Journal of Financial Economics 98 (2010) 40–53

Contents lists available at ScienceDirect

Journal of Financial Economics

journal homepage: www.elsevier.com/locate/jfec

Identifying the effects of a lender of last resort on financial markets: Lessons from the founding of the fed ☆

Asaf Bernstein [a], Eric Hughson [b], Marc D. Weidenmier [b,c,*]

[a] Harvey Mudd College, USA
[b] Claremont McKenna College, 500 East Ninth Street, Claremont, CA 91711, USA
[c] National Bureau of Economic Research, 1050 Massachusetts Avenue, Cambridge, MA 02138, USA

ARTICLE INFO

Article history:
Received 14 November 2008
Received in revised form
12 May 2009
Accepted 11 September 2009
Available online 9 April 2010

JEL classification:
G01
E44
E52

ABSTRACT

We use the founding of the Federal Reserve to identify the effects of a lender of last resort. We examine stock return and interest rate volatility during September and October, when markets were vulnerable because of financial stringency from the harvest. Stock volatility fell by 40% and interest rate volatility by more than 70% following the monetary regime change. The drop is insignificant if major panic years are omitted from the analysis, however. Because business cycle downturns occurred in the same year as financial crises, our results suggest that the existence of the Federal Reserve reduced liquidity risk.

1. Introduction

The recent subprime mortgage crisis in the United States raises serious questions about the role of monetary policy in a financial crisis. The Federal Reserve has responded to the credit crunch by lowering the Federal Funds Rate from 5.25% in September 2007 to near zero by the middle of December 2008. In addition to interest rate cuts, the central bank has dramatically increased the monetary base and helped to orchestrate bail-outs of AIG, Fannie Mae, Freddie Mac, and Wall Street firm Bear Stearns which was heavily invested in sub-prime mortgages. More recently, the Federal Reserve has expanded its balance sheet by purchasing mortgage-backed securities as well as long-term corporate debt.

One problem acknowledged by both proponents and opponents of activist central bank policy is that it is very difficult to identify the effect of lender-of-last-resort policies on financial markets.[1] Fortunately, history provides an experiment to measure the impact of the introduction of a lender of last resort on liquidity risk in financial markets. Following the Panic of 1907, which was accompanied by one of the shortest, but most severe recessions in American history,[2] Congress passed two measures that established a lender of last resort in the United States: (1) the Aldrich-Vreeland Act of 1908 which temporarily authorized some banks to issue emergency

☆ The authors would like to thank Caroline Betts, Vincenzo Quadrini, Richard Burdekin and seminar participants at Claremont McKenna College and the University of Southern California for comments. The authors would also like to thank the Lowe Institute of Political Economy for financial support.

* Corresponding author at: Claremont McKenna College, 500 East Ninth Street, Claremont, CA 91711, USA. Tel.: +1 909 607 8497.
E-mail address: mweidenmier@cmc.edu (M.D. Weidenmier).

0304-405X/$ - see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.jfineco.2010.04.001

[1] For a discussion of the importance of a lender of last resort in American economic history, see Bordo (1990). Bernanke and Gertler (2000) argue that central banks should intervene in financial markets to the extent that they affect aggregate demand. Bernanke and Gertler (1989) argue that the balance-sheet effects of asset price decline can reduce investment and economic activity.

[2] The Panic of 1907 was precipitated when August Heinze's attempted short squeeze at United Copper, financed by borrowing from Knickerbocker Trust, collapsed. This caused a series of bank runs which started at the Knickerbocker Trust. This led to a credit crunch and a sharp decline in stock values (Moen and Tallman, 2000). For a more in-depth discussion of the Panic of 1907, see Bruner and Carr (2007).

currency during a financial crisis and (2) the Federal Reserve Act of 1913 that established a public central bank. The legislation was designed to provide a "more elastic currency" (i.e., liquidity) that could meet the seasonal demands of economic activity caused by the agricultural cycle. Several of the most severe financial crises of the National Banking Period (1863–1913) including the panics of 1873, 1890, and 1907, occurred in the months of September and October because of financial stress associated with the costs of harvesting crops in the fall (Kemmerer, 1911; Sprague, 1910).[3]

The seasonal nature of financial crises in the National Banking Period motivates the identification strategy we employ to isolate the effects of the lender-of-last-resort function on interest rates and stock returns from other macroeconomic shocks.[4] We compare the standard deviation of stock returns across the months of September and October over the period 1870–May 1908 with the standard deviation of stock returns in those same months during the Aldrich-Vreeland (June 1908–1913) and Federal Reserve (1913–1925) periods. We examine the volatility of asset prices in September and October for three reasons: (1) financial market volatility generally increases prior to the onset of a recession (Schwert, 1989a), (2) the effects of the lender of last resort should have been largest in the fall harvest months when financial markets were often illiquid, and (3) given the absence of high-frequency and high-quality macroeconomic data during the National Banking Period, our identification approach should provide some insight into the chicken and egg problem: did financial crises have real effects or did real shocks cause financial crises (Barro, 2000; Davis, Hanes, and Rhode, 2007)? If the former is true, then financial market volatility should have significantly declined with the establishment of a lender of last resort that provided liquidity to financial markets. To answer this question, we analyze the impact of the founding of the Fed on the stock market. We employ Goetzmann, Ibbotson, and Peng's (2001) new comprehensive database of stock prices, hereafter GIP, from 1870 to 1925. The new stock price index significantly improves on the widely used Cowles Index by using month-end closing prices rather than the average of monthly highs and lows, thereby avoiding a significant autocorrelation problem in stock returns (Schwert, 1989b; Working, 1960).

An analysis of the GIP Index shows that stock volatility in September and October declined more than 40% following the passage of the Aldrich-Vreeland Act. Although we find that stock volatility in September and October was significantly greater than the other 10 months of the year prior to the passage of Aldrich-Vreeland, this was not true following the monetary regime change.[5] The results are robust to a wide variety of specification tests with the exception that the result does *not* hold if we use the Cowles Index for the empirical analysis.[6] However, we do not find a statistically significant drop in financial market volatility if the major panic years are dropped from the empirical analysis.[7]

We also examine short-term interest rate volatility in the months of September and October before and after the monetary regime change. The volatility of the call loan rate declined by more than 70% in the months of September and October following the passage of Aldrich-Vreeland. The analysis also shows that the reduction in interest rate volatility can be attributed to a decrease in the standard deviation of the call loan rate, not to a decline in the level and seasonality of interest rates. As with stock returns, we do not find a statistically significant drop in interest rate volatility if the major panic years are dropped from the analysis. Given that the largest financial panics were preceded by the onset of an economic recession, this suggests that the primary effect of the creation of the Federal Reserve was to dramatically reduce liquidity risk in years when there was a business cycle turning point and a financial crisis.

We begin the analysis with a brief history of the National Banking Period prior to World War I. We then discuss the new database on stock prices in the pre-CRSP era. This is followed by an empirical analysis of stock and interest rate volatility. We conclude with a discussion of the implications of our results for future studies in financial economics and the role of monetary policy during a financial crisis.

2. The national banking period (1863–1913)

The National Banking Acts of 1863, 1864, and 1865 were passed to raise revenue to fight the Civil War, create a uniform currency, and to standardize the banking system in the United States. Prior to the passage of the monetary legislation, hundreds of different currencies circulated at different exchange rates in the United States during the antebellum period. The Acts required banks to maintain minimum levels of capital, dependent on the

[3] For a discussion of the links between agricultural shocks in the cotton market and recessions in the pre-World War I period, see Davis, Hanes, and Rhode (2007).

[4] Fishe and Wohar (1990), for example, argue that World War I and the closure of the New York financial markets played an important role in the change in the stochastic behavior of interest rates, in addition to the founding of the Federal Reserve. Given that these events all occurred around the same time, they argue that it is difficult to separate out the effects of these different events on interest rates.

[5] Previous studies by Meltzer (2003), Miron (1986) and Mankiw, Miron, and Weil (1987), find that the introduction of the Federal Reserve also reduced the seasonality and level of interest rates. Caporale and Caporale (2003) find that the introduction of the Federal Reserve led to a large reduction in the term premium a 6-month debt instrument pays over a 3-month one.

