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Evaluating the Timeless Appeal: Gold and Silver as Inflation Hedges

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Abstract

Gold and Silver were in the forefront of monetary policy for a significant part of human history and are now regarded as financial assets with inflation-hedging properties. This thesis seeks to evaluate whether this belief is true in the long-run, by examining their prices during 1792–2022 in the US and the UK, against expected and headline inflation. First, an analysis of inflation-adjusted prices finds that gold has retained and slightly increased its purchasing power. The same is not true for silver which has relied on sporadic peaks and high-momentum markets. Also, other options might be better since both metals are volatile. Second, a VECM is employed, finding that gold is cointegrated with inflation and has been a superior hedge against it, better so for the US and slightly better against expected inflation. Silver is also a hedge, though less consistent and only against expected inflation.

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Declaration

I, Stefanos-Marinos Amanatidis, hereby affirm that this thesis has been written exclusively by me and the content presented is entirely of my own original work. Any parts or ideas that draw on other authors' work, as well as all external sources used, are appropriately cited and listed in the bibliography. I am fully aware that failure to do so, whether intentional or not, is considered plagiarism and may lead to disciplinary action based on my institution's guidlines and policies.

Chapter 1

Introduction

In the complex landscape of modern financial systems, the pursuit of wealth-protection is still at center stage. The most persistent challenge to combat, is the erosive effect of inflation, which reduces the real value of an asset and introduces a new layer of uncertainty. It is reasonable then, that individuals seek the most effective and, ideally, straightforward strategies to protect their financial position. Among common inflation-hedging strategies, gold stands out as a favored choice due to the fact that its intrinsic value is easy to understand, while also being durable, universally acceptable, relatively transportable and easily authenticated (Worthington and Pahlavani, 2007). Another precious metal that shares most of these qualities is silver, which has a long history to support its position as a store of value but is of seemingly lesser importance than its counterpart. The exact reason that such commodities are regarded as inflation-hedges is not clear, though they are commonly perceived as having the ability to reflect future prices faster (Mahdavi and Zhou, 1997).

A question that arises, is how both metals' prices are determined, and for the most part of human history the answer would be by the government, either by assigning a certain weight to the currency or by law of legal tender. The same is true for a considerable share of this thesis' time-period; many countries were in some sort of commodity-based monetary regime long before the 18th century. In contemporary paper-fiat dominated economies, however, precious metals derive most of their value from financial markets, constantly swayed by forces of supply and demand. The gold-demand, for example, can be split into two categories: "use demand" and "asset demand" (Ghosh et al., 2004), the latter of which is becoming the leading influence thanks to investor preference (Baur and McDermott, 2010). On the other hand, total gold-supply is a relatively fixed quantity because of its difficult extraction process, and probably has limited remaining reserves (Erb and Harvey, 2013). This combination causes gold-prices to usually trend upwards, but with high short-run volatility.

This thesis aims to find out whether gold and silver are able to hedge against headline and expected inflation in the long-run, by employing a vector error correction model (Johansen, 1995), and give meaning to the seemingly indecipherable historical fluctuations through their inflation-adjusted prices. The analysis is an extension of Bampinas and Panagiotidis (2015), focusing on domestic gold markets in the United States (US) and the United Kingdom (UK), during the period 1792–2022. Apart from data availability, these two countries are excellent choices for such an analysis for a number of reasons. *First*, the UK was the first nation to switch to a gold-based monetary system and the pound-sterling was the world-reserve currency until the 1920s (Eichengreen and Flandreau, 2009), thus its financial system exerted significant influence in world markets (Knafo, 2006). Similarly, the US adopted the currency-role from the UK, was at the center of the Bretton Woods monetary system and led the switch to a pure paper-fiat currency. *Second*, both nations have had a relatively consistent currency structure, especially the UK (Jastram, 1977). *Lastly*, Jastram (1977) also argues that their similarity across economic institutions, motivations, and their historical influence on the world, renders them "logical companions" for such an analysis.

The thesis is organized as follows: *Chapter 2* provides a brief historical overview of the commodity-based monetary systems of the two countries; *Chapter 3* reviews the related literature; *Chapter 4* explains the methodology of the empirical analysis; *Chapter 5* presents the empirical results and analyses the long-run purchasing power of the metals; and *Chapter 6* summarizes the thesis, with some concluding comments.

Chapter 2

The History of Gold and Silver in monetary policy

The following section provides an overview of the commodity-based monetary systems that took place in the US and UK from the late 18th century onwards. For both countries, and indeed for the whole world economy, gold and silver played a leading role in shaping modern monetary policy, by acting as a link between currency and government fiat well into the latter half of the 20th Century. Since the scope of this thesis is to examine the relative co-movement of inflation and these two metals, markets notorious for their high volatility and sensitivity to real economic events, it becomes necessary to be informed about the underlying policy forces that dictated their value, without exhausting a complete enumeration of historical shocks. Section 2.1 briefly defines relevant bi- and monometallic systems, sections 2.2 and 2.3 explain historical monetary systems in the US and the UK, respectively, and 2.4 gives some insight on the Bretton Woods gold-(dollar) exchange standard and its eventual collapse.

2.1 Definitions and terminology

In most monetary systems the national currency gains its official purchasing power from the government, as established by law. Thus, the currency becomes *legal tender*, i.e., something that has to be accepted in currency-denominated transactions and is protected by law. Within this framework, payments for public or private obligations, that do not specify another medium of exchange, have to be accepted in the legally tendered medium and at face value (Elwell, 2011).

A common example of a legal tender is in the monometallic monetary system, where a single metal is given legal tender value. The classical and historically most common form of monometallism is the *silver standard*. To work as a monetary system, it requires fixing a specific weight of silver to the national currency, the ability to convert privately-owned silver to domestic silver coin at the official mint price (or close to it), and no restrictions for how private parties engage with silver bullions or coins, on a domestic or international scale (Officer, 2010b). Effectively, silver becomes fully integrated into the economy as a legal tender, for as long as the monetary authority is trusted by market participants to protect the legal ratio. Notwithstanding the legal establishment of the silver medium, the use of silver as a de facto currency can be traced back to ancient Greek times, and has been the dominant commodity-currency up until the 19th century, constituting nearly the entire metallic currency of Europe and leaving gold mostly for high-valued transactions (Friedman, 1990).

