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Has Gold been a Hedge against Inflation in France from 1949 to 2011? Empirical Evidence of the French Specificity

Thi Hong Van HOANG

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Thi Hong Van HOANG[1]

Abstract
This article aims to examine the role of gold quoted in Paris as an inflation hedge in France over the period 1949 to 2011. With a French monthly database of the prices of one-kilo ingots, Napoleon coins and the consumer price index, we test for the short-term and long-term relationships between gold and inflation in France. The Pearson and Spearman correlation coefficients and linear regression are used to study the short-term relationship. Cointegration tests of Engle and Granger (1987) and Phillips and Ouliaris (1990) are used to study the long-term relationship. The results show no significant relationship between the price of gold quoted in Paris and French inflation. This leads to the conclusion that gold quoted in Paris is not a good hedge against inflation in France, unlike gold quoted in London or New York.

Keywords: gold, inflation, correlation, linear regression, unit root, integration, cointegration
JEL classification: G1, G11

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[1] Assistant professor in Finance, Groupe Sup de Co Montpellier Business School, Montpellier Research in Management, 2300 avenue des Moulins, 34185 Montpellier, France. Email: thv.hoang@supco-montpellier.fr.
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Introduction

Many studies have shown that gold quoted in London or New York is a good hedge against the inflation of the US dollar (*e.g.* Jastram 1977, 1983 Sherman, Lawrence 2003 or Dempster and Artigas 2009)[2]. This is due to the fact that its price moves in the same direction as the dollar inflation: when this latter rises, the gold price increases and vice versa.

This close link between gold and US dollars was created in 1944 when the Bretton Woods Agreement was established. The objective of this Agreement was to implement a new international exchange system based on the gold exchange standard. This means that gold and the US dollar were equivalent in foreign exchange at the rate of 1 gold ounce[3] = $35. Despite the official dissolution of the system in April 1978, the link between gold and the US dollar has remained until today. The US dollar is even one of the fundamental determinant factors of the gold price.

However, is the role of gold in the hedge against inflation also true for other currencies such as the euro (or the French franc before 1999)? Is gold quoted in Paris also a good hedge against inflation for French investors? These are the questions that we address in this article.

With this objective, the paper is organized as follows. The first section presents a review of the literature about the role of gold in the hedge against inflation. The second section is devoted to the presentation of the database and the methods used. The third section analyzes the results.

I. Gold and the hedge against inflation: a literature review

Gold is often seen as an effective way for investors to hedge against the rise in prices of goods and services because its price moves in the same direction as inflation: when inflation rises, the price of gold rises and vice versa.

In the literature, there are two main streams of research devoted to studying the relationship between gold and inflation. The first assumes that inflation is one of the fundamental determinants of gold prices, while the second assumes only the relationship between inflation and gold prices. The concerned markets are London and New York. To our knowledge, only Harmston (1988) studied the French case.

Inflation, one of the fundamental determinants of the gold price

The article of Lipschitz and Otani (1977), published by the International Monetary Fund (IMF), is considered as the first study dedicated to the *private market*[4] for gold where its price has been able to move freely since 1968. It is also the first study that sought to explain the determinants of the gold price when it was no longer regulated by the monetary rules of the Bretton Woods regime. With quarterly data from 1968 to 1974, the authors built econometric models explaining the supply and demand of gold. Among the mentioned factors, *inflation appeared to be a variable that had significant impact on the demand for speculation and hoarding of gold* (excluding industrial demand). In the model of the demand for gold, the estimated coefficient of the variable "inflation" was positive. This means that *an increase in inflation causes an increase in the demand for gold and so in the price of gold.*

Sherman (1983) also proposed a gold price model with annual data over the period from 1971 to 1982. Among the determinants of gold prices, there were two factors concerning inflation: the expected inflation (measured by the excess of liquidity in the money supply)

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[2] A more complete review of the literature is presented in section I.

[3] 1 ounce = 31,10348 grams.

[4] In March 1968, because of the international monetary system crisis, the IMF decided to create a private gold market where the gold price could move freely. In parallel, there was an official market between central banks where the gold price had to be fixed at $35 an ounce. This was the principle of the "double gold market".

and the unexpected inflation. The results showed that there was *a positive relationship between gold prices and these two variables.*

Koutsoyiannis (1983) built a multifactor model to study the fundamental factors affecting the evolution in the price of gold. His model was based on the equilibrium relationship between the supply and demand of gold. The data were daily and covered the period from January 1980 to March 1981. The author found that there was *a positive relationship between inflation and gold prices.*

Cai *et al*. (2001) studied the effect of macroeconomic announcements on the future price of gold in New York (Comex) from 1983 to 1997 with intraday data. The results showed that *the announcements about inflation in the US and Japan had significant impacts on the price of gold.*

Ghosh *et al.* (2002) used the cointegration test to investigate the relationship between the monthly gold prices and macroeconomic variables on the London market from 1976 to 1999. This model confirmed *the positive relationship between gold prices and inflation*. However, the authors emphasized that this was not the case for the period *from 1982 to 1995 where there was a divergence in the evolution in these two variables.*

Lawrence (2003) used quarterly data from 1975 to 2001 on the gold market in London. Through the correlation coefficients and the cointegration test, the author concluded that there was *no significant relationship between gold prices and inflation.*

Levin and Wright (2006) studied the price of gold in London over the period from 1968 to 2005 with monthly data. The results of the multifactor regression model indicated that there was *a positive relationship between gold prices and US inflation*. However, the authors found that there was *no significant relationship between gold prices and global inflation*. This can be explained by the fact that gold is priced in US dollars on the London market.

Lucey and Tully (2007) used the APGARCH model (Asymmetric Power GARCH) to examine the price of gold. On monthly data from 1984 to 2003, the authors found that there was *no significant relationship between gold prices and inflation*.

Faugere and Van Erlach (2008) studied the determinants of gold prices by the "Required Yield Theory" model that they proposed in 2003. This model was built on the assumption that gold functions only as a safe haven. The data used were quarterly and covered the period from 1979 to 2002. The authors found that there was a *positive relationship between gold prices and inflation.*

Artigas (2010) examined the impact of the money supply on the price of gold over the period from 2001 to 2009 with monthly data. The author used the spot price of the gold ounce traded in New York to build a multifactor linear model. The dependent variable was the gold price. The independent variables were the changes in the money supply (lagged to six months) in the United States, the eurozone, and India and Turkey. The results showed that there was *a positive relationship between the money supply and the price of gold.* This means that the rise in the money supply in the world (higher inflation) led to higher gold prices. The author also confirmed that the price of *gold could be used as an indicator of future inflation.*

Mani and Vuyyuri (2011) studied the fundamental determinants of the gold price in India in the periods 1978-1979 and 1999-2000. In this gold price model, the authors included the following independent variables: expected inflation, expected interest rates, foreign exchange rate, stock market performance, price of silver, lagged gold price and a dummy variable (equal to 1 when significant events affect gold prices and 0 for other years). The results showed that the *expected inflation coefficient was significant,* which was explained by the important contribution of inflation to the US dollar/Indian rupee exchange rate. Thus, when inflation in India rises, the exchange rate between the dollar and rupee increases, the gold demand increases, and thus the gold price rises.

