THE WISSELBANK AND AMSTERDAM PRICE VOLATILITY: A FRACTAL TEST OF THE AUSTRIAN FRACTIONAL-RESERVE BANKING HYPOTHESIS

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Resumen: Analizando los datos históricos correspondientes al Banco de Ámsterdam de 1708 a 1788 concluimos que la evidencia empírica confirma (o al menos no refuta) la hipótesis austriaca sobre los negativos efectos de la banca con reserve fraccionaria.

Palabras clave: Banca con reserva fraccionaria, expansión monetaria, estabilidad de precios, equilibrio.

Clasificación JEL: E42, E44, N13, N23, N83.

Abstract: Using 1708-1788 historical data, we test the Austrian hypothesis that fractional-reserve banking destabilizes commodity prices, complicating economic calculation and entrepreneurial planning, and contributes to boom-bust cycles. The Bank of Amsterdam («Wisselbank», 1609-1819) maintained high reserve requirements until the Fourth Anglo-Dutch War (1780-1784), when its reserve ratio plummeted from nearly 100% in 1778 to around 20% by 1788. We compare price volatilities for 1722-1779 and 1780-1788 using fractal Hurst exponents. For all commodity prices tested, fractal volatility was higher during the lower fractional reserve period, except for rye, wheat, and Hamburg Bills of Exchange. Bill of Exchange stability was likely attributable to Hamburg transport ships' ability to evade British incursion and to the Wisselbank's legal

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monopsony in the secondary commercial paper market. However, rye and wheat prices — directly indicative of bread prices — generally (and contrary to Austrian theory) stabilized even though British blockades significantly reduced Dutch bread grain imports. We attribute this unexpected result primarily to emergency wartime provision by the Amsterdam municipal granary. The Wisselbank experience may confirm, or at least does not clearly falsify, the economic relevance of the Austrian Fractional-Reserve Banking Hypothesis.

Keywords: Fractional reserve banking, monetary expansion, price stability, equilibrium.

JEL Codes: E42, E44, N13, N23, N83.

I
INTRODUCTION

Many prominent Austrian School economists have objected to fractional-reserve banking (Mises 1998; Rothbard 1994, 2009; Hayek 2008; Huerta de Soto 2009, 2011)[1]. As Hayek describes fractional reserve banking, a bank is maintaining fractional reserves if it «grants credit to an amount exceeding this [amount] in deposits» (Hayek 2008, p. 82), or in other words, «re-lends several times the amount deposited» (Hayek 2008, p. 86). In contrast, the loan-making of a full-reserve (i.e. 100-percent-reserve) bank never exceeds the actual deposits held by the bank.

The Austrian concern with fractional-reserve banking — particularly when coordinated by central banks — is that prices, employment, and output all become more *volatile*, subject to more dramatic booms and busts (Mises 1998; Rothbard 1994, 2000, 2009; Hayek 2008; Haberler 1996; Huerta de Soto 2009, 2011). Austrians have slightly different theoretical accounts of why this occurs, but Huerta de Soto (2011) offers a particularly concise and clear exposition. He notes that the first step in the economic cycle caused by fractional-reserve banking is an economic expansion («boom»), ac-

[1] Not all Austrians endorse this view. See, for instance, Selgin & White (1996), p. 86.

companied by a general, dramatic price increase in consumer commodities:

> «The money created through [fractional-reserve] credit expansions is used by entrepreneurs to demand factors of production, which they employ mainly in capital goods industries more distant from consumption. As the process has not been triggered by an increase in savings, no productive resources are liberated from consumer industries, and the prices of commodities, factors of production, capital goods and the securities that represent them in stock markets tend to grow substantially and create a market bubble. Everyone is happy, especially because it appears it would be possible to increase one's wealth very easily without any sacrifice in the form of prior saving and honest hard individual work» (Huerta de Soto 2011, p. 79).

Huerta de Soto, like many Austrians, contends that at some point, the boom reverses into an economic contraction («bust»): a collapse in commodity, capital, and consumer goods prices artificially inflated by the fractional-reserve expansion, along with a reallocation of resources from capital (advanced technology) sectors to consumer goods (immediate consumption) sectors. The Austrian identification and explanation of the microeconomic mechanisms by which this happens are described elsewhere (Huerta de Soto 2009; Mises 1998) and need not be restated here. What is important to recognize is that, under this «*Austrian Fractional-Reserve Banking Hypothesis,*» («Austrian Hypothesis» for short) commodity price and interest rate volatility are predicted to increase significantly as a result of both the expansionary and contractionary forces at play as fractional-reserve banking is initiated or increased (Rothbard 2000, pp. 8-19).

The Austrian Hypothesis directly implicates and condemns core practices of contemporary banking. Yet after the 1844 Peel Act was passed in England, the world's banking systems have migrated almost universally to fractional-reserves (Huerta de Soto 2011). Consequently, the Austrian Hypothesis is largely untestable using modern data, as there is no full-reserve banking system to compare alongside the global fractional-reserve system.

We must therefore look to earlier history to see whether full-reserve banking stabilized economies. But in considering how one might «test» the Austrian Hypothesis, we must first address whether empirical testing of the hypothesis is methodologically proper or informative.

II
EMPIRICALLY «TESTING» THE AUSTRIAN HYPOTHESIS

Our article's title itself will be provocative to Austrians who contend that no empirical test can be made of economic principles. Rothbard (2000), states that *praxeology* — the logical-verbal deduction of economic 'truths' beginning with an Aristotelian 'action' axiom — is the exclusive form of legitimate economic theory:

> «The only test of a theory is the correctness of the premises and of the logical chain of reasoning. … Theory cannot emerge, phoenix like, from a cauldron of statistics; neither can statistics be used to test an economic theory» (Rothbard 1951, p. xl).

Rothbard's view is that while praxeologically derived theory can be used to glean corroborative evidence from the mass of historical data, historical data cannot inform or modify economic theory:

> «[H]istorical facts are complex and cannot, like the controlled and isolable physical facts of the scientific laboratory, be used to test theory. There are always many causal factors impinging on each other to form historical facts. Only causal theories *a priori* to these facts can be used to isolate and identify the causal strands» (Rothbard 1951, p. xxxix).