The natural course for a system with monometallic characteristics and a complimentary de facto metal, is the *bimetallic standard*. The bimetallic standard fulfills all requirements for a monometallic (silver) standard, but instead the government has to give equal care to two metals, in our case gold and silver. As such, one unit of national currency is equal to a fixed amount of gold and silver, and each metal has a fixed value to each other. The goal of such a policy is to create a balanced circulation of both metals and avoid the creation of secondary markets that differ from official mint prices. This balance is difficult to achieve, however, as is evident from the quick devaluation of silver in the US during the bimetallic standard, effectively reducing to a silver standard.

To counteract such imbalances and with the support of an ever-rising influx of gold mining, many governments switched their policy towards the *gold standard*, i.e., to a monometallic monetary regime with gold acting as the sole legal tender. This popular standard reached most countries with a monetary system, except for a few traditional silver-standard countries in central-east Asia and Latin America, and Portugal and Italy which quickly left the gold standard, but retained exchange rate stability (Officer, 2010a). The necessary requirements are similar to the silver standard, though the popularity of the classical gold standard created a few distinct variations, most of which emerged before the first World War as a result of an international (collaborative) commitment to its stability. Under such regimes, gold is not necessarily coin, but can remain in the form of bullions (*bullion standard*) or is pegged to a convertible foreign exchange (*gold-exchange standard*). The latter became the preferable monetary system as central banks opted for more diversified reserve portfolios, by utilizing the newly developed (and liquid) financial markets for a safe and convenient policy, and distancing themselves from the costly necessities of handling gold (Bloomfield, 1963, as cited in Eichengreen and Flandreau, 2009). For "periphery" countries (i.e., countries with small gold reserves and little to no impact on the world market ratio) the gold-exchange enabled them to "[hold] their reserve in interest-bearing form" and avoid additional costs of accumulating gold.

The success of a monetary system with a precious metal as legal tender relies heavily on contemporaries' trust towards the preservation of convertibility. Most notably, a country's monetary authority must be perceived as trustworthy in fulfilling its commitment towards the metallic standard, not only towards convertibility, but also by adhering to the "rules of the game". During the gold standard, the central authority was expected to balance gold reserves, interest rates and money supply in accordance to an informal set of rules implied by the gold standard (though in practice this was not always the case). As a result of this trust, the classical gold standard (until 1913) evolved largely into a hitherto successful monetary system, thanks to "a confluence of 'virtuous' interactions, involving government policies, credible commitment to the standard, private arbitrage and speculation, and fostering economic and political environment" (Officer, 2010a, p.106).

2.2 Monetary policy regimes in the US

During colonial times and the first decades after declaring its sovereign independence, the US largely followed a de facto silver standard, with a fixed-exchange rate pegged to the Spanish dollar (Officer, 2010b). The first official US coin regulation came in 1792 under the Coinage Act of the same year, which legally formed the US Mint. Then Treasury Secretary Alexander Hamilton recommended a bimetallic standard (even though he himself reported the greater stability of gold), on the grounds that silver was a well-integrated specie among most states, and that the more valuable gold was rare and more liable to instances of increased commercial demand (Friedman, 1990). The mint ratio was set at the existing market prices (15 grains of pure silver to 1 of gold), the latter of which soon increased to 15.5:1. Despite the dangers of an undervalued silver coin, US congress did not alter its ratio to follow market prices for decades. In essence, silver coins became the dominant currency for domestic transactions, while gold was used primarily for international transactions, virtually returning to a de facto silver standard (Elwell, 2011).

In 1834, the US government altered the mint ratio to restore the balance between the two metals. The new ratio, 16:1, corresponded to a fixed price of $20.67 per fine ounce of gold, or $1.29 per fine ounce of silver, an official market-price that remained as such until the 1930s (Friedman, 1990). In order to bring back the gold coins into domestic circulation, the US mint reduced the amount of pure gold in coins and declared it as being legal tender and at par with previous ones, effectively reducing the face value of the gold coin both for past (debt) and future payments. The new de facto gold standard within the de jure bimetallic standard meant that silver became obsolete in domestic transactions and was mostly exported to international markets at a premium; this development also accelerated in the wake of the 1840s-50s gold rush. Leading up to the events of the Civil War, the US government suspended all specie conversions and, for the first time in its contemporary history, introduced a purely fiat paper currency; the "greenback". Resembling Treasury notes, the greenback acted as legal tender for any transactions that would otherwise be made in gold or silver (except for customs fees), with a government guarantee of at least preserving their face value. Since the metallic standard was suspended, the only way of obtaining gold or silver was in secondary markets, often at a significant premium, a spread that policymakers alleviated after the war by removing some of the paper money in circulation. The latter action continued until the official price of $20.67 per ounce of gold returned, slowly preparing for the upcoming monometallic gold standard.

The Act of 1873 marked the point where the US officially adopted the gold standard, a monetary regime that lasted until 1933, and which Elwell (2011) calls "the only period in U.S. history that can strictly be called a gold standard". By this law, the greenback paper-currency was now legal tender (including for customs fees) and its convertibility was fully restored only for gold; importantly, it downgraded the legal tender status of silver, which now held the role of just a fractional currency. The choice of a pure monometallic standard was by no means coincidental. By the 1870s, many advanced economies (including the UK, Germany and France) had already shifted to a gold standard, or had plans to do so, and various real events contributed to a continuously decreasing world-price of silver. Thus, it was almost as if the act aimed to protect the existing de facto gold standard from turning into a de facto silver standard, as shown by earlier experiences. However, immense pressure from supporters and producers of silver led to the acts of 1878 and 1890, eventually allowing the strictly limited convertibility of silver to gold or greenbacks (market-mint spread was paid by the government) and introducing a type of Treasury deposit for silver coins ("silver certificates"). The latter two acts where carefully proposed by the US government, so as to not fully restore the legal tender status of silver but at the same time satisfy the demands of silver holders. Nevertheless, increasing worries by investors of a renewed bimetallic regime pushed the US to publicly reaffirm its commitment in maintaining the gold standard and its official ratio, in passing the "Gold Standard Act" of 1900 (Elwell, 2011).