[6] Future research may usefully revisit some questions in financial economics using the new GIP Index. Some well-known studies that have employed the Cowles Index from the pre-CRSP era that have the autocorrelation problem include Shapiro (1988), Shiller (1992), and Siegel (2002). Other studies have relied on stock indexes such as the Dow, which have a very small number of stocks, but do not have significant autocorrelation problems Schwert (1989a, 1989b).

[7] Obviously, the results would not hold if we included the Great Depression as part of the analysis. Many studies, most notably Friedman and Schwartz (1963), argue that the Federal Reserve exacerbated the severity of the Great Depression because of tight monetary policy (i.e., the Fed failed to play the role of a lender of last resort).

local population where the bank was situated, and deposit a minimum quantity of eligible bonds with the US Treasury before commencing business.[8] National bank notes were fully backed by holdings of US government bonds. The amount of notes returned to the issuing bank for a given deposit of bonds was either 90% or the par of the market value of the bonds deposited, whichever was lower.[9]

The National Banking Act established a three-tiered reserve system. The top tier consisted of banks in central reserve cities such as New York City.[10] The second tier consisted of reserve city banks while the third tier was composed of country banks. Required reserves were held in the form of lawful money. Reserve city banks could hold half of their reserves as deposits in a central reserve city bank, and country banks could hold as much as three-fifths of their reserves as deposits in reserve city banks or central reserve city banks.

The structure of reserve requirements is considered one of the primary shortcomings of the National Banking System. Banks often held the maximum amount of reserves in central city banks since they received 2% interest on their balances. On the other hand, reserves held in their own vaults yielded no return. Called the "pyramiding of reserves" by Sprague (1910), reserves tended to concentrate in central reserve cities such as New York City (and to a lesser extent, other central reserve cities). In turn, central city banks lent (call loans) many of these funds to investors to purchase stock on margin. Outside banks were more inclined to pull their reserves out of New York City (or another center city bank) in a time of monetary stringency or panic which could significantly reduce the reserves of center city banks, and precipitate or exacerbate liquidity or financial crises.

Another problem during the National Banking System was the increase in loan and currency demand during the fall and spring planting seasons. The seasonal rise in loan and currency demand increased interest rates and reduced the reserve deposit ratio. The spike in interest rates was not met with a commensurate increase in the money supply, however. Called the "perverse elasticity of the money supply," this problem could help trigger a financial crisis. As discussed by Miron (1986), a financial institution might be forced to call in loans to meet deposit demand following a large withdrawal or loan default (in the absence of a lender of last resort). In response, other banks might also call in their loans, some of which were for margin-buying of stocks. This had the effect of not only depressing the stock market, but also could cause depositors to withdraw money from banks, leading to bank runs. Finally, the financial crisis could then spread to the real economy through the balance-sheet channel (see Bernanke and Gertler, 1989).

In *Seasonal variations in the New York money market*, Kemmerer (1911) points out that panics seemed to occur at the same time as periods of monetary stringency. As noted by Sprague (1910), many of the major panics of the National Banking Period occurred during the fall harvest season (1873, 1890, and 1907) when financial markets were illiquid because of seasonal stress from financing the harvesting of crops. Sprague (1910, p. 157) wrote that "with few exceptions all our crises, panics, and periods of less severe monetary stringency have occurred in the autumn."

In response to the 1907 crisis, Congress passed the Aldrich-Vreeland Act in May 1908. The Aldrich-Vreeland Act was used only once, at the outbreak of World War I, before the Federal Reserve assumed the role of lender of last resort in late 1915. Silber (2005, 2007a, 2007b) argues that the lender-of-last-resort legislation was important in preventing a large scale US financial crisis following the outbreak of World War I. He points out that the Aldrich-Vreeland Act contained provisions that allowed the private sector to respond quickly to a financial crisis. The monetary act allowed a bank to issue notes that did not require the currency to be backed by government bonds. The commercial bank, rather than the central bank, decided the timing and amount of additional currency it needed for liquidity assistance. This meant that the money supply could increase endogenously to meet a shortage of liquidity (Silber, 2005, p. 6). Champ (2007), on the other hand, provides evidence that bank notes exhibited greater seasonal fluctuations following the passage of Aldrich-Vreeland in May 1908. It is difficult to know whether the increased seasonality in bank notes can be attributed to Aldrich-Vreeland or another factor, however, given that the monetary legislation was only used once over a very short period of time.

The Aldrich-Vreeland Act also created the National Monetary Commission to investigate the US banking system. The Commission recommended the establishment of a public central bank. The Federal Reserve Act replaced the Aldrich-Vreeland Act on December 23, 1913. As noted in the preamble of the Federal Reserve Act, the purpose of the measure was to "furnish an elastic currency." The Federal Reserve would accommodate seasonal money demand by increasing the supply of high-powered money as economic activity varied across the year. In the analysis that follows, we use Sprague's (1910) observations that monetary stringency and the severity of financial crises were greatest in the fall harvest season to identify the effect of the introduction of a lender of last resort on the American financial markets. If a lender of last resort mattered, then its biggest effects on markets should be observed during the fall.

3. Empirical analysis

3.1. Model

One way to motivate our empirical analysis is by using the random withdrawal risk framework first developed by Diamond and Dybvig (1983). In this model, agents with uncertain consumption needs live in a world where there are costs to liquidating long-term investments. Miron

[8] Champ (2007).

[9] The backing requirement was raised to 100% in March 1900.

[10] The list of central reserve cities was expanded to include Chicago and St. Louis in 1887.

(1986) adopts this framework to examine the effect of a lender of last resort on financial markets. He assumes that the supply of bank funds is relatively inelastic, so that seasonal increases in loan demand, withdrawals, or in their volatility will systematically increase interest rates and potentially increase the likelihood of panic. The model predicts that the quantity of loans is high under the following conditions: (1) demand for loans is high; (2) bank deposits are high; or (3) when the variance of withdrawals is low. On the other hand, reserves are higher when loan and deposit demand is higher. The ratio of loans to reserves increases as (1) loan demand increases, (2) deposit demand decreases, and the (3) variance of withdrawals decreases.

Another prediction of the model is that without a lender of last resort, interest rates will be high in seasons where loan demand is high or deposit demand is low. This implies that in the harvest months, when there is generally either a higher demand for loans or a greater demand for cash to bring crops to market, interest rates should be higher, on average, than the rest of the year. Loan demand is not only higher during the harvest season, but it is also highly variable *across* harvest seasons. Even if loan uncertainty were constant over the year, interest rates should vary across harvest seasons simply because output fluctuates from year to year. It is probably not unreasonable, however, to also assume that withdrawal uncertainty is higher during the harvest months, which would increase the magnitude of the effects but leave them qualitatively unaffected otherwise.

The effects detailed above are reinforced if one also examines the variation in the value of bank assets. Calomiris and Gorton (1991) and Calomiris and Wilson (2004) argue that a decline in the value of bank assets can lead to a banking panic. If the decline in asset values occurred before the fall harvest, then it would impair a bank's ability to extend loans when money demand was at its seasonal peak.[11] In this scenario, major banking panics are most likely to occur in the fall harvest months after a business cycle peak (Calomiris and Gorton, 1991).

Although Miron (1986) finds that the founding of the Federal Reserve reduced interest rate seasonality and the probability of a financial crisis, our framework has a number of other testable hypotheses. Short-term interest rate volatility should decline in all months if the introduction of a lender of last resort increased the elasticity of the money supply. Second, the variability of short-term interest rates should be highest in the harvest months because money demand was more volatile during this period. Short-term interest rate volatility should not be statistically different from the rest of the year, however, following the introduction of a lender of last resort.

An increase in interest rates also reduces stock values to the extent that a higher cost of funds and liquidity constraints increased the probability of a financial crisis. This implies that prior to the passage of the Aldrich-Vreeland Act: (1) stock market volatility should be higher and (2) monthly stock return volatility should be highest in the harvest months before the introduction of a lender of last resort since interest rate spikes were more likely to occur then. Monthly stock return volatility in the fall should not differ statistically from the rest of the year following the passage of the Aldrich-Vreeland Act, however. Finally, if private banks and the Federal Reserve perform the lender-of-last-resort function equally well, stock and bond market volatility should be about the same under Aldrich-Vreeland as after the founding of the Federal Reserve.