The relationship between gold price and inflation

The articles presented in this section are not dedicated to studying the gold price determinants, but focus only on the relationship between gold price and inflation.

Jastram's book (1977) is regarded as the most comprehensive study on the relationship between gold prices and inflation. The author examined the annual change in gold prices in the UK from 1560 to 1976 and in the US from 1808 to 1976. As the name of the book, "*The Golden Constant*", implies, the author demonstrated the constancy of the real value of gold over the centuries. *In terms of gold, the price of bread or a brick was the same in 1560 as in 1960*. Jastram's results also showed that gold tended to lose its purchasing power during periods of inflation, and vice versa during periods of deflation. However, *the price of goods always came down to the same level in terms of gold* (Retrieval Phenomenon). In 2009, the book was reissued with two new chapters written by Leyland to extend the study until 2007. Leyland confirmed that *the purchasing power of gold continued to be maintained from 1977 to 2007 in the UK and the US.*

Feldstein (1983) studied the relationship between inflation and the price of gold using the model of portfolio equilibrium. In contrast to the traditional theoretical conclusion that relative prices are unaffected by the rate of inflation, Feldstein (1983) showed that, because of unindexed taxes on capital income, a higher expected rate of inflation raises the prices of land and gold relative to the general price level of produced goods. More generally, a change in the expected equilibrium rate of inflation alters the real net rate of interest, the stock market value of real capital, and the real net marginal product of investment. In an economy with capital income taxes, inflation is far from neutral. The author concluded that changes in expected inflation can have powerful effects on the relative prices of such investment assets.

Harmston (1998) took up the idea of Jastram (1977) and studied the changes in the annual purchasing power of gold in the US (from 1796 to 1997), the UK (from 1596 to 1997), France (from 1820 to 1997), Germany (from 1873 to 1997) and Japan (from 1880 to 1997). The results showed that *gold maintained its long-term purchasing power* in these countries, despite some periods of instability. Similarly, the purchasing power of gold increased after the end of the convertibility between gold and the US dollar in August 1971. However, gold tended to lose its purchasing power during periods of war or social and economic instability.

Brown (1987) studied the futures market for gold in New York (COMEX) for the period from 1975 to 1983 with monthly data. The author concluded that futures on *gold did not allow investors to hedge against inflation because their returns did not evolve with the same rhythm as inflation.*

Laurent (1994) examined the role of gold in the international monetary system after the collapse of the Bretton Woods regime in April 1978. Even when gold was no longer a currency, it still played an important role in the monetary system as *it could be used as an indicator of inflation because of its positive correlation with inflation*. However, Lawrence (1994) showed that *small changes in inflation were not always reflected in the price of gold*.

Garner (1995) argued that the price of *gold can be used as an indicator of inflation.* Despite its demonetization, it is always a store of value. When investors expect higher inflation in the future, the demand for gold (as a store of value) increases. Thus, the gold price increases. For this reason, an increase in the price of gold may be a sign of a future rise in inflation. Garner (1995) noted, however, that *this indicator is not always reliable* because there are also other factors in the demand for gold.

Mahdavi and Zhou (1997) compared gold with other commodities (traded in London) for their effectiveness as an indicator of future inflation. The data used were quarterly and covered the period from 1958 to 1994. Using the technique of cointegration, the authors found that *the price of goods was a better indicator of future inflation than gold*.

Adrangi *et al.* (2003) used the monthly prices of gold quoted in London over the period from 1968 to 1999. To investigate the relationship between gold prices and inflation, the authors also used the cointegration test. The results show that there is *a positive relationship between gold prices and inflation.*

Capie *et al*. (2005) investigated the role of gold in the hedge against the devaluation of the exchange rates between the US dollar and both the pound sterling and the Japanese yen. The authors used weekly data from January 1971 to February 2004. The methods used were cross-correlation coefficients, multivariate linear regression and the models of ARCH, GARCH and EGARCH. The results showed that there was *a negative relationship between the price of gold in the US dollar and its exchange rates with the pound sterling and the yen*. Thus, gold acted as a hedge against the devaluation of the dollar exchange rates. However, *this role was not stable over time*. It depended on unpredictable political attitudes and events.

Ranson (2005) compared the effectiveness of gold and the inflation-linked bonds, called TIPs (Treasury Inflation Protected Securities) in the hedge against inflation. Several results emerged from the empirical study. First, *the price of gold was a good indicator of future inflation*. Second, *gold was more effective in forecasting inflation than the consumer price index*. Third, *gold was more sensitive to inflation than TIPs bonds* (a 1% rise in inflation caused a rise of 8.8% in the gold returns and a decrease of 2.8% in the TIPs bonds). From these results, he concluded that *gold was a better hedge against inflation than the bonds indexed to inflation*. In addition, Ranson (2005) showed that *gold was a better indicator of inflation than oil* because it was more correlated with inflation than oil.

Pahlavan and Worthington (2006) examined the role of gold in the protection against inflation with monthly data from 1945 to 2006. The cointegration results showed that there was *a positive long-term relationship between gold prices and inflation*. The authors also concluded that investments in gold, both physical and paper, allowed investors to *protect themselves against inflation.*

McCown and Zimmerman (2006) also used cointegration tests to study the relationship between gold prices and inflation. The data included the price of gold in London (in US dollars) and the US consumer price index. The periodicity of the data was annual, quarterly and monthly and the studied period was from 1970 to 2003. The results showed that there was *a long-term relationship between gold prices and inflation.*

Dempster and Artigas (2009) used a monthly US database over the period from 1974 to 2008. The authors demonstrated that there was a *strong positive correlation between gold prices and inflation during periods of high inflation* (above 5% per year). They also found that real returns (net of inflation) of gold were higher than that of stocks, real estate and inflation-indexed bonds (TIPs). During periods of high inflation, gold was less volatile than the other three assets. The authors thus concluded that *gold was a good hedge against inflation.*

Blose (2010) studied the relationship between gold prices and expected inflation. The original point of this article was that the author took into account the impact of expected inflation on the carrying cost of gold. According to the author, there are two possibilities. First, expected inflation causes an immediate change in gold prices. Second, expected inflation has no impact on gold prices. The explanations of the latter possibility are as follows. The expected inflation causes a rise of the interest rate (considered as a risk-free asset). Then, the rise of the interest rate causes a rise in the carrying cost of gold investment. The rise in the carrying cost will cancel the speculative profit from investing in gold over the inflationary period (under the hypothesis that gold has a zero-beta in the CAPM model). Thus, the changes in the expected inflation have no impact on the price of gold. Using non-linear regression on American monthly data from March 1988 to February 2008, the author found that the second possibility was validated. This means that *expected inflation had no impact on gold prices*.

Joy (2011) studied the relationship between gold and the US dollar in a weekly database from January 1986 to August 2008. The data included gold prices from the London market and 16 US dollar exchange rates (expressed in terms of home currency per dollar). The author used the conditional correlation with the multivariate GARCH model to study the relationship between gold prices and exchange rates. The results showed that *the conditional correlation between changes in the price of gold and changes in the US dollar exchange rate was negative*. This means that increases in *the price of gold tended to be associated with decreases in the value of the US dollar*. However, *this relationship was not constant over time*.