The gold standard in the US lasted until 1933, with the exception of a short-lived suspension of payments and a restriction on gold exports during the First World War. The "interwar gold standard" (resumed in 1919 and as late as 1926 for other countries), however, was "institutionally" different from the classical one, namely, it was mostly a gold-exchange standard and now had a second world leader; the US. Under this regime, "core" countries (most importantly the US, France, Germany) held their reserve mostly in gold, while "periphery" countries held reserves of both specie and dollars or pounds (Bordo, 1981). Several causes of instability emerged, especially by imbalances in foreign-exchange markets and strained central-bank liquidity, which made fulfilling the commitments on the gold-exchange parity more difficult (Officer, 2010a). The interwar gold standard broke down during the Great Depression in the 1930s, coinciding with Britain's departure from gold. If the US Fed were to preserve gold-convertibility it would have to retain high interest rates (high returns disincentivised exports of gold-reserves), a contradictory policy for the already depressed US economy. For this reason, then-President Franklin Roosevelt pushed a series of changes for the banking and monetary system, that discontinued gold-convertibility, nationalized all gold-holdings, and established a new parity at approximately $35 per ounce of gold (lacking convertibility, the dollar value of gold mattered only for international transactions; Elwell, 2011). The latter gold-ratio would also remain the official US price during the upcoming international gold-dollar-exchange standard, the Bretton Woods System (Section 2.4).

2.3 Monetary policy regimes in the UK

The UK's path of monetary policy regimes was markedly simpler compared to the US, though the structure of the former's financial system and its influence on the world economy created a more complex policy dynamic. From as early as the 13th century, England had established a de jure bimetallic coin standard, despite the generally predominant circulation of silver coins (Officer, 2010a and Officer, 2010b.) Following the coinage of the "popular" gold guinea and shifting foreign ratios, the

Royal Mint undervalued the silver coin in 1717 as a way of compensating for ratio discrepancies, but the new price ratio overvalued the gold coin, thus pushing the silver coin out of circulation. Therefore, England was in a de facto gold standard in the 18th century, a monometallic regime that was later legalised in 1816. Incidentally, and similarly to the US, England formalised the de jure gold standard following a period of suspended gold convertibility (1797–1821), in an effort to support the mass financing of the Napoleonic Wars (Eichengreen and Flandreau, 1997). Since issuing banknotes was, at the time, still part of a non-institutionalised monetary framework, private banks were incentivised to issue banknotes without the fear of a bank run for gold, thus undervaluing fiat money relative to gold and increasing inflation (Knafo, 2006). In 1819, the British parliament ordered the Bank of England to resume full convertibility in 1821, at the existing market ratio of approximately £4.23 per ounce of gold. The classical gold standard would remain stable until the First World War, in spite of a few banking crises and a monetary reform. It is worth mentioning that the exact reasoning behind the adoption of gold instead of silver, or a combination of the two, is somewhat debated on. On the one hand, some authors cite technological advancements in coinage, relating to both the processing of precious metals and protection against counterfeits, as well as the ability to have a smaller medium of exchange in circulation (Redish, 1990). Others, such as Friedman (1990), describe the emergence of the gold standard as mere happenstance; a by-product of a "self-fulfilling prophecy", that gold is more stable than silver, which other countries emulated in the wake of international developments and an undervalued silver.

For most of the pre-World War I era, England was in the forefront of the gold standard and acted as a de facto leader for the other core countries. Notwithstanding the vast reach of its Dominions and the economic powerhouse that it was, it also played a seminal role in the conduct of international policy and payments. This role can be divided into two separate branches: practices of modern banking and the sterling as a world-reserve currency. Regarding the former, Knafo (2006) argues that England became an example on how to establish and retain a gold standard, not just by its conduct of monetary policy, but also with the expansion and the practices of its financial institutions. He also cites the adoption of convertibility by European countries as a means to regain credibility in the banking sector, especially after inflationary periods, and the ability to issue banknotes by broadly emulating the British financial system. Also, the international markets in London were the center of the world's commodities and capital markets (Bordo and Schwartz, 1999; Officer, 2010a), which gave significant leverage to the Bank of England's conduct of monetary policy. More specifically, the elaborate network of short-term financing in-between financial institutions (Bordo, 1981) and the ability of the Bank of England to engage in sterilising open-market operations without altering real gold reserves (Ford, 1997; Bordo, 1981; Knafo, 2006), allowed the British banking system to have considerable influence on international developments.

The aforementioned market prowess in combination with the sophisticated issuance of securities by the Bank of England laid the foundations for the second branch of the country's international role; the dominant pound sterling. As the gold-exchange standard became more popular during the early 20th century, a significant amount of central bank reserves was held in the form of foreign exchange assets, of which 64 percent were sterling-denominated (Lindert, 1969, as cited in Eichengreen and Flandreau, 2009). In fact, the Bank of England could manipulate its gold reserves and Bank Rate, thus altering the flow of short-term credit and significantly influencing credit conditions in other countries (Bordo, 1981; Lindert, 1969, and Eichengreen, 1987, as cited in Bordo and Kydland, 1995; Sayers, 1957 as cited in Bordo, 2010). In spite of the reliance on sterling-denominated assets and claims, the Bank of England held only a small amount of gold in its reserves, accounting for three percent of world reserves in 1913, or a reserve-to-liabilities ratio of 31 percent (Officer, 2010a). However, Eichengreen (1997b) argues, that the bank's international affairs and the credibility to defend its commitments were enough to dampen most dangers against the sterling, as evidenced by a few instances of shocks in investor confidence.