What Rothbard leaves unanalyzed is what happens when historical facts do not support praxeology's «causal strands». Let us take an analogy from the realm of the physical sciences, as Austrian philosopher Long (2006) does, to address this point. Suppose we somehow knew, *a priori*, gravity to be a true force of -9.8 m/sec^2. (Obviously scientific theories are in part empirically inferred, so this analogy is not perfect — we are assuming someone could praxeologically «deduce» gravity without actually observing empirical events first.) If we have a ball and drop it from a certain height, it should fall 9.8 meters in the first second. In other words, our *a priori* expectation leads to a logical causal prediction.

But what if the ball levitates? Is gravity then false? We might then look for other historical facts to explain why this happened. Say, for instance, we discover that there was a repulsion magnet on the ground and that the ball is likewise magnetic. Assume we also somehow knew *a priori* that repulsion magnets exert repulsive forces on magnetic objects. This additional fact permits us to say that the ball hovers, because the forces of gravity and the opposing magnetic field cancel each other for that specific weight of the ball at that specific height.

Long says the correct epistemological view is that gravity has not been disproven by the lack of corroborative empirical evidence, because «whatever other forces may be acting on the object, we can still predict the object will end up [9.8] feet further downward that it would have if gravity had not been acting on it» (Long 2006, p. 13). In other words, just because historical facts in the *real* world do not permit us to see the *isolated* causal effect of gravity (e.g. the ball that never fell because of a magnet lying on the ground), there is an *imagined yet realistically possible* world in which the ball would have fallen to the ground, if only the magnet were not there, or if only the ball had been made of (non-magnetic) rubber rather than iron. Gravity was still acting in the real world. Its effects were obscured by the complexity of reality that involved a magnet.

With this gravity-magnet analogy in mind, let us return to the Austrian Hypothesis, taking the Hypothesis, derived praxeologically, as the economic equivalent of gravity. According to the Hypothesis, commodity price and interest rate volatility is a harmful symptom of the undesirable malinvestment occurring during the fractional-reserve business cycle. The Hypothesis, however, is not just one nondescript Austrian praxeological conclusion among many. It is one of the fundamental principles of the Austrian School. Fractional-reserve banking is touted widely as a, if not *the*, primary ill of the modern economy. In speaking about the Great Depression, Rothbard spoke with a deterministic air when he proclaimed that «credit expansion, with resulting accumulation of malinvested capital, leads finally and *inevitably* to economic crisis» (Rothbard 2000, p. xlii. (emphasis in original)).

And yet, the same Austrians who tout the «inevitability» of price volatility whenever fractional-reserve banking is present are not so naïve as to ignore the fact that counteracting causes can exist in reality. For example, praxeology indicates that improvements in innovation and technology also cause natural price fluctuations (Haberler 1996; Rothbard 2000). But Austrians say such price fluctuations — though empirically indistinguishable — are *desirable*, as opposed to the '*undesirable*' price volatility inherent to the fractional-reserve business cycle. If monetary expansion is 'gravity,' technological improvement and innovation could be a 'magnet' capable of offsetting or amplifying the volatility attributable to fractional-reserve banking.

Therefore, even if one thinks praxeologically, one cannot immediately conclude (as even prominent Austrians like Rothbard have) that where price volatility and fractional-reserve banking coexist, economic crisis becomes inevitable. One must look to the historical record to see what happened. Mises (1998) recognized that once one seeks confirmation of praxeological theorems (e.g. the Austrian Hypothesis), praxeology's comfortable objectivity is lost:

> «[T]here necessarily enters into [factual] understanding an element of subjectivity. … Two historians … may fully agree in establishing that the factors *a*, *b*, and *c* worked together in producing the effect *P*; nonetheless they can widely disagree with regard to the relevance of the respective contributions of *a*, *b*, and *c* to the final outcome. … [T]hese are not judgments of value, they do not express preferences of the historian. They are judgments of relevance. … [A]s far as historians disagree with regard to judgments of relevance it is impossible to find a solution which all sane men must accept»(Mises 1998, p. 57-58).

Per Mises, consider the following: an Austrian and a non-Austrian each look at historical data of price fluctuations in countries that fractional-reserve banked stretching back to time immemorial. The Austrian will point to price fluctuations and emphasize the *primacy* of fractional-reserve banking's effects in each case and that imperfect goods-market arbitrage (also a legitimate explanation, per praxeology) was often only a secondary factor. Conversely, the non-Austrian may describe imperfect arbitrage (Rogoff, Froot, & Kim 2001) and not even mention fractional-reserve banking, considering it only a *de minimis* contributory force. And Mises himself contends there is no way to sort out which story is the better one. One can legitimately question (and, per Mises, such scrutiny supposedly cannot be objectively dismissed) the *primacy of relevance*. The Austrian Hypothesis, although praxeologically true, may have only tertiary or quaternary empirical relevance or causal significance, and may not even be worthy of mention, perhaps being only a comparatively weak force behind historical business cycles, rather than the «root cause» (Hülsmann 2000).

We contend that one epistemologically objective way to evaluate the relevance of the Hypothesis to economic cycles would be for Austrians to point to, and non-Austrians to concur with, historical instances — real banks that have come and gone — when full- or high-reserve banking seemed to have primacy of relevance in empirically stabilizing an economy. These might serve as inspiring models to emulate. Notable Austrians have praised the historical Bank of Amsterdam («Wisselbank») as an exemplary full-reserve bank «from its opening in 1609 until it yielded to the temptation of financing Dutch wars in the late eighteenth century» (Rothbard 1994, p. 44; Huerta de Soto 2009; Andrews 2010; Salerno 2014). French (2006, 2009) takes a more nuanced view, claiming that Amsterdam's free coinage and legal-tender laws in the Wisselbank's early years allowed for the tulipmania bubble between 1630-37 due to an influx of New World and European specie to prosperous Amsterdam despite the bank's admirable full-reserve principles. Still, even French does not admonish the Wisselbank's *eighteenth* century practices, well after tulipmania ended.