Wang *et al.* (2011) compared the role of gold in the protection against inflation in the US and Japan with monthly data from January 1971 to January 2010. The authors studied the relationship between gold prices (in dollars and yen) and the consumer price index (in dollars and yen) in both the short-run and long-run. For the long-run relationship, the authors used cointegration tests (Engle and Granger 1987, and Enders and Siklos 2001). The advantage of the test of Enders and Siklos is that it allows verifying the non-linear cointegration relationship between two variables. For the short-run relationship, the authors tested the symmetric relationship between variables. If the short-run relationship is not linear and the long-run relationship is linear and stable (symmetric), the threshold vector error correction model is used to analyze the short-run adjustment process. If the long-run relationship is not linear and stable (asymmetric), the threshold cointegration-threshold vector error correction model is used. Finally, the causality test was used to analyze the relationship in the short-run between gold returns and inflation. The results showed that *gold was only partially effective in hedging against inflation in Japan in the long-run*. In the short-run, in the periods of low momentum regimes, *gold was unable to hedge against inflation*, in both the US and Japan. In contrast, in the periods of high momentum regimes, *gold was able to hedge against inflation in the US but not in Japan.*

In summary, the role of gold in the hedge against inflation was confirmed in most of the studies presented above. The studied periods were spread between 1968 and 2010. Most of the studies were about gold quoted in London and New York where the price is in the US dollar.

However, some studies showed that the relationship between gold and inflation was not stable over time and was not significant everywhere (not in Japan, for example). The role of gold in the hedge against inflation was not always guaranteed, especially during the very high-inflation periods (such as periods of war or crisis).

Are these conclusions valid for gold quoted in Paris from 1949 to 2011? In order to answer this question, we begin in the next section by giving details on the database and the econometric methods used in our empirical study. We also present a brief history of the gold market in Paris.

II. Data and methodology

The Paris gold market from 1949 to 2011: from regulated to over-the-counter

Not very much studied in the literature, the Paris gold market has an interesting history starting in February 1948 when an official market was opened in the Paris Stock Exchange[5]. Before this date, gold possession and trade were prohibited in France[6].

After 56 years of vicissitudes, the gold market in the Paris Stock Exchange was closed in July 2004 following the departure of the *Crédit du Nord* bank, one of the three last members of the market (with the *Compagnie Parisienne de Réescompte* and the company of *Cookson France*).

[5] Although the Paris gold market opened in 1948, our study period begins in December 1949 because the data for inflation are available only from this date.

[6] For more details, see De Litra (1950) and Hoang (2011).

With two remaining members, gold price fixing could no longer be maintained. Thus, Euronext Paris[7] announced the suspension of gold trade on August 2, 2004.

Despite this closing, gold trade is still free in France. However, gold is no longer traded on a regulated and official market but on an over-the-counter market where rules are determined freely by buyers and sellers. However, to ensure market liquidity, the *Compagnie Parisienne de Réescompte*[8] determines the equilibrium price every day by a fixing which takes place between 12.30 pm and 1 pm. The price thus determined is the reference for gold transactions in France. In addition, other prices can also be determined at any time of the day by any gold trading house based on the bid and ask price.

The gold assets traded in Paris are fine gold (12-kg bars or 1-kg ingots) and several gold coins. Among them, we find French coins (20 francs, 10 francs), English coins (sovereign, half sovereign), US coins ($20, $10, $5) and Tunisian coins (20 francs), etc. The best known and most popular coin is the French 20-franc which is usually called "Napoleon"[9].

Monthly French database from December 1949 to August 2011: prices of ingots and Napoleon coins and the consumer price index

At the beginning of our study, we did not find a comprehensive database on the gold market in the Paris Stock Exchange. We therefore had to look for information related to this market in newspapers, brochures and archives.

The first data source that we used is the *Cote Officielle* (Official Listing of the Paris Stock Exchange) from 1969 to 1989 which published the prices of gold assets quoted in the Paris Stock Exchange. From these brochures, we manually recorded the monthly prices of the principal gold assets such as the 1-kg ingots and the Napoleon coins. The ingot is chosen to represent the fine gold listed in Paris and the Napoleon coin is chosen for its high transaction volume in Paris[10].The first price on the last day of the month is considered the price of the month.

In searching for gold prices from 1948 to 1968, we found a second source which is the Archives of the Bank of France[11]. During two research stays in Paris (April-June 2007 and April-May 2009), several archival documents were consulted. The prices of gold were found in some handwritten records[12]. We then recorded them by hand for the period 1948 to 1968.

To complete the database over the period from 1990 to 2004, the task is easier because the data are available on the website of the *Compagnie Parisienne de Réescompte*[13] and the Bank of France[14]. On the former, there are daily prices of all gold assets since 1990. On the latter, there are prices of only ingots and Napoleon coins since 1999.

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[7] Euronext Paris is the new name of the Paris Stock Exchange after its merger with other European exchanges in 2000 (Amsterdam Stock Exchange, Brussels Stock Exchange) to form Euronext, a pan-European exchange. In 2002, the Lisbon Stock Exchange joined Euronext. In 2006, Euronext merged with the New York Stock Exchange and became NYSE Euronext.

[8] For more information, see its website, http://www.cpordevises.com

[9] The coins of 20 germinal francs were minted as of 1804 under the reign of Napoleon, hence their name. Its coinage was stopped in 1914. Between 1804 and 1914, several effigies were successively used (see De Litra 1950, page 22). One "Napoleon" coin weighs 6.4 grams with 5.8 grams of fine gold.

[10] See Hoang (2011) for more details.

[11] I would like to thank the members of the Archives of the Bank of France, and especially Mr. Frederick Grélard, for their help throughout my research stays in 2007 and 2009. I also thank the *Historical Mission* of the Bank of France for its confidence and encouragement by giving me a research grant for PhD Students in 2009.

[12] These handwritten records were archived under the General Directorate of Foreign Exchange Services (DGSC), in box n° 1495200501/278.