The feasibility of the specie standard reached a limit during World War I, stressing the fragile balance of British institutions and forcing the strict control of all payments. Though convertibility was not legally suspended, the Bank of England was the sole actor of international gold transactions, by managing bank behaviour through various regulatory or informal methods (Officer, 2010a). By the end of the war, England (among others) was left picking up after a chaotic economy, a development that significantly hampered the restoration of the gold (exchange) standard, since the real price of gold was considerably lower due to inflation and decreased mining rates. The original plan was to fully restore pre-war exchange parities by again raising the real price of gold, at the cost of deflating prices. The alternative (proposed at the infamous Genoa conference in 1922), was to further institutionalise the gold-exchange standard, by increasing the ratio of foreign-exchange reserves against gold ones (Eichengreen and Flandreau, 2009). In 1925, the de facto gold restrictions were lifted off and the UK resumed anew the gold-exchange standard, as per the alternative solution.

As mentioned in section 2.2, the interwar gold-exchange was in a lot of ways different from the pre-war one, especially for its short-lived duration. During the 1920s, Eichengreen and Flandreau (2009) argue that the sterling had already lost its reserve-currency status to the US dollar, with the latter's gold value now acting as the reference point for exchanges. Also, the gold coin was rapidly disappearing from money circulation, while at the same time the Bank of England accumulated evermore foreign liabilities, even though its gold reserves were still small in comparison with other reserve-centers, such as France and the United States. Thus, the UK lost both its dominant currency and international market status, and more importantly was prone to the distrust of sterling holders. This distrust materialised into a run on sterling-denominated assets, a chain-reaction triggered by the gravity of the Great Depression, which finally led to the depletion of central-bank reserves and the UK's official abandonment of the gold standard in September 1931.

2.4 The Bretton Woods system

The interwar gold-exchange standard turned out to be a framework that lacked the fundamental attributes that strengthened the classical one, namely, the tight cooperation of all counterparties and "blind" confidence in the "rules of the game". Bordo (1993) identifies three key misalignments that subsequent policies aimed to correct: the conflicting reserve adjustments by deficit (UK) and surplus countries (US, France), the lack of adequate gold supplies (and liquidity) to accommodate growth at prevailing parities, and the loss in confidence towards the dichotomous share of the reserve-currency role and the crumbling commitment of convertibility. In a paper for the League of Nations, Nurkse (1944, as cited in Kenen, 2008) discussed the widely acknowledged risks involved in retaining a floating exchange rate, especially regarding the costly adjustment mechanism needed and the incentives of competitive currency devaluations. Additionally, bi- and multilateral central bank cooperation suffered after World War I, let alone the halted operations during the second one, which introduced a number of new restrictions on capital flows. Thus, it seemed more sensible for currency parities to be determined by a collectively operated international institution, which would promote exchange rate stability and shield the system from the aforementioned flaws. The new monetary system came into effect after reaching a unanimous agreement at the Bretton Woods conference in 1944, also establishing some of today's international institutions (IMF, World Bank, IBRD). The negotiations preceding unanimity, however, created a heated debate between economists and decision-makers in the US and the UK, who each proposed their respective plans of what the post-war monetary system should look like.

On the one side of this debate was the US; a country of significant monetary importance to the world economy since the interwar period, and whose productive capacity was to largely remain intact after the war. It expected to act as a creditor nation (Bordo, 1993), directing its surplus towards other countries for reconstruction purposes, while being in the forefront of international politics and economic growth. As a result, the proposed plan (lead by Harry D. White) was a rather conservative one, primarily targeting the stability of exchange rates and the controlled supply of international money (Kenen, 2008). The latter was to be regulated by two new institutions: a bank, aimed at providing liquidity for the quick restoration of destroyed nations; and a fund, made of currency and gold contributions, that would distribute a finite resource pool from surplus to deficit countries, all the while maintaining a par value against an international unit of account (Bordo, 1993).

On the other side was the UK, which made relatively larger expenditures, borrowed heavily against its assets and suffered greater material losses during the war. Thus, it expected to remain a debtor nation in the foreseeable future. The UK's final draft (lead by John M. Keynes) focused more on expanding world trade and restoring balance-of-payments to healthy levels, in the form of higher international reserves (Bordo, 1993). In a similar fashion to White, Keynes proposed the establishment of an international central bank, but which would issue a new currency (the "bancor") and provide liquidity to individual central banks and governments at a seemingly high level (Kenen, 2008). Finally, Keynes was keen in protecting the fixed parities from failures or speculative attacks, by imposing stiffer capital controls and regulating the balances of participating governments.

The final agreement signed at Bretton Woods was a lot more similar to White's plan than Keynes', though both parties accepted to compromise on a number of clauses for the sake of restoring postwar stability. At its core, the new system relied on the discretion of the US to preserve a fixed parity of dollars to gold ($35 per ounce). Other members would have to choose to peg their currency against either the dollar or gold, while retaining the right to freely convert between the two of them (only for central banks and governments). Though the commitment faintly resembled that of a gold standard, the pegged exchange rates could be adjusted in the case of a "fundamental disequilibrium", under the supervision of the newly established International Monetary Fund (IMF), without having to restore the original parity again (Eichengreen, 2004). The IMF also supported countries that ran a deficit, by providing liquidity based on their individual quotas and, since the pre-conditions for such actions were not clearly agreed upon, monitored their situation closely through commitments of domestic policy (Kenen, 2008). In addition, a number of countries relied on capital-flow restrictions to cushion speculative attacks on their currency, a strategy which, in hindsight, further complicated the initial liberation of exchange markets. In fact, the mandatory currency convertibility laid out by the Bretton Woods agreement was significantly delayed (notably for Western European countries), partly due to these restrictions, since currency-holders would make a run towards the dollar once their nation freed up its exchange.