The Wisselbank was not the only historical high-reserve bank. Kindleberger (1984) identifies banks in Hamburg and Venice as other candidates at different times. But in this article, we accept the Austrians at their word: the Wisselbank, particularly after tulip mania ended, allegedly merits special consideration as one of the most promising historical examples of a prominent full-reserve bank whose sound banking principles were relevant in averting harmful business cycles in Amsterdam.

As demonstrated in the next section, the Wisselbank enjoyed a lengthy period of high-fractional-reserve and full-reserve banking, brought to an abrupt and stark end in the 1780s, when the bank shifted from full-reserves to low-fractional-reserve banking (around 20%) in the course of a few years to finance the Fourth Anglo-Dutch War (1780-84). If Austrians are correct that fractional-reserve banking is the «inevitable» «root» primary cause of price volatility, with no close secondary contributing cause, then the waning bank's post-1779 low fractional-reserve years should reflect far greater commodity and interest rate price volatility than in its preceding high- and full-reserve years.

What if the volatilities are instead unchanged or even dampened? Empiricists might say we have produced evidence that falsifies the Austrian Hypothesis. Yet as we have explained above, this strong empiricist position is unlikely to satisfy Austrians who deny that historical data can falsify praxeological theory. At the very least, what one could say about such empirical results that might satisfy both the empiricist and the Austrian alike is that, under the most ideal Austrian banking conditions of the last millennium, the Austrian Hypothesis did not have the primacy of relevance Austrians routinely ascribe to it. In other words, fractional-reserve banking — while perhaps a *true* cause of economic booms and busts — may not often be a *primary* cause. Ultimately, however, our article demonstrates that Amsterdam price volatility generally did increase, with explainable exceptions, during the relevant Wisselbank era. To our knowledge, this paper and its results are among the first of their kind to empirically «test» the primacy of the Austrian Hypothesis's causal relevance for a historical business cycle. We conclude by laying out possibilities for future research that may enhance this article's preliminary findings.

III
THE WISSELBANK: BALANCES AND RESERVES, 1700-1795

A chronology of the era in which the Wisselbank was active is provided in Table 1. The Wisselbank's strength came from the bank's practices of assigning a book value to deposited specie and coinage.

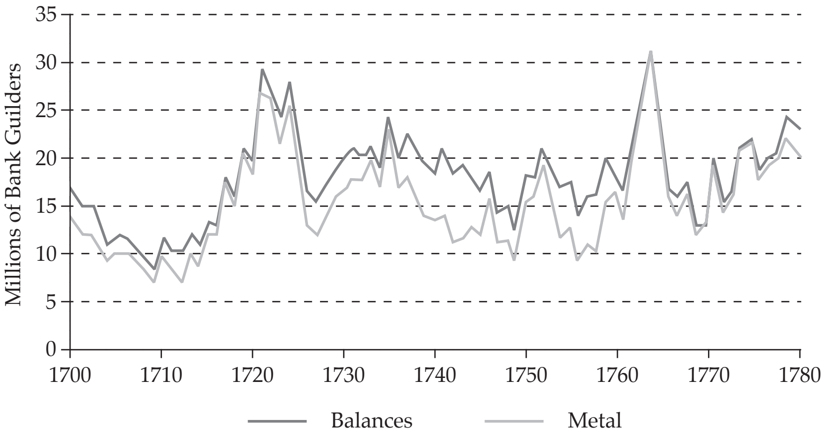
The book value was based not on the specie's official sovereign value, but on its true metallic content. This led in the 1600s to the creation of a stable, fractional «agio» (exchange rate) between bank guilders (book currency) and circulating metal specie, although there was a penalty for conversion and withdrawal of specie (Quinn & Roberds 2006, 2009). Unregulated financial transactions of considerable complexity and sophistication had become routine in Amsterdam and London during the seventeenth century (Stringham 1999, 2002, 2003).

TABLE 1
CHRONOLOGY OF DUTCH HISTORY
DURING THE WISSELBANK ERA

1581	The Act of Abjuration by the States General of the Netherlands declares independence from Spain and the Hapsburg King Phillip II (1527-1598).
1609	Wisselbank founded in the City of Amsterdam.
1637	Tulip mania speculative bubble bursts.
1648	Peace of Westphalia. Spain recognizes Dutch independence.
1652-1654	First Anglo-Dutch War.
1665-1667	Second Anglo-Dutch War.
1672-1674	Third Anglo-Dutch War. William III of Orange (1650-1702) elected Stadtholder.
1688-1689	British Parliament invites William III and Mary II (1662-1694) to assume the British throne. They inaugurate their joint rein by granting the British Bill of Rights. William reigns as king of Great Britain while Stadtholder of the Netherlands, reigning alone after Mary's death.
1780-1784	Fourth Anglo-Dutch War.
1791	City of Amsterdam takes control of the Wisselbank.
1819	Wisselbank liquidated.

Austrian praise for the Wisselbank as a rare «full-reserve» bank is not entirely merited. From its earliest days, the Wisselbank frequently engaged in lending and fractional-reserve banking, but only on a limited scale. It often attained high-fractional or even full-reserves. (Quinn & Roberds 2010, 2014a, 2014b). Figure 1 displays the high-reserve ratio common to the bank throughout the 1700s.

FIGURE 1
WISSELBANK BOOK BALANCES AND METAL RESERVES, 1700-1780



Source: Quinn & Roberds (2014a), reprinting van Dillen (1934).

With Dutch entry into the Fourth Anglo-Dutch War in 1780, unique pressure mounted on the Wisselbank's directors to underwrite massive loans to the Dutch East India Company, because the British blockaded Dutch ports and captured Dutch trading posts in Asia. As part of this war-footing, the Wisselbank made additional loans to the City of Amsterdam, private parties through a new lending facility (Municipal Loan Chamber), and provincial governments (Quinn & Roberds 2014a). Post-1780 loans made to the City and the Company were interest-free (Quinn & Roberds 2014b). Bank loan profits were given to the City, not returned to the bank (Quinn & Roberds 2014b).

