use the square root of initial per capita income as a weighting series; columns 7 and 8 use the level of initial per capita income; and columns 9 and 10 use the logarithm of initial per capita income. Only the results with the Midwest regional dummy are presented; as in previous equations, the Northeast and West regional dummies carried little "explanatory" power. In every case, the rate of growth of per capita income is significantly related to highway capacity and pavement quality; further, the quantitative values of the coefficient estimates remain within a small interval of the original unweighted estimates.

Of course, one should be concerned about the potential for simultaneity bias in the estimated coefficients contained in Table 1. For instance, it may be argued that a portion of the positive correlation between highway capacity and per capita income growth is simply due to the fact that high income growth states are likely to be states with adequate resources to invest in additional highways. Similarly, states with such resources would be in a position to undertake appropriate maintenance expenditures in order to avoid an erosion of pavement quality over time.

To address the possibility of such simultaneity bias, Table 2 exhibits results of estimating the relationship between highway quantity and quality variables and per capita income growth by two-stage, least-squares methods. Instruments chosen for estimation are the initial 1960 stock of highway mileage, initial 1960 vehicle registrations, initial 1960 population, new road mileage financed with federal aid highway funds during 1980, seasonal heating degree days, and the number of local governmental units in 1982. The reasoning behind the choice of certain instruments, such as initial highway capacity, initial vehicle registrations, and initial population require no explanation. New road mileage financed through federal grants is taken as exogenous to individual states and is expected to be correlated with highway capacity and quality. Heating degree days is a measure of temperature extremes and is expected to be correlated with pavement quality. Finally, the extent to which a state's governmental decision-making is concentrated, measured by the number of local governmental units, arguably will affect its ability to collect and disburse funds for the purpose of

TABLE 2

Per capita income growth and highway quantity and quality
(Dependent variable: Dy_j)

	1	2	3	4	5	6	7	8
method	**TSLS**	**TSLS**	**WTSLS**	**WTSLS**	**WTSLS**	**WTSLS**	**WTSLS**	**WTSLS**
weight	--	--	sq. rt. of y(0)	sq. rt. of y(0)	level of y(0)	level of y(0)	log of y(0)	log of y(0)
constant	–6.92	–8.28	–7.17	–8.53	–7.45	–8.70	–6.83	–8.18
	1.10	1.30	1.15	1.27	1.20	1.24	1.09	1.31
$y_j(0)$	–1.44	–1.71	–1.48	–1.76	–1.53	–1.79	–1.43	–1.69
	.19	.23	.20	.23	.21	.22	.18	.23
hi_j	.26	.33	.25	.34	.25	.34	.26	.33
	.06	.07	.06	.07	.06	.07	.06	.07
pq_j	--	–016	--	–018	--	–019	--	–015
		.008		.008		.007		.008
mw	–25	–36	–25	–37	–26	–38	–25	–35
	.08	.10	.08	.10	.08	.09	.09	.10
R^2	.63	.64	.39	.42	.31	.38	.69	.70
SER	.25	.25	.26	.25	.26	.25	.25	.25

Instrument list: $y_j(0)$, $hi_j(0)$, $v_j(0)$, $p_j(0)$, $newhi_j(0)$, hdd_j, $govu_j$.

highway construction and maintenance. As before, only results from estimating with a dummy variable for the Midwest region are displayed; inclusion of other regional dummies does not affect the conclusions in any important way.

Column 1 of Table 2 shows that the basic relationship between highway capacity and economic growth is not reflective of a reverse causation from per capita income growth to highways. The point estimate of the effect of highways on economic growth remains the same as with ordinary least squares regression, and there is no change in the standard error associated with the coefficient on highway capacity. The results contained in Column 2 reflect an increase in the quantitative relationship between pavement quality and economic growth, with a near doubling of the relevant coefficient estimate. However, the associated standard error increases by a large amount, with the result that the relationship between pavement quality and per capita income growth is of somewhat diminished statistical significance. Nevertheless, the negative relationship between deficient highway mileage and economic growth still remains at roughly the 5% significance level. Columns 3 and 4 repeat the estimation utilizing weighted two-stage least squares, with the square root of initial per capita income as a weighting series; the point estimates are similar to those in Columns 1 and 2 with some improvement in the statistical importance of pavement quality. Columns 5 and 6 make use of initial per capita income as a weighting series; the only discernible difference in results is a further increase in the importance of the pavement quality variable. Finally, Columns 7 and 8 use the logarithm of initial per capita income to weight the observations; in this case, the statistical association between pavement quality and per capita income growth is attenuated and returns to that obtained in Column 2.