The first decade after the war was a period of slow transitioning towards peace and reopening of world trade. Many countries experienced fast-paced growth that lasted well into the 1950s, easing the burden of domestic policy and making-up lost ground from decades of economic stagnation (Eichengreen, 1997a). The pressures of speculative attacks towards weak currencies, however, were a frequent occurrence that plagued countries with a balance-of-payments deficit, leading to a number of devaluations. As most countries pegged their currency to the dollar instead of gold, the US would suffer from a gradual appreciation and a weakened competitive position (Kenen, 2008). At the same time, US gold reserves steadily fell from 70 percent in 1947 (a significant sum was accumulated due to capital flight during the war and the revaluation of gold to $35 in the 1930s) to less than 50 percent by the end of the 1950s, a development that increased the liabilities to gold ratio at an alarming rate (Eichengreen, 2004). The latter created a lot of anxiety for holders of large dollar-reserves (i.e., foreign central banks and governments), who would suffer sizeable losses if the dollar were to be devalued due to policy or doubtful markets. Consequently, high-growth countries were reluctant to revalue against the dollar and started questioning the feasibility of a dollar-denominated world-reserve asset. At the centre of this situation also lay the huge expenditures of US military ventures abroad, straining the balance surplus of the country, and the US elections of 1959, that contributed to the sharp rise of gold prices in London markets above the New York one. To avoid arbitrage temptations of (central) banks, the European central banks formed the Gold Pool in 1961, thus sharing the costs of maintaining the official parity and taking collective action in protecting stability. The mounting costs were not well received, however, and a number of non-member central banks abused price differences (including France, which did so by lifting private gold imports and withdrawing from the Pool), leading to its eventual disbandment in 1968 and replacement by a promise ("Gentleman's Agreement"; Eichengreen, 2004). Subsequently, a "two-tier" market was formed (Jastram, 1977). The first tier was intended for settling IMF obligations, with gold transactions being directly orchestrated by the US and at the constant $35 mark. The second tier was a free market place for private individuals looking to buy or sell gold, at prices dictated by simple equilibrium forces. Evidently, the latter one was overrun by immense demand and second-tier gold prices surged, in the wake of the US closing the gold window in the first tier.

The practical inflexibility of the "adjustable" peg became much more pronounced in the years after the Gold Pool. The sheer momentum of market rumours alone was able to crack the confidence of fixed exchange rates in major economies, enough to force the German authorities to let the Deutschemark float (1969 and 1971) before an official revaluation was arranged. Following an increasing number of gold demand instead of dollars, the US Treasury was instructed to suspend convertibility at the official rate and arrange new rates in cooperation with other members (Kenen, 2008). Despite the new rates, most major currencies fell rapidly and were allowed to float again in order to protect their reserves, leaving second-tier gold markets as the sole marketplace. The end of the Bretton Woods system became official in 1976, by altering the agreement of the IMF and allowing members to choose any exchange rate regime (except for fixed gold prices), all the while gold prices and convertibility may remain at the discretion of market dynamics. The definition of currency on the basis of gold has been practically erased from the international monetary system and, to this day, has been replaced by pure fiat money. Nevertheless, gold is still a much used commodity in the manufacturing industry and plays a substantial role in the portfolios of investors and central banks alike.

Chapter 3

Literature Review

Academics have been analysing commodity prices since their use as legal tender, mostly for their predictive and explanatory capacity in the macro-economy and monetary policy. More recently, commodities have been utilized as financial assets in investor portfolios, offering various advantages in the balancing of risk and return. Gold, especially, stands in the forefront of commodity markets since its return to public trading in 1971, because of its universally acceptable intrinsic value, counter-cyclical demand and, reportedly, properties of risk-protection (Arnold and Auer, 2015). It is also a durable, relatively transportable and easily authenticated asset (Worthington and Pahlavani, 2007). Consequently, previous literature has focused more on the performance of gold, and less so for other commodities, also reaching conflicting results depending on the country and time-frame examined. This review is split into three general categories that gold literature has focused on, and that are relevant to this thesis, namely: the ability of gold to act as a safe haven, hedge or diversifier in portfolios; the specific role as a hedge against inflation; the gold/inflation relationship, including cointegration approaches and determinants of gold prices. Since research on the performance of silver is relatively scarce compared to gold, a brief repetition of citations that include silver in their analysis are provided at the end of each section, also following the aforementioned categorization.

Gold and Silver as a hedge, diversifier or safe haven

The first category relates gold prices with equity and bond markets, to establish the metal's capacity of decreasing or neutralising portfolio risk. Though maybe not all authors use the same exact explanation for the types of assets that achieve this, Baur and Lucey (2010) provide practical and clear definitions for three distinguishable asset-types: an asset that is uncorrelated or negatively correlated with another asset/portfolio on average (*hedge*), an asset that is positively, but not perfectly, correlated with another asset/portfolio on average (*diversifier*), and an asset that is uncorrelated or negatively correlated with another asset/portfolio at times of market stress or turmoil (*safe haven*).

Existing literature has provided ample evidence in favor of gold, regarding it as a situationally useful addition to investor portfolios. Baur and Lucey (2010) find that gold acted as a hedge and safe haven during 1995–2005 in the US, UK and Germany, though the safe haven properties were present only at very extreme market conditions. Lucey and Li (2015) analyze monthly US data between 1989 and 2013, to test the safe haven properties of four precious metals (gold, silver, platinum, palladium) during market distress, finding that all four act as safe havens during equity and bond market turbulence. Shahzad et al. (2020) also show that gold is a safe haven, hedge and diversifier in all G7 countries, at a capacity much higher than that of Bitcoin. The former result also stands true for some emerging economies (BRICS), as evidenced by the analysis of Bekiros et al. (2017), though the role as a diversifier tends to reduce in the long run. Hillier et al. (2006) analyze daily data from 1976 to 2004 and show that gold, platinum and silver may act as diversifiers or hedges during extreme market volatility, and conclude that portfolios with a moderate amount of gold outperform others consisting of solely financial assets. Boubaker et al. (2020) test the safe haven properties of gold in the wake of global crises, using a UK dataset spanning from 1257 to 2018, and by estimating a linear model with a Markov-switching process that discriminates between bear and bull markets. Their results suggest that gold has acted as a safe haven in the very long-run (with stronger effects during bull markets), though primarily after World War I, i.e. after the classical gold standard.