[13] http://www.cpordevises.com

[14] http://www.bdf.fr

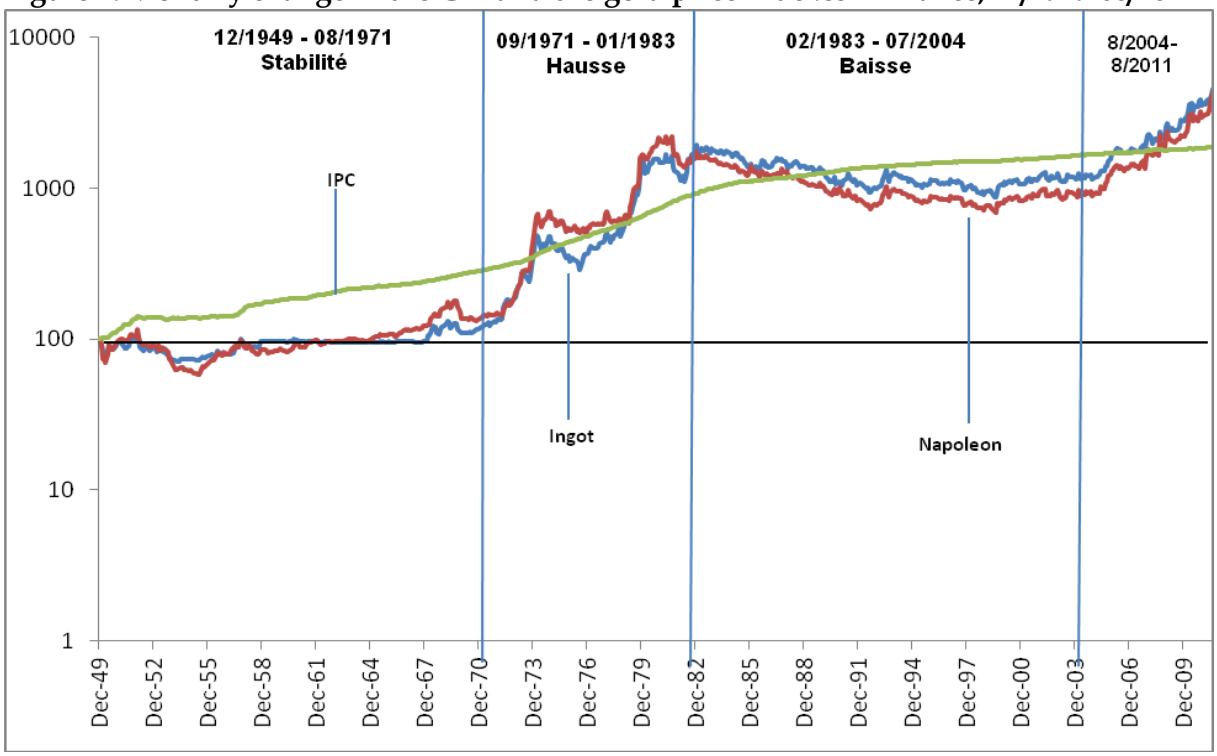
From 1948 to 1959, prices were expressed in francs. From 1960 to 1998, they were in new francs (1 new franc = 100 old francs). From 1999 to 2011, they are in euros (1 euro = 6.55957 new francs). Because the trading period in new francs is the longest (39 of 62 years), new francs are the reference currency. The conversion is calculated using the above rates.

For the consumer price index (CPI), we use the index published by Insee (the French National Institute of Statistics and Economic Studies). The base of 100 was set in December 1949. Thereafter, the index was rebased on 100 twice, in December 1990 and December 1998. Thus, in our study, a recalculation was made to obtain a single common index with the base of 100 established in December 1949 (see Appendix for more details). For the period from 1949 to 1990, the data are taken from the study of Gallais-Hamonno and Arbulu (1995). From 1990, the data are available on the Insee website[15].

In order to have a comparison between the price of gold and the CPI, we transform the price of gold into an index with the base of 100 from December 1949 (see Appendix for more details).

The following figure shows the parallel evolution of the gold price indexes and the CPI in France from December 1949 to August 2011.

Figure 1: Monthly change in the CPI and the gold price indexes in France, 12/1949-08/2011



The analysis of the gold price changes shows that we can divide the total period into four sub-periods[16].

- Sub-period 1 (SP1) from February 1948 to August 1971 is characterized by the stability of gold prices because of the fixed exchange rate regime of Bretton Woods.
- Sub-period 2 (SP2) from September 1971 to January 1983 is characterized by the strong rise in gold prices because of its demonetization, first by the end of the parity "1 ounce = $35" in August 1971 and then, by the official end of Bretton Woods in April 1978. The rising price of

[15] http://www.indices.insee.fr

[16] This division of sub-periods was confirmed by significant differences in statistical measures (mean, variance and distribution law) between the sub-periods. For more details, see Hoang (2010).

gold during this period was also due to the two oil shocks in 1973 and 1979.
- Sub-period 3 (SP3) from February 1983 to July 2004 is the period during which the price of gold decreased continuously. This decrease can be explained by the continued increase in the tax rate on gold sales, the end of anonymity in gold transactions in 1981, and the growing attractiveness of the investments in stocks and bonds.
- Sub-period 4 (SP4) from August 2004 to August 2011, after the closing of the gold market in the Paris Stock Exchange, is the period during which the price of gold showed significant increases following the rise in oil prices in 2005, the financial crisis beginning in July 2007, and the European public debt crisis[17] starting in December 2009. The price of an ounce reached the $1,800 threshold for the first time in August 2011.

To test the role of gold as a hedge against inflation, we use both the total period from 1949 to 2011 and the four sub-periods. The objective is to take into account the changes in the gold price over time. In this way, we can test the evolution of the role of gold in the hedge against inflation.

Methodology: correlation coefficients, linear regression and cointegration tests

Gold can be considered as an instrument to hedge against inflation if *its price moves in the same direction as inflation*. Usually, inflation is measured by the variation of the consumer price index (CPI). Therefore, to be a protection against inflation, the gold price has to be positively correlated with the CPI. Moreover, this relation must also be stable in time. This reasoning means that we have to test both the short-run relationship (positive correlation) and the long-run relationship between the gold price and the CPI. The methods that we use are as follows:

1. To test the short-run relationship between the gold price and the CPI, we use two measures. The first is the Pearson and Spearman correlation coefficients. The second is the linear regression between gold returns and inflation.
2. To test the long-run relationship between the gold price and the CPI, we use the cointegration concept. If two variables are cointegrated, there is a significant long-term relationship between them. The tests that we use are those of Engle and Granger (1987) and Phillips and Ouliaris (1989).

The details of each method are presented in the next section, which is devoted to the analysis of the results.

III. Is gold a good hedge against inflation in France from 1949 to 2011?

The short-run relationship between gold prices and the consumer price index (CPI) in France from 1949 to 2011

The Pearson and Spearman correlation coefficients between the logarithmic returns of gold and inflation were calculated. Table 1 presents the results of the total period (from 1949 to 2011) and the sub-periods defined in the previous section.

The results are unequivocal: there is no correlation between the gold returns and inflation in France over the period from 1949 to 2011. The correlation coefficients are very low and not significantly different from 0, except the case of ingots over the total period from 1949 to 2011 (Pearson coefficient equals 0.07 and significant at 10%).

The linear regression confirms these results (see Table 2). The gold return series is the dependent variable and inflation is the independent variable. The results show that the

[17] On December 8, 2009, the Fitch Rating degraded the Greek debt rating from A-to BBB+.

estimated beta coefficients are not significant (except the case of ingots over the total period). Moreover, the R^2 coefficients are very low (close to zero). This means that the evolution of inflation does not explain gold returns.