Highway capacity may be acting as a proxy for some other variable that may be of direct and primary importance to economic growth. One such variable might be the degree to which the economy of a state is geographically concentrated; perhaps highly urbanized states exhibit higher per capita income growth due to the compact nature of the particular state's economy. Table 3 allows one to dismiss the validity of this particular argument. As can be seen, urban density—measured by the raw percentage of total population living in standard statistical metropolitan areas in Columns 1 and 2 and by its natural logarithm in Columns 3 and 4—is, at best, only marginally significant and does not attenuate the strength of the basic relationships between highway capacity, highway quality, and economic growth.

TABLE 3

Per capita growth and urbanization
(Dependent variable: Dy_j)

	1	2	3	4
method	**OLS**	**TSLS**	**OLS**	**TSLS**
constant	−9.41	−13.27	−10.53	−12.71
	1.71	2.96	2.16	2.92
$y_j(0)$	−1.84	−2.44	−1.86	−2.17
	.26	.46	.25	.37
hi_j	.31	.38	.31	.37
	.06	.09	.06	.08
pq_j	−009	−023	−010	−022
	.003	.010	.003	.009
urb_j	.004	.012	.307	.433
	.003	.006	.204	.249
mw	−28	−34	−29	−37
	.08	.12	.08	.11
R^2	.67	.53	.68	.58
SER	.23	.28	.23	.27

Instrument list: see Table 2.

Vehicle density and economic growth

According to the discussion in the theoretical section, an economy with an overburdened highway system—one with traffic density beyond the bottleneck level—will have lower traffic volume and, as a result, lower productivity and per capita income growth. Thus, if during the period under investigation there existed chronic underinvestment in highway capacity across states, one would expect to find a negative relationship between vehicle density—measured as the logarithm of vehicle registrations per highway mile—and per capita income growth. The results contained in Table 4 allow one to gauge the adequacy of the highway capital stock across states.

TABLE 4

Adequacy of highway capital stock
(Dependent variable: Dy_j)

method	1 OLS	2 WLS	3 WLS	4 WTSLS	5 TSLS	6 WTSLS	7 WTSLS	8 WTSLS
weight	--	sq. rt. of y(0)	level of y(0)	log of y(0)	sq. rt. of y(0)	level of y(0)	log of y(0)	log of y(0)
constant	–8.00	–8.30	–8.61	–7.90	–8.80	–9.03	–9.19	–8.70
	.47	1.45	1.42	1.48	1.80	1.71	1.62	1.83
$y_j(0)$	–1.63	–1.68	–1.74	–1.62	–1.78	–1.82	–1.85	–1.76
	.22	.22	.22	.23	.29	.27	.26	.29
hi_j	.28	.27	.27	.28	.30	.30	.30	.30
	.10	.10	.10	.10	.11	.11	.11	.11
pq_j	–009	–010	–011	–008	–016	–018	–020	–016
	.003	.003	.003	.003	.008	.008	.007	.008
vd_j	.027	.033	.038	.026	.041	.043	.044	.040
	.086	.085	.084	.089	.097	.096	.094	.097
mw	–29	–30	–30	–29	–33	–34	–35	–33
	.086	.10	.08	.10	.08	.09	.09	.10
R^2	.66	.47	.45	.72	.62	.40	.36	.69
SER	.24	.24	.24	.24	.25	.25	.25	.25

Instrument list: see Table 2.

Upon scanning the results of Table 4, one finds no evidence of a chronic shortage of highway capacity across states over the entire period 1960 to 1985. The point estimate of the effect of higher vehicle density on per capita income growth is uniformly statistically insignificant regardless of the method of estimation (ordinary least squares, weighted least squares, two-stage least squares, and weighted two-stage least squares). Furthermore, the estimated relationship between highway capacity and economic growth and that between pavement quality and economic growth remain nearly the same as when the vehicle density variable was omitted from the basic empirical specification.

Urban versus rural highway capacity

A natural question is whether urban or rural roads are of greater quantitative and/or statistical importance in determining economic growth across states. Table 5 allows for a decomposition of the initial stock of highways into urban (SSMA) and rural (non-SSMA) mileage. The first Column of Table 5 indicates that both the urban and rural components are quantitatively and statistically important determinants of economic growth, with rural roads having the larger effect. One should note that the diminished statistical significance of the relationship between highways and per capita income growth to a large degree is due to the collinearity between urban and rural highway mileage; the correlation between the two variables across states is .59. Indeed, dropping each of the rural and urban components in turn—as in Columns 2 and 3—leaves significant importance for the remaining highway capacity measure, with individual point estimates of .17 (urban) and .40 (rural) and associated standard errors of .04 (urban) and .09 (rural). Column 4 combines the two components of the highway stock by weighting