The effectiveness of gold in portfolios, however, is not a relationship that should be taken as is from all investors. Baur and McDermott (2010), who analyse a large set of countries between 1979 and 2009, conclude that although gold may act as a stabilising force that reduces losses in financial markets, the effectiveness of gold as a safe haven and hedge also depends on the data frequency and the country in question. For most major economies, gold acts as an effective safe haven and hedge during extreme shocks, but less so for gradual trends. In the case of developed countries, gold acted as a safe haven only during specific crisis periods, while large emerging markets share more or less the same properties with the developed ones. Dee et al. (2013) confirm that gold is a good long-run hedge against stocks in China, but does not protect in the short-run and does not act as a safe haven. Finally, Klein (2017) presents strong evidence that gold is a safe haven in developed markets, but with its effectiveness somewhat diminishing after 2013.

In the case of silver, financial literature has examined its performance as a commodity with possible risk-protection properties, mostly in the context of comparing it with other metals on the market. As evidenced by some of the aforementioned authors, the results are not as robust as these of gold. In the Markov-switching model of Boubaker et al. (2020) the coefficients of silver are both negative and insignificant, meaning that in the very long-run silver did not have the ability to become a safe haven for investors. Klein (2017) concludes that silver is indeed a safe haven, but only a partial one and with weak evidence. In contrast, Hillier et al. (2006) assess that silver can act both as a diversifier and a hedge during extreme market conditions (also Lucey and Li, 2015), so much so that silver has sometimes been stronger at de-risking than gold.

Gold and Silver as a hedge against Inflation

An equally important property assigned to gold, and the central theme of this thesis, is the ability to retain or even increase its purchasing power throughout periods of rising price levels, i.e. to act as an inflation hedge. At first thought, it seems implausible for gold to have had an increase in purchasing power considering its historical status (see Section 2). Indeed, one of the earlier works by Jastram (1977), concludes that gold has struggled to appreciate in real terms, although its purchasing power has remained relatively stable in the long run (except for periods of major inflation), both in the US and UK, thanks to other commodities' prices converging towards the fixed gold. In an updated version (Jastram and Leyland, 2009), Leyland extends the original analysis to include the period 1971–2007, concluding that gold still holds its purchasing power and has at times enjoyed a real appreciation, owing to the now freed gold markets to the public.

Overall, gold literature has been cautiously optimistic about the metal's effectiveness as an inflation hedge, has examined mostly the periods after Bretton Woods, and has presented mixed results based on the conditional situations and different time-horizons in which this very common belief actually stands true. Worthington and Pahlavani (2007), who stress the importance of taking structural breaks into account, find that inflation and gold are cointegrated in two overlapping US samples (one of them including the years before 1973), and therefore gold investments should in theory serve as an inflationary hedge. Dempster and Artigas (2010) find that gold in the US is a stronger hedge against inflation compared to traditional financial assets, has lower overall volatility and can be shown to improve risk-adjusted returns in low-medium inflation environments. Shahzad et al. (2019) comment that the role of gold seems to be diminishing, based on quantile-on-quantile results from six major economies; the hedging ability of gold depends on the country's own economic condition, its reaction is asymmetric across different shocks of inflation, and Granger-causality is also asymmetric across quantiles. A very long-run analysis by Aye et al. (2017) shows that, since the year 1257, gold is cointegrated with inflation and therefore has been a hedge against inflation in the UK. In contrast, Erb and Harvey (2013) show that gold is overpriced in real terms compared to historical prices, and comment that, although gold can be an effective hedge in very long time-horizons, its usefulness becomes much less apparent during practical investment horizons. From a modelling perspective, a number of papers, namely Ghosh et al. (2004), Levin and Wright (2006), Adrangi et al. (2003), McCown and Zimmerman (2006) have attempted to create theoretical pricing models to also account for other determinants of gold. All of the aforementioned find that gold is an effective inflation hedge, both in the short and long-run, and also that short-run factors exert significant influence on gold prices (Ghosh et al., 2004).

Regarding countries other than the usual, Salisu et al. (2019) conclude that gold acts as an inflationary hedge for half of the OECD countries, though its effectiveness has diminished after the global financial crisis, while Shahbaz et al. (2014) confirm its effectiveness as an inflation hedge in Pakistan. Long et al. (2013) conduct their analysis via the Fisher hypothesis, which they confirm to be empirically valid, and show that gold is a good hedge against both ex post and ex ante inflation in Vietnam, though not against unexpected inflationary shocks. Levin and Wright (2006) postulate that, if gold acts as an inflation hedge in the US, then holding gold (denominated in US Dollars) might be profitable for foreign investors whose domestic currency depreciates against the dollar more than the inflation differential. Dee et al. (2013) present evidence that gold is a good hedge against inflation in China, but does so only in the long-run.