3.1.1. Data

To test the effects of the introduction of a lender of last resort on interest rate and stock volatility, we use financial data from several different sources. For short-term interest rates, we use call loan money rates with mixed collateral.[12] We analyze monthly data from 1870 to 1925 for both stock and interest rate volatility. For the stock market, we use Goetzmann, Ibbotson, and Peng's (2001) comprehensive monthly stock market indexes of the pre-CRSP era for the period 1870–1925. The GIP data are the broadest index publicly available for the pre-CRSP period and cover more than 600 securities during our sample period. Month-end prices were obtained by searching for the last transaction price for each stock in a given month from the *New York Times* and other financial newspapers. When a closing price was not available, the most recent bid and ask prices were averaged, in keeping with the methodology employed by CRSP.

The GIP Index significantly improves on the Cowles Index and the Dow Jones Industrial Average, the other two widely employed indexes from this period.[13] The Cowles Index is value weighted over the period from 1872 to 1925, causing a large-cap bias in computed index returns. Prices are also calculated by averaging monthly high and low prices which induces serial correlation in the Cowles Index of monthly returns, r_t^C. As shown in Table A3, the first-order autocorrelation coefficient for the Cowles Index is 29% versus 6% for the price-weighted GIP index.[14] This autocorrelation problem, called the "Working Effect," makes an analysis of monthly seasonal effects problematic because the average of monthly high and low stock data "smoothes" returns (Working, 1960). Also, the Dow Jones Industrial Average is computed based on a much smaller number of stocks than the GIP Index.

[11] Calomiris (2000) argues that in addition to asset shocks being driven by agricultural shocks, the predominance of unit banking in the United States also led to a less elastic supply of loans, and subsequently more bank failures.

[12] The NBER short-term interest rate data are taken from Macaulay (1938).

[13] See Appendix A Table A1 for the sources for all indexes used in the empirical analysis.

[14] Indeed, we construct an equally weighted index using the third of stocks with the highest prices, r_t^B, and the first-order serial correlation drops to 2% (see Table A3), suggesting that autocorrelation induced by non-trading is a problem for low-priced stocks, which are also small stocks (see, Brown, Mulherin, and Weidenmier, 2008).

Table 1
Annualized mean monthly call loan rates.

Annualized mean monthly call loan rates, expressed in percent, are compared between the sample periods 1870 through May 1908 and June 1908 through 1925. The mean call rate for each month is calculated by taking the arithmetic mean of the interest rate for the given month over the relevant sample period. The data are taken from the National Bureau of Economic Research Macro-History Database, Series 13001.

	Sample period	
Month	1870–May 1908	June 1908–1925
January	4.38	3.77
February	3.59	3.88
March	4.30	3.76
April	4.70	3.69
May	3.52	3.67
June	2.95	3.61
July	2.80	3.63
August	3.22	3.57
September	5.72	3.94
October	5.45	4.35
November	5.04	4.65
December	6.48	4.78
Average	4.35	3.94
Average (non-Sept. & Oct.)	4.10	3.90
Average (Sept. & Oct.)	5.59	4.15

3.2. Interest rate volatility

We analyze short-term interest rate volatility using call loans, the interest rate investors used to purchase stock on margin in the late nineteenth and early twentieth centuries. For our core results, we divide the sample period into the National Banking Period from 1870 to May 1908 and the Aldrich-Vreeland/Federal Reserve period from June 1908 to 1925. Even though the National Banking Period began in 1863 during the Civil War, we exclude the war years to minimize the effect of the conflict on the empirical results.[15] Table 1 and Fig. 2 show that the average call loan rate is higher in September and October. Call loan rates during the months of September and October averaged 5.59% from 1870 to May 1908 and 4.15% from June 1908 to 1925, a drop of more than 25%. September and October call loan rates are significantly different from the other 10 months of the year at the 1% level before May 1908, but insignificantly different after the monetary regime change.[16] Although the call loan rate declined from 4.10% to 3.9% in the other 10 months of the year, the difference is not statistically significant at conventional levels. These results essentially replicate Miron's (1986) analysis, albeit in a slightly different time period.

Fig. 1 also suggests that monthly call loan rates appear to be considerably smoother after the passage of Aldrich-Vreeland in 1908. There is a statistically significant drop in volatility from 4.05% before Aldrich-Vreeland to 1.85% afterward. This is consistent with our prediction that interest rate volatility should drop because of the introduction of a lender of last resort (Fig. 2). As reported in Table 3, we also find that interest rate volatility is significantly lower in all months after the monetary reform legislation. The volatility of interest rates in the rest of the year (non-September and October months) declined from 2.83% to 1.85%, or by 30%, between 1870–May 1908 and June 1908–1925.

We next investigate whether the volatility of interest rates declined most in the fall harvest months, as predicted if a change in monetary policy increased the liquidity of financial markets. Miron's model suggests that volatility should decline if activist monetary policy prevents interest rate spikes during some harvest seasons. To test this, we compute average volatility for each calendar month[17] and then compare average variances before and after the change in monetary policy. For many of our tests, we compute the average of monthly variances, which has a non-standard distribution. Therefore, we bootstrap the standard errors. Details for this procedure are found in Appendix C. As an alternative, we also compute the variance of call loan rates by first aggregating over all non-harvest months and then aggregating over all harvest months, and perform a series of standard *F*-tests to determine the effect of monetary policy. Although the results are qualitatively similar to those reported in the paper,[18] this aggregation may be problematic, because as Kemmerer (1911) notes, there are other, albeit smaller, seasonal effects which may affect interest rates.[19]

Table 2 shows that the volatility of interest rates across the months of September and October averaged 6.84% from 1870 until the passage of Aldrich-Vreeland in May 1908. The volatility of call loan rates in September and October declined more than 73% to 1.81% in 1908–1925 after the introduction of a lender of last resort. As shown in Table 3, we can reject the equality of variances of the harvest months with the other 10 months of the year at the 1% level before the passage of the Aldrich-Vreeland Act. We are unable, however, to reject the null hypothesis of the equality of variances between the rest of the year and September and October in the period from May 1908 to December 1925.

To further understand our results, we estimated the baseline model dropping the panic years of 1873, 1884, 1890, 1893, and 1907. Although we find that interest rate volatility declines following the passage of Aldrich-Vreeland in 1908, we cannot reject the null hypothesis of equality of variances comparing September and

[15] Including the Civil War years in the analysis does not qualitatively change the results. Their inclusion strengthens the results presented.

[16] The basic tenor of the results remains unchanged if we replace the call loan rate with the commercial paper rate.

[17] We do this to avoid aggregating across months which may have different interest rate volatilities due to the harvest cycle.

[18] These results are available from the authors upon request.

[19] Using a Levene test for equality of variances, we reject that September and October call loan rates are equally volatile. With stock return data, we cannot reject that September and October stock returns have the same volatilities, nor can we reject that the other 10 calendar months have volatilities that are different from each other. Hence, one can argue that using the *F*-test is reasonable for stock data—although it is less reasonable for call loan data.

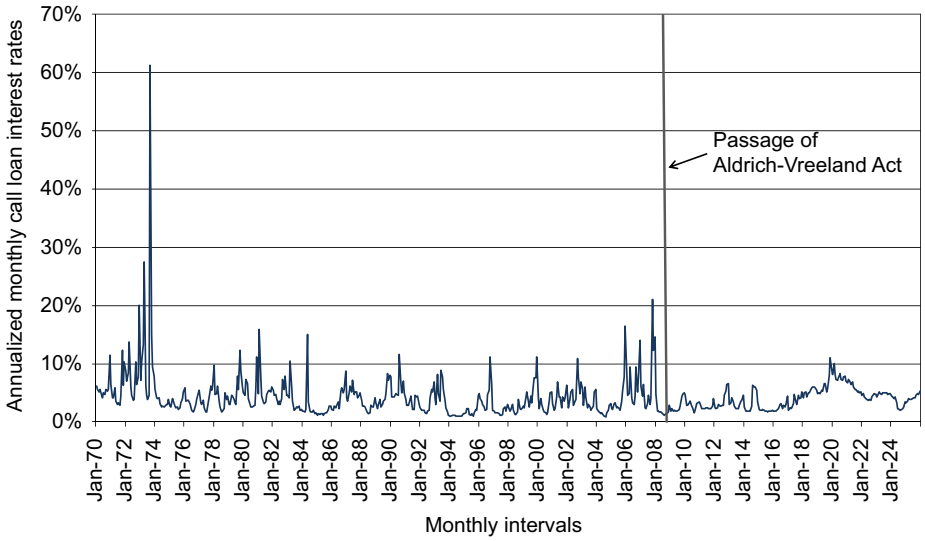

Fig. 1. Monthly call loan interest rates, 1870–1925. Annualized monthly call loan rates, expressed in percent, are presented over the period from 1870 through 1925. The passage of the Aldrich-Vreeland Act on May 30, 1908 had a stabilizing effect on the volatility of call loan interest rates. The data are taken from the National Bureau of Economic Research Macro-History Database, Series 13001.