Not backed by specie, these loans only partly maintained the bank balance sheet[2]. Simultaneous specie flight from Holland led to a precipitous decline in the bank's near-full reserve ratio, reaching a fractional-reserve of around 20% by 1788 (Figure 2). The money supply was growing with cyclical fits and starts up to the start of the Fourth Anglo-Dutch War (Figure 1). Once that war broke out in 1780,

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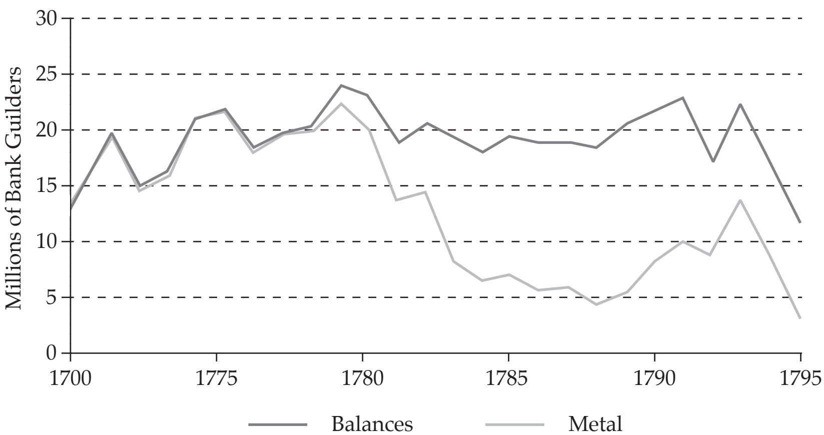
[2] Quinn and Roberds 2014(b), Appendix, recreate the amounts of these loans and repayments.

the increase in the money supply ended (Figure 2). There was no hyperinflation because the war was not financed with limitless issues of unbacked paper notes, though many deposits of specie were withdrawn without a simultaneous reduction in notes outstanding. Note also that the 20% reserves held by the Wisselbank after and during the war is a very conservative reserve ratio by modern standards.

FIGURE 2
WISSELBANK BOOK BALANCES AND METAL RESERVES, 1770-1795



Source: Quinn & Roberds (2014a), reprinting van Dillen (1934).

Quinn & Roberds (2014b, p. 21) estimate from municipal records that «the Bank [was] insolvent by 1784.» This was true despite City repayment of some of its loans (with interest, despite lack of obligation to pay such) in 1783 in an effort to shore up the Bank's balances. By December 1794, when the French Army invaded the Netherlands, most specie had already fled the Wisselbank, and the bank suffered a *de facto* bust. The bank lingered on municipal life support until its ultimate closure in 1819 (Quinn & Roberds 2014a). Wisselbank economic historians Quinn and Roberds ascribe the Wisselbank's demise to three concurrent Bank policy errors after 1780:

> «The Bank's first policy error was its decision to support a large, bankrupt government-sponsored enterprise (the Dutch East India Company) while trying to maintain an indefensible policy target (the agio peg of 4-5 percent). Negative impacts on the Bank's net worth were amplified by a second policy error, which was the City of Amsterdam's practice of keeping Bank profits to itself and allocating losses to the Bank. The first two policies eroded the net worth of the Bank until a fiscal bailout offered the only feasible way to restore the Bank's reputation. A third policy error, of inadequate fiscal backup, was manifested in the City's botched recapitalization of 1791-92. Applied in isolation, any of these policies would have worked to undermine the Bank. The key lesson seems to be that a combination of all three was particularly toxic» (Quinn & Roberds 2014b, pp. 26-27 (citations omitted)).

IV
DATA AND METHODOLOGY

Our data set, available online at www.iisg.nl/hpw/, was electronically assembled by M. Malinowski from a manuscript stored at Harvard University's Kress Library and reproduced at the Netherlands Economic History Association (NEHA). The set provides weekly maximum and minimum prices for fifteen Amsterdam-traded international bills of exchange and commodities (mostly grains and colonial trade goods), as well as the official Bank of Amsterdam agio, which was the annualized discount rate the bank charged on its specie deposits. The Kress manuscript's historical origins are unclear, although Malinowski speculatively traces it to a nineteenth-century academic initiative to collect and record price data from an eighteenth-century Dutch trading company's market records (Malinowski, undated).

The Kress manuscript contains price series for sixty-six commodities and bills of exchange. However, Malinowski electronically tabulated only sixteen price sets because he considered them to be the most representative of the era's market transactions. From Malinowski's data, we excluded from consideration black pepper maximum prices post-1780 and all bills of exchange from Gdansk and Konigsberg, because of sizeable time gaps in price data. (In the case of these two bills of exchange price series, there were no data after 1780, presumably due to effective British blockades of Dutch trade with those regions, thus rendering our comparative analysis impossible). Among those remaining commodities we tested, a few had minor gaps, while others were complete sets (See Malinowski (undated), Table 1). We ran each price series as if there were no time interruptions. Sparsely observed data are not problematic for estimating the Hurst exponent for such self-similar series.

Mandelbrot (1963a, 1963b) demonstrated all stationary series can be categorized in accordance with their Hurst exponent H. The Hurst exponent was introduced in the hydrological study of the Nile valley and is the reciprocal of the characteristic exponent α (Hurst 1951). Some series are persistent or black noise processes with ($0.50 < H < 1.00$). These less noisy series exhibit clearer trends and more persistence the closer H is to one. However, Hs very close to one indicate high risk of large, abrupt changes, e.g., $H = 1.00$ for the Cauchy distribution.

We selected the Hurst exponent to measure price volatility. Hurst exponents are a fractal volatility measure that have become widely accepted as more reliable and indicative of real historical price volatilities than traditional measures that assume other non-parametric or Gaussian distributions (Mandelbrot 1963b; Mandelbrot & Hudson 2004; Mulligan 2010). Mandelbrot's (1972a, 1975, 1977) and Mandelbrot and Wallis's (1969) R/S or rescaled range analysis characterizes time series as one of four types: 1.) dependent or autocorrelated series, 2.) persistent, trend-reinforcing series, also called biased random walks, random walks with drift, or fractional Brownian motion, 3.) random walks, or 4.) anti-persistent, ergodic, or mean-reverting series.