Table 1: The correlation between gold returns and inflation in France from 1949 to 2011

Total period: 12/1949-08/2011 (740 observations)							
Pearson coefficients				*Spearman coefficienrs*			
	Ingot	Napoleon	Inflation		Ingot	Napoleon	Inflation
Ingot	1	0.78***	***0.07****	Ingot	1	0.75***	*0.05*
Napoleon	0.78***	1	*0.04*	Napoleon	0.75***	1	*0.05*
Inflation	***0.07****	*0.04*	1	Inflation	*0.05*	*0.05*	1
Sub-period 1: 12/1949-08/1971 (260 observations)							
	Ingot	Napoleon	Inflation		Ingot	Napoleon	Inflation
Ingot	1	0.77**	*0.08*	Ingot	1	0.69***	*0.07*
Napoleon	0.77***	1	*0.04*	Napoleon	0.69***	1	*0.03*
Inflation	*0.08*	*0.04*	1	Inflation	*0.07*	*0.03*	1
Sub-period 2: 09/1971-01/1983 (137 observations)							
	Ingot	Napoleon	Inflation		Ingot	Napoleon	Inflation
Ingot	1	0.73***	*-0.02*	Ingot	1	0.73***	*-0.11*
Napoleon	0.73***	1	*0.02*	Napoleon	0.73***	1	*-0.02*
Inflation	*-0.02*	*0.02*	1	Inflation	*-0.11*	*-0.02*	1
Sub-period 3: 02/1983-07/2004 (258 observations)							
	Ingot	Napoleon	Inflation		Ingot	Napoleon	Inflation
Ingot	1	0.75***	*-0.00024*	Ingot	1	0.77***	*0.01*
Napoleon	0.75***	1	*-0.06*	Napoleon	0.77***	1	*-0.06*
Inflation	*-0.00024*	*-0.06*	1	Inflation	*0.01*	*-0.06*	1
Sub-period 4: 08/2004-08/2011 (85 observations)							
	Ingot	Napoleon	Inflation		Ingot	Napoleon	Inflation
Ingot	1	0.87***	*-0.04*	Ingot	1	0.86***	*-0.01*
Napoleon	0.87***	1	*-0.06*	Napoleon	0.86***	1	*-0.01*
Inflation	*-0.04*	*-0.06*	1	Inflation	*-0.01*	*-0.01*	1

Note: The asterisks mean the significance level of the correlation coefficients. ***: The correlation coefficient is significantly different from 0 at 1%, **: 5% and *: 10%

These results show clearly that there is no significant correlation between the price of gold and the CPI in France from 1949 to 2011. This means that there is no short-run relationship between the gold price and inflation. This suggests that gold is not a hedge against inflation.

The long-run relationship between gold prices and the consumer price index in France from 1949 to 2011

To study the long-run relationship between gold prices and the CPI, we use the concept of cointegration introduced by Granger (1983) and developed by Engle and Granger (1987).

Two variables are cointegrated if they are integrated[18] of the same order and there is a linear combination between them which is integrated of one order lower. In most cases, we study the cointegration of variables which are integrated of order 1 (unit root).

To test the cointegration between the price of gold and the CPI, we follow two steps (see Appendix for more details).

[18] A variable x_t is integrated of order d if we need to calculate the differences of order d to obtain a stationary series.

Step 1: testing whether these two variables follow a unit root (integrated of order 1)

For this, we use the tests of Augmented Dickey-Fuller (1979, 1981) and Phillips and Perron (1988). If the results indicate that the two variables follow a unit root, we go to step 2.

Step 2: testing whether the linear combination of these two variables is stationary (integrated of order 0).

For this, we use the Engle-Granger test (1987) and the Phillips-Ouliaris test (1990) (see Appendix for more details).

The results are shown in Table 3 below.

Table 2: Simple linear regressions between the returns of gold assets and inflation in France from 1949 to 2011

Total period: 12/1949-12/2011 (740 observations)		
Gold assets	**Beta**	**R^2**
Ingot	*0.61**	0.0051
Napoleon	0.41	0.002
Sub-period 1: 12/1949-08/1971 (260 observations)		
Gold assets	**Beta**	**R^2**
Ingot	0.35	0.0074
Napoleon	0.19	0.0016
Sub-period 2: 09/1971-01/1983 (137 observations)		
Gold assets	**Beta**	**R^2**
Ingot	-0.35	0.0002
Napoleon	0.48	0.004
Sub-period 3: 02/1983-07/2004 (258 observations)		
Gold assets	**Beta**	**R^2**
Ingot	0.003	0
Napoleon	-0.86	0.0041
Sub-period 4: 08/2004-08/2011 (85 observations)		
Gold assets	**Beta**	**R^2**
Ingot	-0.67	0.0016
Napoleon	-1.17	0.003

Note: *: The coefficient is significantly different from 0 at 10%.

There are three parts in Table 3. The first part presents the results of the unit root tests (Augmented Dickey-Fuller and Phillips-Perron). In all cases, gold prices and the CPI follow a unit root with the model including a constant and a time trend (model 3). This allows us to perform the tests of cointegration between gold prices and the CPI.

The results of the cointegration tests of Engle and Granger (1987) and Phillips and Ouliaris (1990) are presented in the last two parts of the table. According to the Engle and Granger (1987) test, *the null hypothesis (no cointegration) is accepted in the total period and the last three sub-periods*. According to the Phillips and Ouliaris (1990) test, there is no cointegration relationship between gold prices and the CPI in any case. This means that *there is no long-run relationship between gold prices and the CPI.*

Table 3: Cointegration between gold prices and the CPI in France from 1949 to 2011

Integration tests **Unit root tests**				***Cointegration test (1)*** **EG (1987) by ADF**			***Cointegration test (2)*** **Phillips-Ouliaris (1990)**		
Total period: 12/1949-08/2011 (740 observations)				*Total period: 12/1949-12/2011 (740 observations)*			*Total period: 12/1949-08/2011 (740 observations)*		
	Ingot	Napoleon	CPI		Ingot	Napoleon		Ingot	Napoleon
ADF	yes	yes	yes	Tstat	-0.03	-0.91	$\hat{Z}_\rho$	10.77	10.06
PP	yes	yes	yes	5% CV	-1.94	-1.94	5% CV	-27.09	-27.09
Model	3	3	3	Model	1	1	Answer	no	no
Sub-period 1: 12/1949-08/1971 (261 observations)				*Sub-period 1: 12/1949-08/1971 (261 observations)*			*Sub-period 1: 12/1949-08/1971 (261 observations)*		
	Ingot	Napoleon	CPI		Ingot	Napoleon		Ingot	Napoleon
ADF	yes	yes	yes	Tstat	**-2.7****	**-2.72****	$\hat{Z}_\rho$	-23.79	-12.32
PP	yes	yes	yes	5% CV	-1.94	-1.94	5% CV	-26.34	-26.34
Model	3	3	3	Model	1	1	Answer	no	no
Sub-period 2: 09/1971-01/ 1983 (137 observations)				*Sub-period 2: 09/1971-01/ 1983 (137 observations)*			*Sub-period 2: 09/1971-01/ 1983 (137 observations)*		
	Ingot	Napoleon	IPC		Ingot	Napoleon		Ingot	Napoleon
ADF	yes	yes	yes	Tstat	-0.48	-1.46	$\hat{Z}_\rho$	-8.7	-6.43
PP	yes	yes	yes	5% CV	-3.41	-1.94	5% CV	-26	-26
Model	3	3	3	Model	3	1	Answer	no	no
Sub-period 3: 02/1983-07/2004 (258 observations)				*Sub-period 3: 02/1983-07/2004 (258 observations)*			*Sub-period 3: 02/1983-07/2004 (258 observations)*		
	Ingot	Napoleon	IPC		Ingot	Napoleon		Ingot	Napoleon
ADF	yes	yes	yes	Tstat	-2.21	-1.55	$\hat{Z}_\rho$	-12.75	-7.87
PP	yes	yes	yes	5% CV	-3.41	-3.41	5% CV	-26.34	-26.34
Model	2	2	3	Model	3	3	Answer	no	no
Sub-period 4: 08/2004-08/2011 (85 observations)				*Sub-period 4: 08/2004-08/2011 (85 observations)*			*Sub-period 4: 08/2004-08/2011 (85 observations)*		
	Ingot	Napoleon	IPC		Ingot	Napoleon		Ingot	Napoleon
ADF	yes	yes	yes	Tstat	-0.09	-1.06	$\hat{Z}_\rho$	-6.87	-6.87
PP	yes	yes	yes	5% CV	-3.41	-1.94	5% CV	-23.3	-23.3
Model	3	3	3	Model	3	1	Answer	no	no