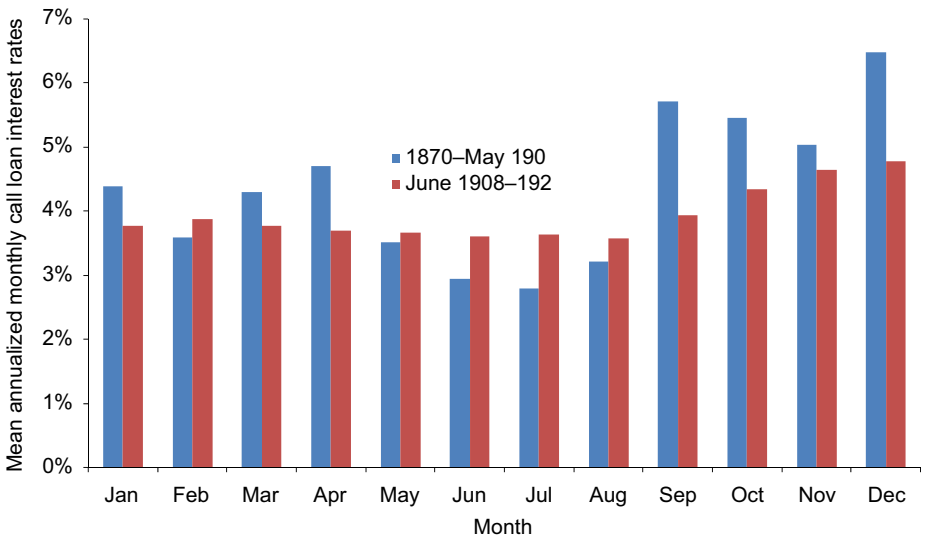

Fig. 2. Mean monthly call loan rates before and after the passage of the Aldrich-Vreeland Act. Annualized mean monthly call loan rates, expressed in percent, are compared between the sample periods 1870 through May 1908, and June 1908 through 1925. The mean call rate for each month is calculated by taking the arithmetic mean of the interest rate for the given month over the relevant sample period. The data are taken from the National Bureau of Economic Research Macro-History Database, Series 13001.

October with the rest of the year prior to 1908. Our results are not driven by a single observation, however: the equality of variances continues to be rejected if any *single* panic year is removed from the analysis. In addition, the average interest rate in September and October before the policy change falls from 5.5% to 4.5% when the panic years are excluded, which is not too much higher than the 4.1% found during the non-harvest months. Taken together, these findings suggest that the primary effect of the creation of the Federal Reserve was to reduce liquidity risk in panic years that were also accompanied by a business cycle turning point.[20]

We also investigate whether a similar pattern holds for volatilities during the spring planting season of March and April. Prior to 1908, the average standard deviations for

[20] As a robustness check, we also individually dropped each panic year to see if the empirical results were driven by a single observation. We did not find evidence to support this hypothesis. Detailed results are available from the authors on request.

Table 2
Call loan interest rate volatility.

Annualized call loan interest rate volatility is compared between the months of September and October with the rest of the year for the National Banking Period 1870–May 1908 and the Aldrich-Vreeland (June 1908–1913) and Federal Reserve (June 1908–1925) periods. Call loan interest rate volatility is calculated by computing the standard deviation of interest rates for each month over the relevant sample period. The standard deviation is reported in percent.

	Months	
Sample period	Rest of the year	Sept. & Oct.
1870–May 1908	2.63	6.84
1879–May 1908	2.36	3.24
June 1908–1913	0.83	1.25
June 1908–1925	1.85	1.81

call loan rates were 3.51% in March and April, and 2.41% in the rest of the year. This is statistically significant at the 1% level using a standard *F*-test, although our empirical *p*-value is only 0.1157. The result is driven entirely by the panic of 1873. Omitting 1873 from the analysis reduces the volatilities to 2.27% in March and April and 2.38% in the rest of the year.

We test the sensitivity of the empirical results using the period from June 1908 to December 1913 as the period for the change in monetary regime. Some previous studies have argued that World War I, the closure of the New York Stock Exchange, the abandonment of the gold standard, and government controls of the call and time-loan markets played an important role (or explain the change) in the change in the time-series properties of interest rates rather than the founding of the Federal Reserve (Fishe and Wohar, 1990; Kool, 1995). To control for this possibility, in Table 4 we compare the volatility of interest rates between 1870 and May 1908 with the Aldrich-Vreeland period (June 1908–1913) before the outbreak of World War I. The analysis is similar to work by Caporale and McKiernan (1998) with the exception that we employ our new identification scheme to separate the effect of the lender-of-last-resort legislation from other macroeconomic shocks by comparing the fall harvest months with the rest of the year. The results are similar to the baseline analysis reported in Table 3. The volatility of call loan rates declined more than 80%, from 6.84% to 1.25% in the Aldrich-Vreeland period. The variance of call loan rates declined from 2.63% to 0.83% in the other 10 months of the year. The decrease in the volatility of the call loan rate is statistically significant at the 5% level for the harvest months and the 1% level for the rest of the year. Finally, we find that the volatility of call loan rates is not significantly higher than the other 10 months of the year in the period (June 1908–1913) (p=0.13).

It is not obvious that the Aldrich-Vreeland Act was a perfect substitute for the founding of the Federal Reserve, however. Table 2 reveals that although call loan rate volatility was not significantly higher during the harvest season at conventional levels, it *was* higher—(1.25% vs. 0.83%), and the difference was almost significant during the 5-year period (1908–1913) of Aldrich-Vreeland. In contrast, during the Federal Reserve period, volatility was actually lower during the harvest months.

Another possibility is that the results are driven by the Aldrich-Vreeland period when interest rate volatility was exceptionally low. To test this hypothesis, we compare the volatility of interest rates after the founding of the Federal Reserve from 1915 to 1925 with the volatility of interest rates in the period before Aldrich-Vreeland and the Fed (1870–1907).[21] As shown in Table 5, we again find a dramatic decline in interest rate volatility that is statistically significant at the 1% level. Interest rate volatility in the months of September and October is significantly larger than the rest of the year prior to the regime change, but not after the introduction of the lender of last resort, where as mentioned above, volatility was lower during the harvest months. This supports the hypothesis that the Federal Reserve Act at least continued the stabilizing effect of the Aldrich-Vreeland Act and perhaps improved upon it. Finally, our results are qualitatively unchanged when we perform our analyses using commercial paper rates instead of call loan rates.[22]

One possible shortcoming of the analysis is that the decline in volatility could be caused by a decrease in interest rate seasonality. That is, interest rates were higher in September and October. Other studies have found this to be an important effect of the founding of the Fed (Miron, 1986; Mankiw, Miron, and Weil, 1987). To test this hypothesis, we decomposed the decline in time-series volatility into the fraction that can be explained by a reduction in the variance of interest rates and the portion that can be explained by a decrease in interest rates. The results are given in Table 6. Bootstrapping the sample means and variances, we find that decreasing average interest rates without a corresponding decrease in the variance of those rates cannot explain the observed drop in volatility (p=0.9979). In contrast, decreasing interest rate variance without altering average interest rates can explain the observed results (p=0.0005).[23]

3.3. Stock return volatility

We next examine stock return volatility before and after the monetary regime change using the equally weighted GIP Index. Table 7 summarizes the standard deviation of stock returns in September and October as well as the rest of the year for the period 1870–1925. The standard deviation of stock returns averaged 7.30% between 1870 and May 1908 in the months of September and October and 5.80% for the rest of the year. In the lender of last resort period (June 1908–1925), stock volatility declined to 3.83% in September and October and 4.68% in the other 10 months (Fig. 3). Volatility declined by nearly 50% in the fall harvest

[21] We start the analysis of interest rate volatility for the founding of the Federal Reserve in 1915 to exclude the closure of financial markets in the last half of 1914 following the outbreak of World War I.