Mandelbrot-Lévy distributions are a general class of probability distributions derived from the generalized central limit theorem, and include the normal or Gaussian and Cauchy as limiting cases (Lévy 1925; Gnedenko and Kolmolgorov 1954). They are also referred to as stable, Lévy-stable, L-stable, stable-Paretian, and Pareto-Lévy. The reciprocal of the Mandelbrot-Lévy characteristic exponent α is the Hurst exponent H, and estimates of H indicate the probability distribution underlying a time series. $H = 1/\alpha = 1/2$

for normally-distributed or Gaussian processes. H = 1 for Cauchy-distributed processes, the most extreme fat-tailed or leptokurtic member of the family. H is also related to the fractal dimension D by the relationship D = 2 - H.

Rescaled-range or R/S analysis is the conventional method introduced by Mandelbrot (1972a). R/S represents the range of a sample divided by the sample standard deviation, where the R/S is computed for various sample sizes. Time series are classified according to the estimated value of the Hurst exponent H, which is defined from the relationship

$$R/S = an^H$$

where R is the average range of all subsamples of size n, S is the average standard deviation for all samples of size n, a is a scaling variable, and n is the size of the subsamples, which is allowed to range from an arbitrarily small value to the largest subsample the data will allow. Putting this expression in logarithms yields

$$\log(R/S) = \log(a) + H \log(n)$$

which is used to estimate H as a regression slope. H ranges from 1.00 to 0.50 for persistent series, is exactly equal to 0.50 for random walks, ranges from zero to 0.50 for anti-persistent series, and is greater than one for a persistent or autocorrelated series. Mandelbrot, Fisher, and Calvet (1997) refer to H as the self-affinity index or scaling exponent.

The roughness/length (R/L) method (Malverino 1990) used in this paper is similar to R/S, substituting the root-mean-square (RMS) roughness s(w) for the standard deviation and the window size w for the range. Then H is computed by regression from a logarithmic form of the relationship $s(w) = w^H$. R/L analysis exploits the structure of dependence in time series irrespective of their marginal distributions, statistically identifying non-periodic long-run dependence as distinguished from short dependence or Markov character and periodic variation (Mandelbot 1972a, pp. 259-260).

The difference between long-memory processes, also called non-periodic long cycles, and short-term dependence, is that each observation in long memory processes has a persistent effect on subsequent observations, up to some horizon after which memory is lost, whereas in contrast, short-term dependent processes display little or no memory of the past, and what short-term dependence can be observed often diminishes with the square of the time elapsed. For price series, long memory can be observed when prices follow a trend or repeat a cyclical movement, even though the cycles can have time-varying frequencies.

Short-term dependence is indicated when there are no observable trends or patterns beyond a very short time span, and the impact of outliers or extreme values diminishes rapidly over time. One significant advantage of Hurst exponents over other common economic measures of variance, therefore, is that it more accurately measures persistent volatility in time series, and is able to do so without resort to dummy variables. There is also no assumption of time-varying volatility clustering as with ARCH-GARCH modeling. Hurst analysis is also ideally appropriate for sparsely-observed data with irregular missing observations, which would impair the power of more conventional techniques.

To measure *comparative* price volatility attributable to the Wisselbank's fractional-lending decision (circa 1780), we then split the Malinowski data into two subsets: (1) prices prior to January 1, 1780 (for some series stretching back as far as 1708), and (2) prices thereafter, and compared computed Hurst exponents for each subset to identify statistically significant differences (i.e., with confidence interval ≤ 95%).

V
RESULTS AND DISCUSSION

Hurst exponents were computed for various Amsterdam grain and colonial goods prices, as well as the Hamburg/Amsterdam bill of exchange price (consisting of the spot exchange rate + shadow interest rate on time to maturity), and the Wisselbank agio. For both the pre-1780 high-reserve era of the Wisselbank (Table 2) and the post-1780 fractional-reserve era (Table 3), all price volatilities reflected statistically-significant non-Gaussian tendencies. In the

TABLE 2

HURST ANALYSIS OF COMMODITY PRICES 1721-1779

		H	*S.D.*	*95% confidence interval upper bound*	*95% confidence interval lower bound*	*Reject H_0: ($H = 0.5$)*
				Grains 1722-1779		
Polish wheat	min	0.553	0.009393	0.571785	0.534215	1
	max	0.578	0.003298	0.584595	0.571405	1
Konigsberg wheat	min	0.560	0.011459	0.582918	0.537082	1
	max	0.568	0.007821	0.583641	0.552359	1
Colorful wheat	min	0.563	0.007121	0.577242	0.548758	1
	max	0.553	0.007537	0.568075	0.537925	1
Prussian rye	min	0.522	0.009145	0.540291	0.503709	1
	max	0.538	0.006925	0.551850	0.524150	1
Konigsberg rye	min	0.517	0.007792	0.532583	0.501417	1
	max	0.531	0.006802	0.544603	0.517397	1
Dried rye	min	0.527	0.004077	0.535154	0.518846	1
	max	0.559	0.004872	0.568744	0.549256	1
Frisian barley	min	0.485	0.009692	0.504385	0.465615	1
	max	0.476	0.015409	0.506818	0.445182	1
Fodder oats	min	0.457	0.007366	0.471731	0.442269	1
	max	0.449	0.008213	0.465426	0.432574	1
				Colonial Goods 1722-1779		
Coffee East-Indies	min	0.511	0.007055	0.525111	0.496889	1
	max	0.521	0.007921	0.536841	0.505159	1
Black pepper	min	0.604	0.015073	0.634146	0.573854	1
	max	0.508	0.001201	0.510403	0.505597	1
Indigo St Domingo	min	0.646	0.009761	0.665522	0.626478	1
	max	0.644	0.014234	0.672468	0.615532	1
Sugar St Domingo	min	0.596	0.018959	0.633917	0.558083	1
	max	0.613	0.021776	0.656552	0.569448	1