Note: *For unit root tests*: ADF means Augmeted Dickey-Fuller, PP means Phillips-Perron, yes means that the unit root hypothesis is accepted, model 3 means the model with constant and trend. *For the cointegration EG (1987) test*: EG means Engle and Granger, Tstat means the test statistic under the null hypothesis (no cointegration), CV means critical value of MacKinnon (1990), model 1 means the model without constant. ** means that the null hypothesis (no cointegration) is rejected at 5%.

For the cointegration Phillips-Ouliaris (1990) test: $\hat{Z}_\rho$ (Rho in the SAS software) means the test statistic under the null hypothesis (no cointegration), CV means critical value calculated by Haug (1992), no means no cointegration relationship between the two variables.

Decision rules for the cointegration tests of Engle-Granger and Phillips- Ouliaris: when the value of the test statistic exceeds the critical value, the null hypothesis (no cointegration) is accepted.

Conclusion

Unlike gold listed in London or New York (see Section I), gold listed in Paris does not allow French investors to hedge against inflation because there is no systematic relation, either short-run or long-run, between the price of gold listed in Paris and the French CPI.

This study showed that the image of gold as a hedge against inflation is not justified in France. Contrarily to what we believe, gold is not a store of value in France. It can be a safe haven because its value increases in times of crisis[19]. It can also be used as a hoarding vehicle because it is very liquid and can be resold at anytime[20]. However, it is not a store of value in France. The results of this study show that there is no significant relationship, in short-run and long-run, between the gold price and inflation in France. This makes the purchasing power of gold decreases over time (See Hoang 2010).

The contradiction between gold listed in Paris and gold listed in London or New York can be explained by the fact that the currency is different: the franc (or euro) in Paris and the US dollar in London and New York. The US dollar was equivalent to gold during the Bretton Woods era (1944-1978) with the parity: 1 ounce = $35. Thus, it still has a strong link with gold price and is even one of its fundamental determinant factors (see Section I). Therefore, the inflation of the US dollar has direct impacts on gold prices in so far as they are expressed in US dollars. Also, when the value of the US dollar is devalued (equivalent to inflation), people lose confidence in this money and turn to gold which is considered as a safe haven. So, when inflation increases in the US, the gold price increases. For these reasons, gold listed in London and New York allows investors to hedge against US inflation. This is not the case of gold listed in Paris.

Appendix

Appendix 1: Calculation of the gold price index

Base date: December 1949

Base value: 100 points

P_{base} : Price of gold on the base date (December 1949 here)

P_t : Price of gold on any date t

PI_t : Price index on date t (to be calculated)

To obtain the gold price index, we have to calculate PI_t as follows:

$$PI_t = \frac{P_t}{P_{base}} * 100$$

Appendix 2: Index refixing calculation

The CPI was refixed twice on the base of 100 (in December 1990 and December 1998). So, in order to correspond to the gold price index (with the base 100 from December 1949), we need to refix the CPI to have the same base of 100 from December 1949. The calculations are explained below.

We will use the date of December 1998 as an example. The calculations for the date of December 1990 follow exactly the same principles.

The new base of the CPI is 100 in *December 1998*. The value of the CPI following the old base (100 in December 1949) is 1502.04. The value of the CPI following the new base in January 1999 is 99.7. So, the value of the CPI in January 1999 following the old base (100 in December 1949) is calculated as follows:

$$CPI_{01/1999} = \frac{1502.04}{100} * 99.7 = 1497.54$$

For the other months, after January 1999, the principle of the calculation stays the same.

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[19] In this way, gold can be used for portfolio diversification because it is negatively correlated with stocks (See Hoang 2011).

[20] The central bank gold reserves are the proof that hold is hoarded (*cf.* Hoang 2010).

$$CPI_{t/1949} = \frac{1502.04}{100} * CPI_{t/1998}$$

With $CPI_{t/1949}$ the value of the CPI following the base of 100 from December 1949.

$CPI_{t/1998}$ the value of the CPI following the base of 100 from December 1998.

Appendix 3: Correlation coefficients

Pearson coefficients

Consider two variables X and Y between which we want to test the correlation. We have two samples x_t and y_t, with $t = 1...T$. The Pearson correlation coefficient between these two variables, called $r_{x,y}$, is calculated as follows:

$$r_{x,y} = \frac{\sum_{t=1}^{T}(x_t - \bar{x})(y_t - \bar{y})}{\sqrt{\sum_{t=1}^{T}(x_t - \bar{x})^2 \sum_{t=1}^{T}(y_t - \bar{y})^2}}$$

With $\bar{x} = \frac{1}{T}\sum_{t=1}^{T} x_t$ the arithmetic average of x and $\bar{y} = \frac{1}{T}\sum_{t=1}^{T} y_t$ the arithmetic average of y.

In order the test the significance of $r_{x,y}$, we verify the following hypotheses:

H0 : $\rho_{xy} = 0$

H1 : $\rho_{xy} \neq 0$

With ρ_{xy} the estimation of the correlation coefficient between two variables $\underline{X}$ and $\underline{Y}$ (not the samples x_t and y_t).

Under the null hypothesis H0, the test statistic is as follows:

$$t_{stat} = \frac{r_{xy}\sqrt{T-2}}{\sqrt{1-r_{xy}^2}} \xrightarrow{L} t(T-2)$$

With $(T-2)$ the degrees of freedom of the Student t-test.

The decision rules are like other two-tailed *Student* tests.

Spearman rank correlation coefficients

The rank correlation coefficient of Spearman is not calculated directly on the values of each variable but on the ranks associated with these values. Therefore, we have to associate each value of the variable with a rank i ($i = 1...n$) following a descending order.