TABLE 5

Urban and rural highway capacity
(Dependent variable: Dy_j)

	1	2	3	4	5
constant	–7.35	–6.81	–7.80	–7.37	–7.53
	1.09	1.08	1.120	1.04	1.06
$y_j(0)$	–1.54	–1.42	–1.65	–1.54	–1.61
	.20	.19	.19	.18	.18
hir_j	.24	.40	--	--	--
	.12	.09			
hiu_j	.10	--	.17	--	
	.05		.04		
hit_j	--	--	--	.34	
				.07	
$hita_j$	--	--	--	--	.26
					.05
$area_j$	–.27	–35	–13	–26	--
	.08	.07	.04	.05	
pq_j	–008	–008	–008	–008	–009
	.003	.003	.003	.003	.003
mw	–36	–42	–25	–36	–31
	10	.10	.09	.09	.08
R^2	.68	.66	.66	.69	68
SER	.23	.24	.24	.23	23

according to the coefficient estimates in Column 1 and then summing the two separate components. The coefficient estimate is highly statistically significant. Finally, Column 5 takes the highway capacity measure in Column 4 and normalizes by the surface area of the state. The coefficient estimate can be compared with that of Table 1, whereupon it is seen that this measure of highway capacity bears a stronger statistical association with per capita income growth than did the original, simpler measure.

Conclusion

This article develops a simple model in which the government sector of a particular jurisdiction can influence the rate of growth of output in that locale. A higher level and better quality of highway capacity expands transportation services and, in so doing, raises the marginal product of private capital. The higher marginal product of capital induces higher investment in physical capital and growing per capita incomes and output. Local governments can thereby exert an important influence on the rate of economic growth within their own locality.

In future research, it would be interesting to expand on the theme of this article by looking at the relationship between other measures of infrastructure—water and sewer systems, airports, mass transit, etc.—and local economic growth. Along with existing results on the importance of public capital to metropolitan production, such as contained in Eberts (1988), such evidence would give an improved indication of the importance of the services of government capital to the development and performance of state and local economies.

APPENDIX

Data description and sources

Dy = average annual growth of per capita income (1972$) from 1960 to 1985. SAUS, various issues.

y = logarithm of level of per capita income (1972$). SAUS, various issues.

p = logarithm of population, average over 1960 to 1985. SAUS, various issues.

hi = logarithm of total existing road mileage, average over 1960 to 1985. SAUS, various issues.

hir = logarithm of total existing rural road mileage, average over 1960 to 1985. SAUS, various issues.

hiu = logarithm of total existing urban road mileage, average over 1960 to 1985. SAUS, various issues.

hit = logarithm of weighted sum of hir and hiu.

area = logarithm of square miles of surface area. SAUS.

hita = hit-area.

pq = percent of highway mileage of deficient quality in 1982 (PSR ≤ or = 2.5 for interstate highways, PSR < or = 2.0 otherwise). HS 1982, Table HM63.

v = total vehicle registrations, average over 1960 to 1985. SAUS, various issues.

vd = logarithm of vehicle registrations per highway mile, average over 1960 to 1985. SAUS, various issues.

urb = percent of total population residing in standard metropolitan statistical areas in 1970. SAUS, 1977 Table 17.

newhi = new road mileage financed with federal aid highway funds in 1980. HS 1980, Table FA1.

hdd = seasonal heating degree days (60_ base). SAUS, 1982-83, Table 378.

govu = number of local governmental units in 1982. SAUS, 1988, Table 452.

FOOTNOTES

[1]For example, consider the following statement by Richard Bartel (1989): "...some economists tend to think of investment in narrow terms--private spending on business plant and equipment. We often forget about additions to the stock of public infrastructure--spending on roads, bridges, mass transportation, airports, waterways, water supply, waste disposal facilities, and other public utilities.

[2]See McDonald and d'Ouville (1989).

[3]See McDonald and d'Ouville (1988).

[4]These conceptual results are consistent with the empirical results in Aschauer (1988) and (1989b), which established a link between general infrastructure capital (inclusive of but not confined to highways), the rate of return to private capital, and the level of private investment in nonresidential equipment and structures. .

[5]For related arguments, the reader is referred to Rostow (1960) and Rosenstein-Rodan (1961).

[6]The U.S. Department of Transportation's "PSR is a numerical value between zero and five reflecting poor pavement condition at the lower end and very good pavement condition at the higher values." Highway Statistics (1982), p. 108).

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