…/…

…/…

		H	*S.D.*	*95% confidence interval upper bound*	*95% confidence interval lower bound*	*Reject H_0: (H = 0.5)*
			Bills of Exchange 1721-1779			
Hamburg, stuivers for 1 thaler of 32 sols of Lübeck, «kort zicht»	min	0.371	0.005227	0.381454	0.360546	1
			Agio 1742-1779			
Weekly bank agio in Amsterdam in %	min	0.398	0.007896	0.413792	0.382208	1

Note: In the far right column, 1 indicates Reject H_0; 0 indicates failure to reject. «Kort zicht» or «short date» indicates short-term bills of exchange.

high-reserve era, nearly all of the goods prices exhibited leptokurtic tendencies (i.e., volatile persistent long memory). This finding is consistent with Hurst calculations for contemporary commodities' prices such as cotton, albeit smaller in magnitude (Mandelbrot 1963b). In contrast, the bill of exchange and the agio exhibited stark platykurtic (i.e. antipersistent long memory) behavior. These pre-1780 financial products' low price volatility has been attributed by some to the bank's worldwide trusted reputation for safeguarding finances (Jonker 2010)[3].

Table 3 reflects Hurst exponents for the same commodities during the post-1780 fractional-reserve era of the Wisselbank. Again, without exception, all price series appear significantly non-Gaussian. The most obvious structural change in price volatilities is observed for pre-and post-1780 rye series (Prussian, Konigsberg, and Dried), which all converted from leptokurtic to platykurtic. We suggest possible reasons for this change below.

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3 Quinn & Roberds (2012) analyze the agio's historical volatility in significant detail.

TABLE 3
HURST ANALYSIS OF COMMODITY PRICES 1780-1788

		H	*S.D.*	*95% confidence interval upper bound*	*95% confidence interval lower bound*	*Reject H0: (H = 0.5)*
			Grains 1780-1788			
Polish wheat	min	0.544	0.001256	0.546511	0.541489	1
	max	0.589	0.003794	0.596588	0.581412	1
Konigsberg wheat	min	0.532	0.001787	0.535573	0.528427	1
	max	0.513	0.001009	0.515017	0.510983	1
Colorful wheat	min	0.574	0.007484	0.588968	0.559032	1
	max	0.517	0.003819	0.524638	0.509362	1
Prussian rye	min	0.474	0.000957	0.475914	0.472086	1
	max	0.472	0.002179	0.476359	0.467641	1
Konigsberg rye	min	0.443	0.000246	0.443492	0.442508	1
	max	0.477	0.000396	0.477792	0.476208	1
Dried rye	min	0.466	0.001207	0.468414	0.463586	1
	max	0.509	0.000763	0.510526	0.507474	1
Frisian barley	min	0.731	0.001219	0.733438	0.728562	1
	max	0.698	0.002868	0.703736	0.692264	1
Fodder oats	min	0.679	0.003783	0.686566	0.671434	1
	max	0.645	0.002955	0.650910	0.639090	1
			Colonial Goods 1780-1788			
Coffee East-Indies	min	0.666	0.000738	0.667476	0.664524	1
Black pepper	min	1.216	0.001157	1.218314	1.213686	1
Indigo St Domingo	min	0.785	0.005270	0.795540	0.774460	1
	max	0.700	0.006658	0.713316	0.686684	1
Sugar St Domingo	min	0.664	0.006354	0.676708	0.651292	1
	max	0.752	0.009581	0.771162	0.732838	1

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		H	*S.D.*	*95% confidence interval upper bound*	*95% confidence interval lower bound*	*Reject H0: (H = 0.5)*
			Bills of Exchange 1780-1788			
Hamburg, stuivers for 1 thaler of 32 sols of Lübeck, «kort zicht»	min	0.307	0.001004	0.309008	0.304992	1
			Agio 1780-1788			
Weekly bank agio in Amsterdam in %	min	0.421	0.001206	0.423413	0.418587	1

Note: In the far right column, 1 indicates Reject H_0; 0 indicates failure to reject. «Kort zicht» or «short date» indicates short-term bills of exchange.

Finally, Table 4 consolidates the findings from Tables 2 and 3 and compares the Hurst exponents for the pre-1780 high-reserve era (H_1) with the exponents for the post-1780 fractional-reserve era (H_2). Particularly stark increases in leptokurtic/fat-tailed behavior are observed for all of the colonial goods, which, although perhaps partly attributable to fractional-reserve banking, may also be associated with wartime importation difficulties due to the highly effective British blockade. For other domestic commodities (e.g., barley and fodder oats) that represent historical transportation and farm animal feed costs, consistently similar increases in price volatility are found. Furthermore, the Wisselbank agio itself, although remaining platykurtic, experienced a significant rise in volatility in the few short years subsequent to the bank's decision to engage in fractional-reserve practices. This seems strong prima facie evidence of the bank's destabilization following its choice to engage in significant clandestine lending.

TABLE 4
COMPARISON OF EARLY AND LATE PERIOD HURST EXPONENTS

		H1	*S.D.*	*H2*	*S.D.*	*Reject H0: (H1 ≥ H2)*
Grains		*1722-1779*		*1780-1788*		
Polish wheat	min	0.553	0.009393	0.544	0.001256	1
	max	0.578	0.003298	0.589	0.003794	1
Konigsberg wheat	min	0.560	0.011459	0.532	0.001787	0
	max	0.568	0.007821	0.513	0.001009	0
Colorful wheat	min	0.563	0.007121	0.574	0.007484	1
	max	0.553	0.007537	0.517	0.003819	0
Prussian rye	min	0.522	0.009145	0.474	0.000957	0
	max	0.538	0.006925	0.472	0.002179	0
Konigsberg rye	min	0.517	0.007792	0.443	0.000246	0
	max	0.531	0.006802	0.477	0.000396	0
Dried rye	min	0.527	0.004077	0.466	0.001207	0
	max	0.559	0.004872	0.509	0.000763	0
Frisian barley	min	0.485	0.009692	0.731	0.001219	1
	max	0.476	0.015409	0.698	0.002868	1
Fodder oats	min	0.457	0.007366	0.679	0.003783	1
	max	0.449	0.008213	0.645	0.002955	1
Colonial Goods		*1722-1779*		*1780-1788*		
Coffee East-Indies	min	0.511	0.007055	0.666	0.000738	1
Black pepper	min	0.604	0.015073	1.216	0.001157	1
Indigo St Domingo	min	0.646	0.009761	0.785	0.005270	1
	max	0.644	0.014234	0.700	0.006658	1
Sugar St Domingo	min	0.596	0.018959	0.664	0.006354	1
	max	0.613	0.021776	0.752	0.009581	1
Bills of Exchange		*1721-1779*		*1780-1788*		
Hamburg, stuivers for 1 thaler of 32 sols of Lübeck, «kort zicht»	min	0.371	0.005227	0.307	0.001004	0

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.../...