Thus, instead of calculating the correlation between the values of x_t and y_t themselves, we calculate the correlation between two series of ranks $R_i(x)$ and $R_i(y)$, with $R_i(x)$ the rank i of x, and $R_i(y)$ the rank i of y. If the two variables are correlated perfectly, we have the same ranking on X and on Y : $\{R_1(x), R_2(x),..., R_n(x)\} = \{R_1(y), R_2(y),..., R_n(y)\}$. In this case, the correlation coefficients of ranks, calculated below, should equal to 1.

$$r_S = \frac{\sum_{i=1}^{n}(R_i(x) - m) \times (R_i(y) - m)}{\sqrt{\sum_{i=1}^{n}(R_i(x) - m)^2 \times (R_i(y) - m)^2}}$$

With r_s the rank correlation coefficient of Spearman; $m = \frac{1}{n}\sum_{i=1}^{n} i$ the average of ranks.

Thus, to test the correlation between X and Y, we test the following hypotheses:

H0 : $\hat{r}_s = 0$

H1 : $\hat{r}_s \neq 0$

With $\hat{r}_s$ the estimation of the Spearman correlation coefficient between two variables $\underline{X}$ and $\underline{Y}$ (not the samples x_t and y_t).

Under the null hypothesis, the test statistic is calculated like in the Pearson correlation coefficients:

$$t_{stat} = \frac{r_s\sqrt{n-2}}{\sqrt{1-r_s^2}} \xrightarrow{L} t(n-2)$$

With $(T-2)$ the degrees of freedom of the Student t-test.

Appendix 3: Linear regression

We call the CPI x_t, and the gold price index y_t. The linear regression between these two variables is as follows:

$$y_t = \alpha + \beta x_t + \varepsilon_t$$

With y_t the dependent variable, x_t the independent variable, α and β constant and ε_t the theoretical error associated with the dependent variable (ε_t takes into account other variables than x_t which also have influences on the dependent variable y_t).

If β is significantly positive, we can conclude that there is a positive relationship between gold prices and the CPI.

Another measure that we use is the coefficient of determination R^2 whose value is between 0% and 100%. This tells us how well the dependent variable y_t is explained by the independent variable x_t. The higher the value of R^2, the better it is. If R^2 is equal to 0%, the variables x_t and y_t are not explained linearly by x_t at all. If R^2 is equal to 100%, the variable y_t is explained linearly by x_t perfectly.

The estimation of this model is performed by the SAS software (procedure *proc reg*).

Appendix 4: Unit root tests

A time series is stationary if the probability distribution is stable over time. In practice, this condition is very difficult to obtain. Thus, stationarity usually means weak or order 2 stationarity and concerns only the stability of the first two moments of the distribution in time: mean and variance.

A time series has a unit root (or integrated of order 1, I(1)) if it becomes stationary after being differentiated one time. This means that P_t is not stationary but $(P_t - P_{t-1})$.

To test for a unit root, Dickey-Fuller (DF, 1979) and Augmented Dickey-Fuller (ADF, 1981) tests are used. In 1988, Phillips and Perron proposed a new test which corrects some of the weaknesses of the ADF test. The details of these tests are presented below.

Augmented Dickey Fuller (ADF, 1981)

The price series P_t follows the auto-regression of order 1, AR(1).

$$P_t = \phi P_{t-1} + \varepsilon_t \qquad (1)$$

With ε_t a white noise.

The stationarity of P_t depends on the value of ϕ. If $\phi < 1$, the series is stationary: it has a permanent tendency to return to the average and constantly cross it. If $\phi = 1$, the series has a unit root or is integrated of order 1: it follows a random walk. If $\phi > 1$, the series is explosive. It never returns to the average.

Thus, the objective of the DF test is to verify whether ϕ equals 1. For that, Dickey and Fuller (1979) proposed the following equation.

$$P_t = \phi P_{t-1} + \varepsilon_t$$
$$\Leftrightarrow P_t - P_{t-1} = \phi P_t - P_{t-1} + \varepsilon_t$$
$$\Leftrightarrow P_t - P_{t-1} = (\phi - 1) P_{t-1} + \varepsilon_t$$
$$\Leftrightarrow \Delta P_t = b P_{t-1} + \varepsilon_t \qquad (2)$$

With $b = \phi - 1$

The test of $\phi = 1$ is equivalent to the test of the following hypotheses:

$$\begin{cases} H_0 : b = 0 \\ H_1 : b < 0 \end{cases}$$

These hypotheses are equivalent to:
H0: no stationarity (unit root)
H1: stationarity

If H_0 is accepted, this means $b = 0$ (equivalent to $\phi = 1$), so the series has a unit root (integrated of order 1) and thus is not stationary. If we reject H_0, or if H_1 is accepted, it means $\phi < 1$, so P_t is stationary in the weak sense.

In most of the financial series, ε_t is not a white noise. Thus, the residuals of the equation (2) are autocorrelated. Dickey and Fuller (1981) thus proposed a parametric solution which consists in adding the lagged values of the independent variable ΔP_t on the right side of equation (2). We need a number of lags so that the residuals ε_t become a white noise. The equations of the ADF test are as follows:

$$\Delta P_t = b P_{t-1} + \sum_{i=1}^{q} \phi_i \Delta P_{t-i} + \varepsilon_t \qquad (6)$$

In the ADF equations, there are three possibilities: 1- Equation without constant, 2- With constant, 3- With constant and a time trend[21] t.

1-Without constant: $\Delta P_t = b P_{t-1} + \varepsilon_t$ $\qquad \Delta P_t = b P_{t-1} + \sum_{i=1}^{q} \phi_i \Delta P_{t-i} + \varepsilon_t$

2-With constant: $\Delta P_t = \alpha + b P_{t-1} + \varepsilon_t$ $\qquad \Delta P_t = \alpha + b P_{t-1} + \sum_{i=1}^{q} \phi_i \Delta P_{t-i} + \varepsilon_t$

3-Constant+Trend: $\Delta P_t = \alpha + \beta * t + b P_{t-1} + \varepsilon_t$ $\qquad \Delta P_t = \alpha + \beta * t + b P_{t-1} + \sum_{i=1}^{q} \phi_i \Delta P_{t-i} + \varepsilon_t$

The number of lags q is determined by the autocorrelation order of ε_t.

[21] When these terms are added, the principles of the test stay the same.

Once q is determined, we have to determine the best model (without constant, with constant or with constant and trend). To do this, we apply the following rules. We begin by the most complete model, model 3 with constant and trend. We then verify the significance of the trend by the coefficient β. If the coefficient is not significant, then model 3 is not the good one. We try then model 2, with constant. We test the significance of the constant α. If it is not significant, then model 2 is not the good one and therefore model 1 is good.

The value of q is determined and the ADF test is performed by the RATs software. The program of the test is available from the author.