[22] See Appendix Table B1 for these results.

[23] We thank Peter Rousseau for suggesting this analysis. Additional details on methodology can be found in Appendix C.

Table 3
Tests for equality of interest-rate variance for various sample periods.
The equality of variance for call loan interest rates is tested over various sample periods. The critical values for the equality of variance tests were simulated using the empirical distribution. The simulation is discussed in detail in Appendix C.

		H_0: Null hypothesis			
Months	Sample period		Months	Sample period	Empirical *p*-value
Sept. & Oct.	1870–May 1908	=	Rest of year	1870–May 1908	0.0004
Sept. & Oct.	1870–May 1908	=	Sept. & Oct.	June 1908–1925	0.0009
Sept. & Oct.	June 1908–1925	=	Rest of year	June 1908–1925	0.4009
Rest of year	1870–May 1908	=	Rest of year	June 1908–1925	0.0001

Table 4
Tests for equality of variance: Aldrich-Vreeland Period versus National Banking Period.
The equality of variance for call loans was tested for the National Banking Period, 1870–June 1908, versus the Aldrich-Vreeland sub-sample period, June 1908–1913. The critical values for the equality of variance tests were simulated using the empirical distribution. The simulation is discussed in detail in Appendix C.

		H_0: Null hypothesis			
Months	Sample period		Months	Sample period	Empirical *p*-value
Sept. & Oct.	June 1908–1913	=	Rest of year	June 1908–1913	0.134
Sept. & Oct.	1870–May 1908	=	Sept. & Oct.	June 1908–1913	0.0479
Rest of year	1870–May 1908	=	Rest of year	June 1908–1913	0.0025

Table 5
Tests for equality of variance: Federal Reserve Period versus National Banking Period.
The equality of variance for call loans was tested for the National Banking Period, 1870–May 1908, versus the Federal Reserve Period, 1915–1925. The critical values for the equality of variance tests were simulated using the empirical distribution. The simulation is discussed in detail in Appendix C.

		H_0: Null hypothesis			
Months	Sample period		Months	Sample period	Empirical *p*-value
Sept. & Oct.	1870–May 1908	=	Sept. & Oct.	1915–1925	0.0002
Rest of year	1870–May 1908	=	Rest of year	1915–1925	0.0033
Rest of year	1915–1925	=	Sept. & Oct.	1915–1925	0.3389

Table 6
Call loan rate variance decomposition.
The change in the variance of call loan rates after May 1908 was decomposed into the fraction due to changes in mean monthly call loan rates after and the fraction due to changes in call loan rate volatility. The first (second) test assumes that mean call loan rates remained constant (changed) but cross-sectional volatility changed (remained constant) after May 1908. The critical values for the equality of variance tests were simulated using the empirical distribution. The simulation is discussed in detail in Appendix C.

		H_0: Null hypothesis (all months)			
Sample period		Sample period	Means	Variances	Empirical *p*-value
1870–May 1908	=	June 1908–1925	Same	Different	0.0005
1870–May 1908	=	June 1908–1925	Different	Same	0.9979

months and more than 19% in the remainder of the year. Table 8 shows that stock return volatility was significantly higher in the months of September and October relative to the rest of the year before the passage of the Aldrich-Vreeland and Federal Reserve Acts. After the monetary regime change, we find that volatility in the fall harvest months was no longer statistically different from the rest of the year. Consistent with the interest rate analysis, we also find that the variance of stock returns significantly declined over the entire year with the biggest decrease occurring in September and October.

In addition, we also dropped the panic years of 1873, 1884, 1890, 1893, and 1907 from the sample. Similar to the analysis for interest rate volatility, we find that there is a secular drop in volatility with the creation of the Federal Reserve. However, we do not find a seasonal component prior to 1908 once the panic years are eliminated from the empirical analysis, although as in our interest rate analysis, our result does persist if any single panic year is removed. Finally, unlike the interest rate analysis before 1908, there is no evidence that stock market volatilities are any higher in the spring planting

Table 7
Stock return volatility.

The standard deviation of stock returns is based on the arithmetic mean of the log of the price relative for the equal-weight index over time for a given month. The standard deviation is expressed in percent. The stock data are taken from Goetzmann, Ibbotson, and Peng's (2001) database on historical stock prices.

	Months	
Sample period	Rest of year	Sept. & Oct.
1870–May 1908	5.80	7.30
1879–May 1908	5.91	6.50
June 1908–1913	3.74	2.97
June 1908–1925	4.68	3.83

season (March and April) than they are the rest of the year. These findings provide further evidence that the primary effect of the creation of the Federal Reserve was to reduce liquidity risk in years when there was a business cycle turning point and a financial panic.

We also conducted a series of robustness checks to test the sensitivity of the empirical results. Table 9 shows the equality of variance tests for stock returns comparing the period 1870–May 1908 with the Aldrich-Vreeland period (June 1908–1913) before the outbreak of World War I. We find that the variance of stock returns was significantly higher in September and October than the rest of the year before the monetary regime change. The variance of stock returns was also significantly lower in the fall harvest months as well as the remainder of the year in the Aldrich-Vreeland period. The standard deviation of stock returns declined by 59% in September and October and more than 35% in the rest of the year following the passage of the monetary reform legislation. In the Aldrich-Vreeland period, we are also unable to reject the null hypothesis that the variance of stock returns in September and October was significantly different from the rest of the year.

Finally, as shown in Table 10, we obtain similar results if stock return volatility in the months of September and October is compared to the rest of the year before (1870–1908) and after the founding of the Federal Reserve (1915–1925) (Fig. 4). Stock return volatility is significantly larger in September and October from the other 10 months of the year before the founding of the central bank. After the establishment of the Federal Reserve, however, we find that stock return volatility in September and October is no longer statistically different from the rest of the year. In contrast with our call loan rate results, Table 7 reveals that stock return volatility during the harvest months was lower than the rest of the year in both the Aldrich-Vreeland and Federal Reserve periods.

We also tested the sensitivity of our results to the construction and choice of the underlying stock market indexes. First, we replicated the empirical analysis using the Dow Jones Industrial Average, r_t^D, which began in 1896 using end-of-month data collected by Brown, Mulherin, and Weidenmier (2008). We also constructed several other market indexes using the GIP data: an equally weighted monthly return index, r_t^{EQ}, an index of railroad stocks, r_t^{RR}, sorting stocks by monthly closing price into the top-third, r_t^B, middle-third, r_t^M, and lowest-third, r_t^S. This indexing strategy is used as a proxy for both liquidity and market cap, since historically they have shown a strong correlation.[24] The basic tenor of the empirical results remains unchanged using the various indexes with the exception of the small firm index. We find that the variability of the small firm index was not statistically different in the fall harvest season from the other 10 months of the year before the monetary regime change. However, we did find that overall stock volatility for small firms declined following the monetary policy change.[25] We do not view the empirical results for the small stock index to be very important, however, given that the small firm index contains many illiquid stocks and constitutes less than 3% of the market capitalization of the GIP Index.

We also performed the same analysis using the Cowles Index, r_t^C. In September and October, stock return volatility across months drops from 3.61% prior to Aldrich-Vreeland to 2.91% afterward. As shown in Table 11, the difference is not statistically significant at conventional levels, however. Further, stock return volatility in other months actually rises from 3.16% prior to Aldrich-Vreeland to 3.23% afterward. Stock return volatility in the National Banking Period was not statistically significantly higher in the harvest months than in other months. We attribute these results to the high degree of first-order serial correlation present in the Cowles Index arising from the use of averaging monthly high and low prices to construct the market benchmark. Our findings highlight the potential erroneous conclusions that can be drawn from using the Cowles Index to study financial markets.

Next, we investigated whether seasonal volatility in interest rates and returns declined after the Aldrich-Vreeland Act because gold points did as well, so that in periods of high money demand, it became increasingly cheaper and easier to send gold to the US from abroad. However, Officer (1996, Tables 9–20) notes that from 1880 to 1913, gold points are essentially stable, falling by about 20%. Hence, the fact that the seasonal component to volatility is present in our data from 1879 to 1908, but absent from 1908 to 1913, suggests that a change in gold

[24] Though numbers are not reported here, analysis by Brown, Mulherin, and Weidenmier (2008) reveal extremely strong correlation between price and market capitalization during this period.