		H1	*S.D.*	*H2*	*S.D.*	*Reject H0: (H1 ≥ H2)*
Agio		*1742-1779*			*1780-1788*	
Weekly bank agio in Amsterdam in %	min	0.398	0.007896	0.421	0.001206	1

Note: In the far right column, the null being tested is that the Hurst exponent is strictly lower for the later period, i.e., that prices become more leptokurtic or fat-tailed during the fractional-reserve (later) period. 1 indicates reject H_0; 0 indicates failure to reject. «Kort zicht» or «short date» indicates short-term bills of exchange.

However, Table 4 is not unambiguously supportive of the Austrian Hypothesis. All rye price series changed significantly from leptokurtic (H > 1/2) to platykurtic (H < 1/2). This indicates a change in the fractal character from persistent to antipersistent long memory. In addition, Konigsberg wheat and maximum colorful wheat prices declined in volatility (while remaining leptokurtic/fat-tailed), and Polish wheat and minimum colorful wheat price volatilities increased only marginally (i.e., remained effectively unchanged). Furthermore, the Hamburg-Amsterdam Bill of Exchange prices stabilized.

The increased stability of the Hamburg Bill of Exchange is likely attributable to two factors. First, the British blockade of imports presumably led to increased Amsterdam trade with Hamburg and a resultant rise in the supply of Hamburg Bills of Exchange. Grain imported through Hamburg was able to avoid the British North Sea blockade because the coastal route to the Netherlands can utilize low-draft vessels, being protected by the Frisian Islands up to the Zuiderzee. British blockaders' deeper draft limited their ability to interfere with this trade[4]. Second, the Wisselbank enjoyed a legal monopsony over secondary sales of Bills of Exchange exceeding 600 guilders (van Tielhof 2002, p. 105-06)[5].

[4] Thanks are due to Professor Joost P.B. Jonker for making us aware of this situation.

[5] While many private bankers defied this law and a black secondary market arose (van Tielhof 2002, p. 106), the Wisselbank's monopsony would have promoted price

The challenge that the wheat and rye Hurst values present to the Austrian Hypothesis is that, all else equal, the Hypothesis would suggest the opposite of what did occur for such fundamental and basic consumer goods as rye and wheat: increasing, not decreasing or unaffected, price volatility. The colonial goods (imported sugar, pepper, coffee, and indigo) were luxury items for which demand was more elastic than it was for foodstuff grains. On its face, this would lead us to an expectation of greater fractal price volatility, ceteris paribus, among foodstuff grains than among the colonial goods. Moreover, Cantillon effects of monetary injection tend to increase price volatility most for the goods initially purchased with the newly-injected money (which in this case could have been grains rather than colonial goods).

Furthermore, demand for wheat and rye was highly inelastic; they were omnipresent in the Dutch diet during the 1700s, as many meals consisted entirely of pottage and wheat or rye bread, with a 2:1 ratio of wheat to rye bread consumption, (de Vries 2012) and with bread constituting at least 45% of the typical caloric intake (van Tielhof 2002, p. 81). And, as Table 5 indicates, Baltic imports of rye and wheat (described as «a lifeline» that was «absolutely essential to the Dutch bread supply,» (van Tielhof 2002, p. 1) suffered massive declines, even relative to other supplies, post-1780 as a result of British blockades — a 70% reduction in Baltic rye imports and 45% for wheat over the previous decade (Welling 1998).

For the Austrian Hypothesis not to be falsified, some unique, offsetting, and prevailing cause(s) of wheat and rye price *stabilization* must have arisen at the same time the bank's destabilizing fractional-reserve lending practices began in 1780. A change in tax policy was certainly not the culprit. Although bread was taxed far more heavily than other Dutch commodities, the grain mill rate remained unchanged for the entirety of the eighteenth century (de Vries 2012).

stabilization after the wartime increase in traded Hamburg Bills of Exchange. Black market prices are not recorded, only official prices, so the absence of a finding of increased volatility is less troubling.

TABLE 5
1772-1787 IMPORTS TO AMSTERDAM[6]

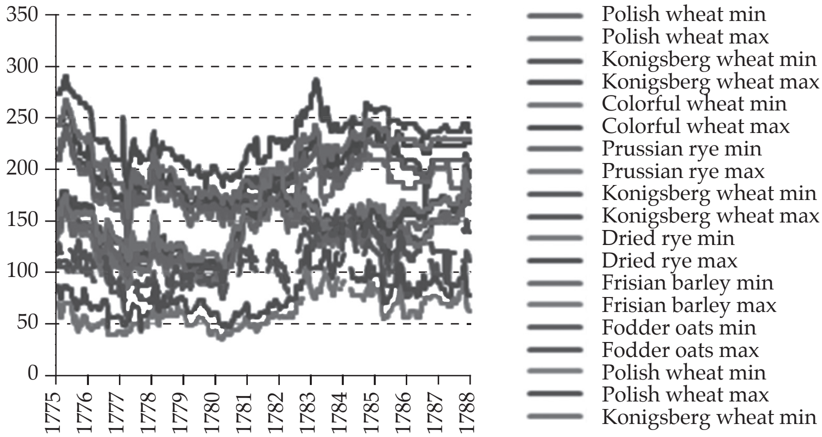
Year	Rye (last)	Wheat (last)	Barley (last)	Sugar (pond)	Coffee (vat)
1772	30,775	7,714	2,836	19,611,000	13,941
1773	24,680	5,176	2,072	18,994,100	15,575
1774	28,354	7,028	2,312	23,939,900	10,395
1775	27,553	7,437	3,676	21,770,000	10,611
1776	8,163	7,067	2,191	24,225,250	15,490
1777	12,580	9,308	1,396	19,802,500	6,110
1778	11,034	8,262	362	18,621,750	9,070
1779	5,270	9,310	1,894	11,191,000	4,140
1780	5,182	12,068	4,504	6,538,250	832
1781	8,824	1,984	1,638	10,972,750	4,122
1782	8,256	3,126	660	30,512,500	18,649
1783	8,436	5,934	3,158	29,035,750	20,908
1784	7,032	5,132	1,664	16,458,250	13,908
1785	6,250	8,204	918	22,537,500	9,705
1786	498	3,870	574	22,526,000	7,024
1787	564	3,194	886	22,924,000	10,298