The last subset of gold-research, that seems to provide mixed results on the topic, treats the gold-inflation relationship as non-linear, arguing that the constancy assumptions of a traditional VECM are too restrictive, due to gold's previous structural changes and business cycle dependence (Beckmann and Czudaj, 2013). One of the first authors to treat the relation as such are Wang et al. (2011), who employ threshold cointegration and error correction models to test the short and long-run dynamics in the US and Japan. Their findings suggest that gold's inflation-hedging ability is dependent on high market momentum, and therefore is not a good long-run hedge, while gold-price flexibility and market symmetry are crucial for short-run hedging; thus, it may not provide protection during all periods and in all markets (case in point: Japan). Beckmann and Czudaj (2013) too reach similar conclusions using a Markov-switching VECM, finding that gold is only a partial inflation-hedge, which depends on time-horizons and the current regime (turbulent vs. "normal" times). By employing a non-linear ARDL model, Hoang et al. (2016) show that gold is not a long-run inflation-hedge in six major economies, while only three out of six markets provide some protection in the short-run (UK, US, India). Bampinas and Panagiotidis (2015) test gold and silver's very long-run (1791–2010) hedging properties against different measures of inflation (headline, core, expected), in a time-invariant and time-varying cointegration framework. Their results suggest that gold has been an effective hedge against all inflation measures in the past two centuries, better so in the US than the UK, all the while time-varying dynamics tend to be stronger. In a similarly long time-span (1833 to 2016), Aye et al. (2016) employ a Markov-switching regression model for the US, that also controls for other investment assets, and find that conventional cointegration tests yield negative results. Their more flexible interrupting cointegration approach, however, presents evidence of cointegration and shows the different dates where the long-run relationship changed (the dates are in line with significant structural breaks in the gold market).

Finally, a very small part of the literature has also taken a look at the inflation-hedging properties of silver. Interestingly, Jastram (1981) does a similar analysis on the purchasing power of silver as with gold, citing it as a metal with lesser value but with a more "erratic" and "volatile" monetary history. During most of the last four (two) centuries in the UK (US), and except for after the second World War, silver has lost purchasing power but has at times appreciated during deflation and somewhat decreased the losses of inflation. McCown and Zimmerman (2006) estimate traditional pricing models in the US and find that, although silver's market "beta" is statistically different from zero, its hedging abilities are weak and less consistent than gold. In the two-century analysis of Bampinas and Panagiotidis (2015) there is strong (weak) evidence that there is a long-run relationship between silver and different measures of inflation in the UK (US), however only in the time-varying cointegration model. Lastly, in the model of Adrangi et al. (2003), silver is a hedge against inflation both in the short and long-run, except for unexpected shocks of price increases.

The Gold ∼ Inflation relationship and price determinants

The last categorization is dedicated to a number of research papers, that have attempted to model gold prices and/or examine the relationship between gold, inflation and other determinants of gold prices, so as to test whether gold has the necessary capacity to act as an informative index for investment or policy decisions.

In reviewing previous literature, Mahdavi and Zhou (1997) find that previous studies had found commodity price-indices (including gold) to be of weak predictive power regarding inflation and had yielded mixed results of causality. The view that these indices can be used as policy guides, the authors argue, rests on flexible, forward-looking markets, which is not as factual as once believed. In their own empirical analysis, they look for a cointegrating relationship between gold/commodity prices with the Consumer Price Index (CPI) and estimate an error-correction model, only to conclude that the predictive capacity of gold in out-of-sample forecasts is unfounded, and relatively weaker than a commodity index. Worthington and Pahlavani (2007) note, however, that earlier cointegration analyses did not incorporate the "substantial structural changes" that affected gold markets — gold was not at the centre of the international monetary system anymore — thus producing distorted results. The latter's analysis, laden with structural-break tests, found gold and CPI to be cointegrated at the 1% level.

Regarding the inverse relationship, Sharma (2016) employs the flexible generalized least squares predictive estimator, to test whether the CPI can predict gold price returns. Out of 54 countries tested, only ten reject the null hypothesis of no predictability, four of which fail out-of-sample tests. Overall, and including in-sample tests, there is some evidence in favor of gold-price predictability by the CPI. Blose (2010) tests two hypotheses for predicting gold prices. First, the notion that an upward revision in expected inflation positively affects gold prices, for hedging against future losses of purchasing power or speculation, which the author finds not to be true; thus, gold is not a good indicator of inflation expectations. Second, in the case of higher expected inflation, one also expects interest rates to rise, therefore creating the argument that holding gold is associated with a higher opportunity cost (an alternative asset might as well be the risk-free asset), which nullifies the beta of gold. Since bond yields are found to be closely linked with unexpected changes in the CPI, the author argues that investors are better off moving their capital towards bond markets, rather than gold. Batten et al. (2014) analyse the time-varying nature of the gold/inflation relationship, confirming that a stable link does not exist and pointing out periods in the 1980s where financial and macroeconomic turmoil had altered this link. Lucey et al. (2017) present similar results for a period in the mid-1990s, but also find some evidence that gold is cointegrated with both predicted and realized inflation in the US, UK and Japan.

Lastly, a selected subset of previously mentioned papers has based their analysis on theoretical models and hypotheses, to extract as much information as possible regarding the determinants of gold prices in markets. Adrangi et al. (2003) split gold/silver demand in speculative, industrial and government demand, and provide alternative explanations based on economic theory. Since the gold/silver supply is limited, fluctuations in demand will have a noticeable influence on their respective market price. Considering that government demand is on the low side after the collapse of the gold-exchange standard, a rise in inflation will reduce real economic activity and negatively affect industrial demand, while inflation fears will boost speculative demand. If the latter exceeds the former, then gold (silver) demand increases and gold (silver) prices rise. Empirically they find a positive relationship between expected inflation and real gold/silver returns (but not with unexpected inflation), confirming the possibility of hoarding pressures during inflationary periods, while gold/silver prices do tend to move together with inflation in the long-run.