[25] The results for the small stocks are not surprising for two reasons: (1) as shown in Table 3, the first-order serial correlation of the small stock index, r^S, is 11% and (2) the annualized volatility of the index is 37%, three times higher than the volatility of our index of high-priced stocks. This increased volatility is unlikely due to bid-ask bounce, which could arise if trading were infrequent enough for small firms—that leads to negative serial correlation. Perhaps surprisingly, the median amount of serial correlation in individual monthly stock returns during the period is −8% for stocks in the low-price index and −6% for stocks in the high-price index—nearly the same. However, this negative correlation for individual returns should cancel out in the index, so that the primary driver of the positive serial correlation in the index should be non-trading. The amount of serial correlation for the low-price index is only 11%, however, meaning that the main reason that it is difficult to attain statistical significance is because low-price firms are more volatile. Detailed results are available from the authors upon request.

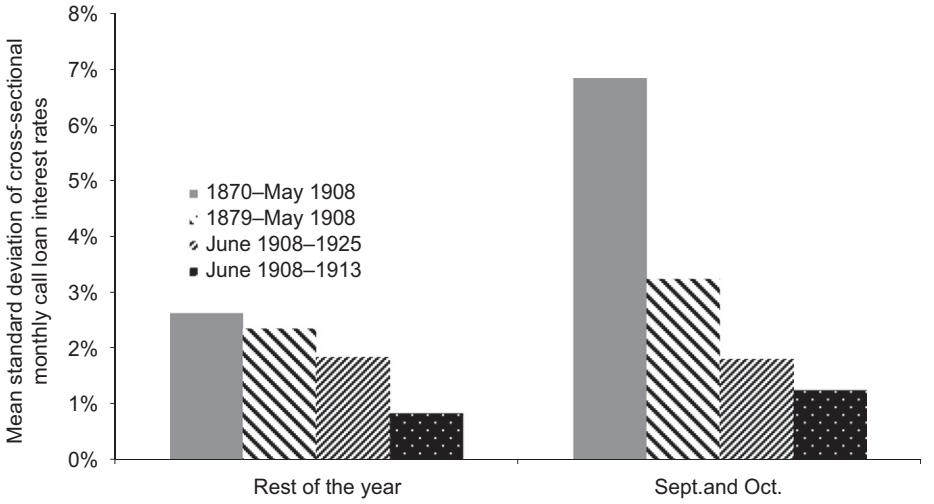

Fig. 3. Volatility of monthly call loan rates before and after the passage of the Aldrich-Vreeland Act. Call loan interest rate volatility is compared between the months of September and October with the rest of the year for the National Banking Period 1870–May 1908, an alternative definition of the National Banking Period that omits the Panic of 1873 (1879–May 1908), the Aldrich-Vreeland (June 1908–1913), and Federal Reserve (June 1908–1925) periods. Call loan interest rate volatility is calculated by computing the standard deviation of interest rates for each month over the relevant sample period. The standard deviation is reported in percent.

Table 8
Tests for equality of stock return variance for various sample periods.
The equality of variance for stock returns was tested over various sample periods from 1870 to 1925. The critical values for the equality of variance tests were simulated using the empirical distribution. The simulation is discussed in detail in Appendix C.

		H_0: Null hypothesis			
Months	Sample period		Months	Sample period	Empirical *p*-value
Sept. & Oct.	1870–May 1908	=	Rest of year	1870–May 1908	0.0448
Sept. & Oct.	1870–May 1908	=	Sept. & Oct.	June 1908–1925	0.0029
Sept. & Oct.	June 1908–1925	=	Rest of year	June 1908–1925	0.2211
Rest of year	1870–May 1908	=	Rest of year	June 1908–1925	0.0050

Table 9
Tests for equality of variance: Aldrich-Vreeland Period versus National Banking Period.
The equality of variance for stock returns was tested for the National Banking Period, 1870–May 1908, versus the Aldrich-Vreeland Period, May 1908–1913. The critical values for the equality of variance tests were simulated using the empirical distribution. The simulation is discussed in detail in Appendix C.

		H_0: Null hypothesis			
Months	Sample period		Months	Sample period	Empirical *p*-value
Sept. & Oct.	June 1908–1913	=	Rest of year	June 1908–1913	0.2610
Sept. & Oct.	1870–May 1908	=	Sept. & Oct.	June 1908–1913	0.0431
Rest of year	1870–May 1908	=	Rest of year	June 1908–1913	0.0091

points cannot explain the reduction in volatility over that period.[26]

Finally, we investigate whether our results are driven by the fact that agriculture constituted a declining fraction of US Gross National Product over the course of our sample period. The US Bureau of the Census (1976, p. 232)[27] reports that agriculture's share of GNP averaged approximately 35% in the 1870s, 22.5% around the turn of the century, 17% in 1908, 16% by 1916 and 11.6% in 1925. Although agriculture's share of GNP fell between 1870 and 1925, it still remained higher than 10% and agricultural output was concentrated during the harvest season (i.e., the months of September and October). Second, Fig. 1 clearly shows that interest rate volatility does not decline until the dramatic drop around the passage of the Aldrich-Vreeland Act. Further, even though agriculture's share of GNP continued to fall after 1908, financial market volatility remained quite stable over this period—volatility in the Aldrich-Vreeland and Federal Reserve periods are not statistically different from one

[26] We focus on the gold point estimates from 1880 to 1913 since the United States did not join the gold standard after the Civil War until January 1879.

[27] See also Gallman (2000), who reports similar agricultural shares until 1900.

Table 10
Tests for equality of variance: Federal Reserve Period versus National Banking Period.

The equality of variance for stock returns was tested for the National Banking Period, 1870–May 1908, versus the Federal Reserve sub-sample period, 1915–1925. The critical values for the equality of variance tests were simulated using the empirical distribution. The simulation is discussed in detail in Appendix C.

Months	Sample period	H_0: Null hypothesis	Months	Sample period	Empirical *p*-value
Sept. & Oct.	1870–May 1908	=	Sept. & Oct.	1915–1925	0.0284
Rest of year	1870–May 1908	=	Rest of year	1915–1925	0.0554
Rest of year	1915–1925	=	Sept. & Oct.	1915–1925	0.2042

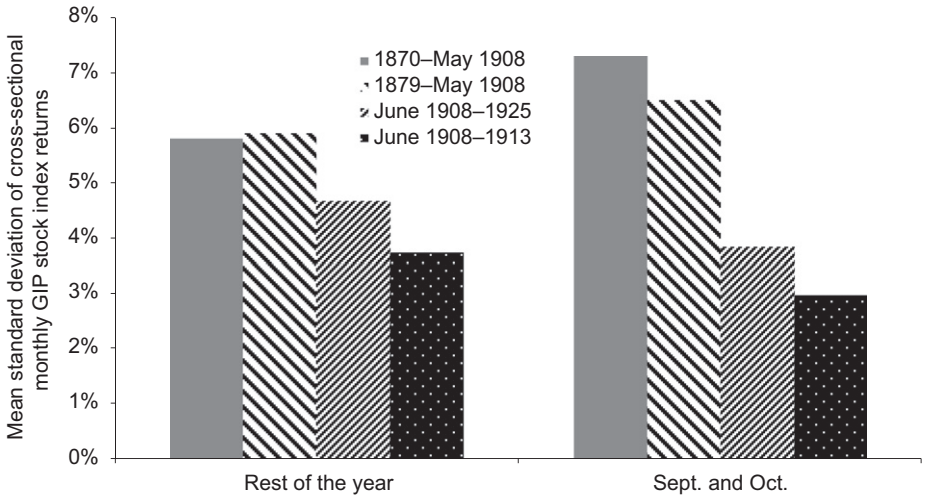

Fig. 4. Volatility of monthly equal-weight GIP stock index returns before and after the passage of the Aldrich-Vreeland Act. The volatility of monthly stock index returns is compared between the months of September and October with the rest of the year for the National Banking Period 1870–May 1908, an alternative definition of the National Banking Period that omits the Panic of 1873 (1879–May 1908), the Aldrich-Vreeland (June 1908–1913), and Federal Reserve (June 1908–1925) periods. The standard deviation of stock returns is based on the arithmetic mean of the log of the price relative for the equal weight index over time for a given month. The standard deviation is expressed in percent. The stock data are taken from Goetzmann, Ibbotson, and Peng's (2001) database on historical stock prices.