Nor did exogenous demand for bread change substantially between 1750 and 1800 (van Tielhof 2002, p. 86). One might conjecture that Amsterdam government officials established official market prices for grains at the outbreak of the war in 1780. Our research has failed to yield evidence of this. Moreover, a plot of price trends for all grains in Malinowski's data set (Figure 3) reveals variability, suggesting that if such «official» prices indeed existed, Amsterdam markets did not adhere to them. Notice also the number of gaps in some price series, attributable to the war, that occur during the early 1780s.

One possible explanation for grain price stabilization could be differences in the relative magnitudes of substitution for colonial goods and grains. The colonial goods each had few suitable substi-

[6] Data are from Welling (1998), available at: http://www.let.rug.nl/welling/paalgeld/, transcribed from the Portbooks of the Levy of the Paalgeld.

FIGURE 3
AMSTERDAN GRAIN PRICES, 1775-1788



tutes, thus potentially offsetting the relatively greater elasticity afforded to them by their luxury status. By contrast, although the overall demand for grains was inelastic and the war and blockade impaired the supply of nearly all such grains from foreign sources, the fact that foodstuff grains were acceptable substitutes for each other may have ensured relatively higher demand elasticity for individual grain types, in comparison to colonial goods.

Second, it is also possible that the war expenses of sending large fleets to convoy colonial goods soaked up a large amount of the newly-injected money. Although these expenditures did not enhance demand for colonial goods, they ensured a more secure, lower cost supply (ceteris paribus) and the Cantillon effect would then have resulted in heightened colonial good — not grain — price volatility.

Probably the most relevant finding for addressing the mystery of grain price stabilization, is that Amsterdam had a municipal granary that dispensed grain in times of market scarcity to bakers, who «had to sell bread to the poor at a fixed price» (van Tielhof 2002, p. 109). By maintaining a relatively stable supply, the municipal government would have prevented market prices from fluctuating as severely, although there still may have been extreme

— though less frequent — price swings if the city granary was ever fully depleted. Having consulted several prominent Dutch economic historians who uniformly lack specific knowledge about the granary's operations during the 1780s, we can only conjecture that the granary logically would have been in significant operation during the war to fill the import shortfall and to avoid riots or famine (of which there is also no historical evidence).

If the granary sensitively adjusted its daily market supply to maintain stable market prices and the government mandated a maximum price for bread sales to the poor, this could readily explain the post-1780 stabilization of wheat and rye prices, even in the face of destabilizing credit expansion by the Wisselbank. The granary's market influence had to have been significant to overcome the countervailing effects of fractional-reserve banking *and* the grain import blockade, both of which were factors theoretically destabilizing grain and bread prices.

VI
CONCLUSION

This article has examined the Austrian Hypothesis and found it supported by economic events during the Wisselbank's rapid conversion in the 1780s from a high-reserve bank to a low-reserve one. To some empiricists, our results may suggest either specific or general verification (or, at least, failed falsification) of the Austrian Hypothesis. Others may not be convinced that we have fully separated the confounded effects of war and fractional-reserve banking, which in the Wisselbank's instance were clearly intertwined. What must be kept in mind is that a researcher can *always* find exogenous historical factors and attribute greater relevance to their effects on economic cycles than to co-existent fractional-reserve banking. For the Wisselbank in the 1780s, a significant exogenous factor was the war with Great Britain. In a different historical circumstance it might be a natural disaster, the launching of an exploratory armada, radical technological innovation, mass emigration, etc. The point is that one's theoretical grasp of economics flavors one's emphasis on what is, or is not, empirically relevant.

For an Austrian audience, even at their epistemological weakest, our results imply an actual banking illustration not inconsistent with the praxeological benefits of full-reserve banking. A stronger epistemological position that some Austrians may take from our results is that the *general* causal relevance of fractional-reserve banking, relative to other causes, is as significant as many Austrians claim it to be. However, Austrians should heed Mises' admonition about difficulties in objectively determining a praxeological theorem's general historical (and future) relevance. More refined philosophical insights about relevance (Guzelian 2016) and additional historical studies will likely be required to persuade non-Austrians.

Future research could benefit if additional weekly or biweekly price data became available that extended beyond the Kress set which ends in 1788[7]. With such data, one could recalculate the Hurst exponents to see if persistent volatility continues at a later date during the bank's decline and eventual failure[8]. In addition, comparative price volatility studies for other commodities or nations during the same era might yield additional insights. Moreover, studies of other high-reserve banks, such as Hamburg and Venice in appropriate eras (Kindleberger 1984), might provide further insight into the relevance of low fractional-reserve banking to economic cycles. Finally, comparative examination of Amsterdam price volatilities during earlier high- or full-reserve Wisselbank eras when other Dutch wars were fought might help to more fully separate the effects of war and banking practices on the Amsterdam economy.

VII
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[7] One such data set, compiled by Posthumus (1946), exists but provides only monthly data with significant gaps.

[8] Quinn & Roberds (2014b), p. 23-26, note accelerated volatility in the Bank's agio in the 1790s and the ultimate demise of the Bank florin in 1795.

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