Phillips and Perron's test (PP, 1988)

In 1988, Phillips and Perron proposed a new unit root test based on the models of Dickey and Fuller (1979, 1981). Their objective was to correct the shortcomings the ADF test in order to cancel the effect of the heteroscedasticity of the residuals ε_t. To do this, Phillips and Perron used nonparametric tests, without adding any lag to the original equations. The principles of this test are:

- Estimate, by the Ordinary Least Squares method, the three initial models proposed by Dickey and Fuller (1979).
- Estimate the variance of the residuals: $\hat{\sigma}_{\varepsilon}^2 = \frac{1}{T-1}\sum_{t=1}^{T}(\varepsilon_t - \bar{\varepsilon}_t)^2$
- Then, instead of directly using the variance of the residuals in the test statistic, Phillips and Perron (1988) estimated a correction factor s_t^2 from the structure of the covariance of the residuals of the three models:

$$s_t^2 = \frac{1}{T}\sum_{t=1}^{T}\varepsilon_t^2 + 2\sum_{i=1}^{l}\left(1-\frac{i}{l+1}\right)\frac{1}{T}\sum_{t=i+1}^{T}\varepsilon_t\varepsilon_{t-i}.$$

Thus, there is a new value l which is called the Newey-West truncation estimated in function of the number of observations, $l \approx 4(T/100)^{2/9}$.

So, we see that the covariance of the residuals is taken into account in the correction factor s_t^2.

- Calculate the test statistic:

$$t_{stat}(PP) = \frac{\hat{\phi}-1}{\hat{\sigma}_{\hat{\phi}}} + \frac{T(k-1)\hat{\sigma}_{\hat{\phi}}}{\sqrt{k}}$$

With $\hat{\phi}$ the estimator of the coefficient of P_{t-1} in the initial equations of Dickey and Fuller, T the total number of observations, $\hat{\sigma}_{\hat{\phi}}$ the estimator of the standard deviation of $\hat{\phi}$ and $k = \frac{s_t^2}{\hat{\sigma}_{\varepsilon}^2}$.

The decision rules and the strategy of the test stay the same as the DF test. The critical values are calculated by MacKinnon as for the DF test.

This test is performed by the SAS software (the *proc autoreg* procedure).

Appendix 5: Cointegration tests

Two variables are cointegrated if they are integrated of the same order[22] and if their linear combination is integrated of one order lower. In order to simplify, we present here only the case of two series which are integrated of order 1. The two conditions of cointegration cited above become: $x_t \to I(1)$, $y_t \to I(1)$ and $z_t = \alpha x_t + \beta y_t \to I(0)$, where $I(1)$ and I(0) mean integration of order 1 (unit root) and order 0 (stationarity), z_t is the linear combination between x_t and y_t and (α, β) is the cointegration vector.

So, in order to do the cointegration test, we have to test the unit root hypothesis of each variable. For that, we use the ADF test (1979, 1981) and the PP test (1988). The cointegration test can be done only if the unit root hypothesis is validated. The details of the unit root tests are presented in Appendix 4.

To test the cointegration relationship between two variables, Engle and Granger (1987) proposed two steps:

Step 1: test the unit root hypothesis of the variables (integration of order 1, $I(1)$) by the ADF test and the PP test.

Step 2: test the stationarity of the linear combination $(\alpha x_t + \beta y_t)$ (integration of order 0, $I(0)$).

For this, the principle is as follows. First, we normalize the coefficients of the cointegration vector (α, β) in order to obtain a new vector $\left(\frac{\alpha}{\beta}, 1\right)$. The objective is to obtain the following linear combination: $(bx_t + y_t)$, with $b = \frac{\alpha}{\beta}$. Thus, to test the stationarity of the initial linear combination, we use the following linear regression:

$$\hat{y}_t = \hat{a} + \hat{b}x_t + \hat{\varepsilon}_t$$

$$\to \hat{\varepsilon}_t = y_t + (-\hat{b}x_t) - \hat{a}$$

With $\hat{a}$ and $\hat{b}$ the estimators of the constants a and b, and $\hat{\varepsilon}_t$ the estimated residuals.

Therefore, testing the stationarity of the initial linear combination becomes testing the stationarity of the residuals $\hat{\varepsilon}_t$. If these latter are stationary, or integrated of order 0, the variables x_t and y_t are cointegrated. They thus converge in the long-term. If the residuals are not stationary, the variables x_t and y_t are not cointegrated and they do not have any long-term relationship.

Following these general principles, we use two tests.

Test of Engle and Granger (1987)

To test the stationarity of ε_t, Engle and Granger (1987) used the ADF test. However, we cannot use the same critical values because we test the stationarity of the residuals and not of the "true" variables. MacKinnon (1991)[23] thus simulated new critical value tables for the Engle and Grander cointegration test.

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[22] The variable x_t is integrated of order d if we have to calculate differences of order d to obtain a stationary series.

[23] A new version of this article was published in 2010, see References.

Test of Phillips and Ouliaris (1990)

To test the stationarity of ε_t, Phillips and Ouliaris (1990) followed the same principle as Phillips and Perron (1988). These latter corrected the bias of heteroscedasticity of the residuals. Phillips and Ouliaris (1990) assumed that the residuals ε_t take the following form:

$$\hat{\varepsilon}_t = \rho\hat{\varepsilon}_{t-1} + \hat{\mu}_t$$

With $\hat{\mu}_t$ the residuals of the equation of $\hat{\varepsilon}_t$.

Thus, the objective is to test the null hypothesis $\rho = 1$ (this means that $\hat{\varepsilon}_t$ are not stationary and so there is no cointegration). As for the test of Phillips-Perron (1988), to eliminate the impact of the heteroscedasticity of the residuals, Phillips and Ouliaris (1990) built a nonparametric statistic of the test, $\hat{Z}_\rho$, as follows:

$$\hat{Z}_\rho = T(\hat{\rho} - 1) - (1/2)\left(s_{Tl}^2 - s_\mu^2 \left(T^{-2} \sum_{t=2}^{T} \varepsilon_{t-1}^2 \right)^{-1} \right)$$

With T the size of the sample; s_μ^2 the variance of $\hat{\mu}_t$ where $s_\mu^2 = \frac{1}{T}\sum_{t=1}^{T} \hat{\mu}_t^2$; and s_{Tl}^2 the correction factor which takes into account the autocorrelation of μ_t.

$$s_{Tl}^2 = T^{-1}\sum_{t=1}^{T} \hat{\mu}_t^2 + 2T^{-1}\sum_{s=1}^{l} w_{sl} \sum_{t=s+1}^{T} \hat{\mu}_t \hat{\mu}_{t-s}$$

With $w_{sl} = 1 - \frac{s}{(l+1)^4}$, l the Newey-West truncation which indicates the number of autocorrelations to add. It is estimated in function of the number of observations T, $l \approx 4(T/100)^{2/9}$.

In their article of 1990, Phillips and Ouliaris calculated the critical values for $\hat{Z}_\rho$ for a sample of 500 observations and in three possible equations of ε_t (without constant, with constant, with constant and trend). In 1992, Haug calculated the critical values of $\hat{Z}_\rho$ for several sample sizes (50, 100, 150 and 250). The null hypothesis, equivalent to no cointegration, is rejected if the test statistic is lower than the critical value.

To calculate the test statistic $\hat{Z}_\rho$, we use the SAS software with the *proc autoreg* procedure.

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