Table 11
Tests for equality of stock return variance using the Cowles Index.

The equality of variance for stock returns using the Cowles Index was tested over various sample periods. The critical values for the equality of variance tests were simulated using the empirical distribution. The simulation is discussed in detail in Appendix C. The Cowles data are taken from the website of the Yale Center of International Finance.

Months	Sample period	H_0: Null hypothesis	Months	Sample period	Empirical *p*-value
Sept. & Oct.	1870–May 1908	=	Rest of year	1870–May 1908	0.163
Sept. & Oct.	1870–May 1908	=	Sept. & Oct.	June 1908–1925	0.1365
Sept. & Oct.	June 1908–1925	=	Rest of year	June 1908–1925	0.2990
Rest of year	1870–May 1908	=	Rest of year	June 1908–1925	0.3894

another. Finally, as Miron (1986) notes, the seasonality of interest rates reappeared during the Great Depression. He attributes the rise in interest rate seasonality during the interwar period to the failure of the Federal Reserve to play the role of lender of last resort and accommodate seasonal money demand (Friedman and Schwartz, 1963).

Our empirical results also provide some insight into the macroeconomic effects of the introduction of a lender of last resort. The poor quality of high-frequency—greater than annual frequency—pre-World War I macroeconomic indicators such as GDP and industrial production makes it difficult to identify the effect of financial panics on economic activity (Davis, 2004).[28] Given that stock volatility is a leading indicator of future economic activity, our analysis suggests that the introduction of a lender of

[28] Grossman (1993) finds that banking panics had large negative and statistically significant effects on economic activity during the National Banking Period.

last resort probably reduced the probability of a financial crisis as well as its attendant economic effects (Miron, 1986).

4. Conclusion

Can a lender of last resort reduce liquidity risk in financial markets? This question has recently received considerable attention since the implied stock volatility for many broad market US indexes has more than doubled since the onset of the subprime mortgage crisis in 2007. The large rise in stock volatility and concomitant economic downturn may be the most severe since the Great Depression. We provide a historical perspective on this question by examining the effects of one the most important monetary regime changes in American history—the Aldrich-Vreeland Act in 1908 and the creation of the Federal Reserve in 1913—on stock and interest rate volatility.

We introduce a new identification strategy to isolate the effect of the introduction of a lender of last resort on American financial markets from other macroeconomic shocks such as World War I, the shutdown of American financial markets from July to December 1914, and the abandonment of the gold standard. Our identifying strategy is motivated by the observation that many of the largest financial crises of the National Banking Period occurred in the months of September and October when the money and short-term credit markets were relatively illiquid because of the harvest season. We exploit the seasonal variation in equity and credit markets to identify the effect of the Aldrich-Vreeland Act and the creation of the Federal Reserve on financial market volatility.

Using Goetzmann, Ibbotson, and Peng's (2001) new comprehensive pre-CRSP database, we find that the monetary regime change was associated with a dramatic reduction in financial market volatility. Stock volatility in the months of September and October declined nearly 50% in the Aldrich-Vreeland and Federal Reserve period. Interest-rate volatility declined more than 70% in September and October following the monetary regime change. Although we find that financial market volatility in September and October was significantly higher in the pre-Aldrich-Vreeland period than the other 10 months in the year, this was not the case after the introduction of a lender of last resort. In addition, we also do not find that financial market volatility declined if the major panic years are dropped from the empirical analysis. Given that recessions were coincident with major panics, the results provide strong evidence that the primary effect of the creation of the Federal Reserve was to reduce liquidity risk in financial markets in years where there was a business cycle turning point and a financial crisis.

The analysis also provides some evidence on the economic effects of a lender of last resort. The poor quality of high-frequency macroeconomic indicators such as GDP, investment spending, and industrial production before World War II has previously made it difficult to assess the effect of the policy changes on the US economy, although Schwert (1990) finds that during the period 1889–1925, lagged stock returns do forecast the current level of real activity. Another problem is that it is difficult to analyze the linkages between the financial and real sectors given that credit and equity markets are forward looking and economic data are not. By examining financial market volatility, we gain some insight into the effects of the introduction of a lender of last resort given that stock volatility is a leading indicator of future investment spending and economic activity. We interpret our results as evidence that the introduction of a lender of last resort significantly reduced the probability of a financial crisis and its potentially negative effects on economic activity, especially in the fall harvest months.

Our results have several implications for future studies of financial markets as well as monetary policy in a time of crisis. First, the findings highlight the potential problems in using the Cowles Index to test hypotheses in financial economics. Future research in financial economics may want to revisit the findings of previous studies that have relied on the Cowles Index to study the behavior of stock returns or stock volatility over a long period of time. Second, from the perspective of policy-makers, liquidity assistance from a lender of last resort can be very important in preventing a larger meltdown in financial markets that can have real economic effects.

Appendix A

The sources for all indexes used in the empirical analysis are given in Table A1. Correlations of monthly returns for stock market indexes over the period 1870 to

Table A1
Stock market index definitions.
Definitions and data sources for the stock market indexes used in this paper. GIP refers to the stock data taken from Goetzmann, Ibbotson, and Peng's (2001) database on historical stock prices.

Stock market indexes	Sample period	Data source
r_t^{Wt} = price-weighted index	1870–1925	GIP (2001)
r_t^{D} = Dow-Jones industrial average	1896–1925	Brown, Mulherin, and Weidenmier (2008)
r_t^{C} = Cowles stock index	1870–1925	Cowles
r_t^{B} = equally weighted index of stocks with prices in the top-third of the index each month	1870–1925	GIP
r_t^{M} = equally weighted index of stocks with prices in the middle-third of the index each month	1870–1925	GIP
r_t^{S} = equally weighted index of stocks with prices in the lowest-third of the index each month.	1870–1925	GIP
r_t^{Eq} = equally weighted index	1870–1925	GIP
r_t^{RR} = equally weighted index of railroads	1870–1925	GIP

1925 are given in Table A2. Stock return index volatility and first-order serial correlation are given in Table A3.

Appendix B

Equality of variance tests for commercial paper rates are shown in Table B1.

Appendix C. Simulation details

To test our hypotheses, we therefore compute an average variance for each month, $\sigma^m = (1/(T-1))\sum_{t=1}^{T}(r_t^m - \bar{r}_m)^2$, where m={January, February, … December}, T is the number of months either before (*pre*) or after (*post*) the monetary policy change, and $\bar{r}_m$ is the average call loan rate in a particular month, m.

We compute, $\sigma_{pre}^{2h} = 1/2(\sigma_{pre}^{2Sep.} + \sigma_{pre}^{2Oct})$, the sample average variance before the policy change, and $\sigma_{post}^{2h} = 1/2(\sigma_{post}^{S2ep.} + \sigma_{post}^{2Oct})$, the sample average variance after the policy change. Finally, we compute the difference of the two, σ_{diff}^{2h}.

Next, we compute the standard error of the difference in volatilities. But σ_{diff}^{2h} does not have a standard sampling distribution. We therefore use a parametric bootstrap to compute empirical p-values. We first compute the sample means and variances of the empirical distributions from September and October from 1870 to 1925. Then, we impose normality (using distributions with fatter tails had little effect on the results) and create September (October) call rates by taking random draws from the September (October) distributions. Then, we choose the first 38 observations (1870–May 1908) for both September and October and compute two monthly variances. We do the same for the 18 observations "after" June 1908 and compute the difference of the two. To form the empirical distribution, we repeat the procedure 10,000 times. We then look to see where σ_{diff}^{2h} falls on this empirical distribution to compute p-values.

We use an analogous procedure to test whether the variances of call loan rates are significantly different during the harvest season from the rest of the year. To compute the average variance over the rest of the year, we again average over monthly variances for the months other than September and October. Empirical p-values for the average variance are computed using the same bootstrap procedure.

To identify the effect of a change in means on volatility, we employ a procedure similar to the methodology used to compute empirical p-values before and after the monetary regime change. We first compute the percent drop in time-series volatility using sample means and variances from 1870 to May 1908 and then sample means and variances from June 1908 to 1925. Then we decompose the decline in volatility into: (1) the effect that can be attributed to a change in variance and (2) the effect that can be attributed to a change in mean. In the first case, we calculate the drop in the volatility using means (for each month) from 1870 to 1925 but allow the volatility to be different between 1870–May 1908 and June 1908–1925. For the second case, we employ the same methodology except that we keep the mean change and use the sample variance (for each month) over the entire sample period. We then compute empirical p-values for both cases based on the initial computed percent drop in the series volatility.

Table A2
Correlations of monthly returns for stock market indexes over the period 1870–1925 (where data is available).
A description of each of the indexes is available in Table A1.

	r_t^{Wt}	r_t^{D}	r_t^{C}	r_t^{B}	r_t^{M}	r_t^{S}	r_t^{Eq}	r_t^{RR}
r_t^{Wt}	–							
r_t^{D}	0.72	–						
r_t^{C}	0.66	0.67	–					
r_t^{B}	0.92	0.71	0.61	–				
r_t^{M}	0.92	0.70	0.60	0.77	–			
r_t^{S}	0.81	0.65	0.59	0.63	0.77	–		
r_t^{Eq}	0.94	0.74	0.65	0.81	0.91	0.95	–	
r_t^{RR}	0.88	0.64	0.61	0.76	0.86	0.92	0.96	–

Table A3
Stock return index volatility and first-order serial correlation.
For stock market indexes over the period 1870–1925 (where data is available) σ is the annualized standard deviation of monthly index returns and ρ is the serial correlation of monthly index returns. A description of each of the indexes is available in Table A1.

	r_t^{Wt}	r_t^{D}	r_t^{C}	r_t^{B}	r_t^{M}	r_t^{S}	r_t^{Eq}	r_t^{RR}
σ	0.14	0.20	0.11	0.11	0.20	0.37	0.20	0.23
ρ	0.06	0.06	0.29	0.02	0.06	0.11	0.10	0.08

Table B1
Equality of variance tests for commercial paper rates.
The equality of variance for commercial paper rates is tested over various sample periods. The critical values for the equality of variance tests were simulated using the empirical distribution. The simulation is discussed in detail in Appendix C. Commercial paper rates are taken from the National Bureau of Economic Research Macro-History Database, Series 13002.

		H_0: Null hypothesis			
Months	Sample period		Months	Sample period	Empirical p-value
Sept. & Oct.	1870–May 1908	=	Rest of year	1870–May 1908	0.0050
Sept. & Oct.	1870–May 1908	=	Sept. & Oct.	June 1908–1925	0.0068
Sept. & Oct.	June 1908–1925	=	Rest of year	June 1908–1925	0.3590
Rest of year	1870–May 1908	=	Rest of year	June 1908–1925	0.0025

References

Barro, R.J., 2000. Macroeconomics. MIT Press, Cambridge.

Bernanke, B., Gertler, M., 1989. Agency costs, net worth, and business fluctuations. American Economic Review 79, 14–31.

Bernanke, B., Gertler, M., 2000. Asset price volatility and monetary policy. Unpublished working paper, National Bureau of Economic Research.

Bordo, M., 1990. The lender of last resort: some historical insights. Unpublished working paper. National Bureau of Economic Research.

Brown, W., Mulherin, J., Weidenmier, M., 2008. Competing with the NYSE. Quarterly Journal of Economics 123, 1679–1719.

Bruner, R., Carr, S., 2007. The Panic of 1907: The Lessons Learned from the Market's Perfect Storm. Wiley and Sons, New Jersey.

Calomiris, C., 2000. Bank Deregulation in Historical Perspective. Cambridge University Press, Cambridge.

Calomiris, C., Gorton, G., 1991. The origins of banking panics: models, facts, and bank regulation. In: Hubbard, R.G. (Ed.), Financial Markets and Financial Crises. University of Chicago, Chicago, pp. 109–173.

Calomiris, C., Wilson, B., 2004. Bank capital and portfolio management: the 1930s capital crunch and the scramble to shed risk. Journal of Business 77, 421–456.

Caporale, B., Caporale, T., 2003. Investigating the effects of monetary regime shifts: the case of the Federal Reserve and the shrinking risk premium. Economics Letters 80, 87–91.

Caporale, T., McKiernan, B., 1998. Interest rate uncertainty and the founding of the Federal Reserve. Journal of Economic History 58, 1110–1117.

Champ, B., 2007. The National Banking System: empirical observations. Unpublished working paper, Federal Reserve Bank of Cleveland.

Davis, J., 2004. An annual index of industrial production, 1789–1915. Quarterly Journal of Economics 119, 1177–1215.

Davis, J., Hanes, C., Rhode, R., 2007. Harvests and business cycles in nineteenth century America. Unpublished working paper, SUNY-Binghamton.

Diamond, D., Dybvig, P., 1983. Bank runs, deposit insurance, and liquidity. Journal of Political Economy 91, 401–419.

Fishe, R.P., Wohar, M., 1990. The adjustment of expectations to a change in regime: comment. American Economic Review 80, 968–976.

Friedman, M., Schwartz, A.J., 1963. A Monetary History of the United States, 1867–1960. Princeton University Press, Princeton.

Gallman, R.E., 2000. Economic growth and structural change in the long nineteenth century. In: Engerman, S., Gallman, R. (Eds.), Cambridge Economic History of the United States, Vol. II: The Long Nineteenth Century. Cambridge University Press, Cambridge, pp. 1–56.

Goetzmann, W.N., Ibbotson, G.R., Peng, L., 2001. A new historical database for the NYSE 1815 to 1925: performance and predictability. Journal of Financial Markets 4, 1–32.

Grossman, R., 1993. The macroeconomic consequences of bank failures under the National Banking System. Explorations in Economic History 30, 294–320.

Kemmerer, E.W., 1911. Seasonal variations in the New York money market. American Economic Review 1, 33–49.

Kool, C., 1995. War finance and interest rate targeting: regime changes in 1914–1918. Explorations in Economic History 32, 365–382.

Macaulay, F.R., 1938. Some Theoretical Problems Suggested by the Movements of Interest Rates, Bond Yields and Stock Prices in the United States since 1856. National Bureau of Economic Research, New York.

Meltzer, A., 2003. A History of the Federal Reserve. Chicago University Press, Chicago.

Mankiw, N.G., Miron, A.J., Weil, D.N., 1987. The adjustment of expectations to a change in regime: a study of the founding of the Federal Reserve. American Economic Review 77, 358–374.

Miron, J., 1986. Financial panics, the seasonality of the nominal interest rate, and the founding of the Fed. American Economic Review 76, 125–140.

Moen, J., Tallman, E., 2000. Clearinghouse membership and deposit contraction during the panic of 1907. Journal of Economic History 60, 145–163.

Officer, L.H., 1996. Between the Dollar–Sterling Gold Points: Exchange Rates, Parity and Market Behavior. Cambridge University Press, Cambridge.

Schwert, G.W., 1989a. Business cycles, financial crises and stock volatility. Carnegie-Rochester Conference Series on Public Policy 31, 83–125.

Schwert, G.W., 1989b. Why does stock market volatility change over time? Journal of Finance 44, 1115–1153

Schwert, G.W., 1990. Stock returns and real activity: a century of evidence. Journal of Finance 45, 1237–1257.

Shapiro, M.D., 1988. The stabilization of the US economy: evidence from the stock market. American Economic Review 78, 1067–1079.

Shiller, R., 1992. Market Volatility. MIT Press, Cambridge.

Siegel, J., 2002. Stocks for the Long Run: The Definitive Guide to Financial Market Returns and Long-Term Investment Strategies. McGraw-Hill, New York.

Silber, W.L., 2005. What happened to liquidity when World War I shut the NYSE? Journal of Financial Economics 78, 685–701

Silber, W.L., 2007a. When Washington Shut Down Wall Street: The Great Financial Crisis of 1914 and the Origins of America's Monetary Supremacy. Princeton University Press, Princeton.

Silber, W.L., 2007b. The great financial crisis of 1914: What can we learn from Aldrich-Vreeland emergency currency? American Economic Review Paper and Proceedings 97, 285–289

Sprague, O.M., 1910. History of Crises under the National Banking System. US Government Printing Office, Washington.

US Bureau of the Census, 1976. Historical Statistics of the United States, Colonial Times to 1970. Basic Books, New York.

Working, H., 1960. A note on the correlation of first differences of averages in a random chain. Econometrica 28, 916–918.