Ghosh et al. (2004), who present a theoretical model to explain equilibrium prices in gold markets, split the demand for gold in just two: use demand, i.e. gold used in production and services, and asset demand. Their goal is to explain the turbulent short-run volatility of gold prices by incorporating other variables to the model, such as gold lease rates and real interest rates, that act as determinants of long-run gold prices. The model predicts that equilibrium gold-prices are equal to the marginal cost of extraction, also equal to the lease rate of central banks, and as long as the marginal cost of extraction keeps up with inflation, then gold can be regarded as a long-run inflation hedge. The empirical analysis for the US in 1976–1999 supports the central idea of the model and shows a cointegrating relationship between the two. In a similar way, Levin and Wright (2006) model short-run determinants of gold prices that cause temporary volatility (much like Ghosh et al., 2004). Their empirical findings suggest that there is a significant long-run relationship of co-moving gold prices and the US price level (1976–2005), which, after a temporary shock, returns to two-thirds of the equilibrium value after approximately five years. Regarding other explanatory variables, they find a positive relationship between gold prices and US inflation, inflation volatility and credit risk, and a negative relationship with the trade-weighted US dollar exchange rate and gold lease rate.

Chapter 4

Methodology

The empirical methods of this thesis are wholly based on the work of Bampinas and Panagiotidis (2015), and are part of a strand of literature as outlined in the second and third category of the literature review (Chapter 3). Owing to the long-run nature of the analysis, Bampinas and Panagiotidis (2015) employ cointegration techniques to look for a relationship between prices and precious metals, that is long lasting and excerpts similar dynamics to that of an equilibrium equation. The former is achieved via a Vector Error Correction Model (VECM), — the authors also estimate a time-varying form which is not the case here— while the latter is a combination of the VECM's inherent properties and the theoretical underpinnings of the generalised *Fisher Effect* (Fisher, 1930). Finally, they use a number of filters and estimators to extract various measures of inflation (headline, core, expected), since different nuances of price levels may have different effects on asset prices.

4.1 Cointegration

The term "co-integration" was first coined by Clive Granger, and later extended in Engle and Granger (1987), to encapsulate the non-stationary nature of time-series and relate it to the long- and short-run equilibrium dynamics of economic theory. In essence, two non-stationary variables are said to be cointegrated, if there exists a linear combination between them that is a stationary process. Following economic theory, this combination is the long-run equilibrium point, while short-run deviations are temporary and captured through the equilibrium error.

In more technical terms, a non-stationary series x_t is said to be integrated of order d, denoted $x_t \sim I(d)$, if it must be differenced d times for it to become a stationary process. Therefore, a series with a single unit root, $I(1)$, will become stationary, $I(0)$, after differencing $d = 1$ times.

For two series x_t, y_t with the same order of integration $I(d)$, it is generally true that their linear combination $z_t = x_t - \alpha y_t$ will also be $I(d)$(Engle and Granger, 1987). However, Engle had previously shown that it may still be possible for the former to not hold, if $I_x(d)$, $I_y(b)$ and their combination results in $I_z(d-b), b > 0$. In such cases, α acts as a scaling force, so that it removes the long-run components of the two series and they move together without drifting apart. Though this is situational, the idea that unstable economic variables tend to create a stable relationship gives reasoning to the definition of what the author called "cointegration". As per Engle and Granger (1987):

Cointegration. *"The components of the vector x_t are said to be cointegrated of order d,b, denoted $x_t \sim CI(d,b)$, if (i) all components of x_t are $I(d)$, and (ii) there exists a vector $\alpha(\neq 0)$ so that $z_t = \alpha' x_t \sim I(d-b), b > 0$. The vector α is called the cointegrating vector."*

As an example, consider the central theme of this thesis. Suppose the purchasing power of gold does indeed remain stable in the long-run. Then, if both gold and price levels are non-stationary processes and integrated of order 1, they are said to be cointegrated of order (1,1), if there exists a linear combination of the two that is integrated of order 0, i.e. that is a stationary process. Though this is just an example, one would expect based on economic theory, that any form of equilibrium is prone to external shocks, which lead to temporary deviations; for example an unforeseen increase in inflation. Therefore, the aforementioned combination is bound to, at times, produce measurable errors, but which should largely remain close to a zero mean. The latter becomes the basis of the testing procedure established by Engle and Granger (1987), though this thesis follows the cointegration-testing and error correction modelling of Johansen (1995).

4.2 Johansen cointegration and VECM

Johansen test for cointegration

The cointegration test proposed by Johansen (thoroughly summarized in Johansen, 1995) is a likelihood-ratio-based test on the error correction form of a vector autoregressive (VAR) model. A VAR model with k lags and a deterministic term, D_t (can contain a constant, a linear term, dummies or other regressors), takes the following form:

$$X_t = \Pi_1 X_{t-1} + \Pi_2 X_{t-2} \ldots + \Pi_k X_{t-k} + \Phi D_t + \epsilon_t,$$

where X_t is a $n \times 1$ vector of n dependent variables, Π_t are $n \times 1$ coefficient matrices of each lag and the independent Gaussian errors are $\epsilon_t \sim N_k(0, \Omega)$. In the previous section, cointegration was defined as a property between two or more variables that are usually integrated of an order higher than 1 (i.e. have at least one unit root). To remove the properties of non-stationarity and avoid spurious results, the VAR model is differenced and presented in error correction form:

$$\Delta X_t = \Pi X_{t-1} + \sum_{i=1}^{k-1} \Gamma_i \Delta X_{t-i} + \Phi D_t + \epsilon_t \qquad t = 1, 2, \ldots, T\,, \tag{4.1}$$

where $\Pi = \sum_{i=1}^{k} \Pi_i - I$ and $\Gamma_i = -\sum_{j=i+1}^{k} \Pi_j$. Granger's representation theorem states that if all variables have at least one unit root, and $rank(\Pi) = r < k$, then there exist $k \times r$ matrices α and β of rank r, such that $\Pi = \alpha\beta'$, and $\beta' X_t$ is stationary (Johansen, 1995). Effectively, r denotes the number of cointegrating relations in the *cointegration matrix* β', and the *loading matrix* α measures the speed of adjustment to past equilibrium errors ($\beta' X_t$).

Johansen has proposed two distinct approaches in determining the rank of the cointegrating vector: the eigenvalue test and the trace test. Out of the two, the latter one seems to be the most favored test, since its results are more robust (Cheung and Lai, 1993) and its overall performance is generally better than the eigenvalue test (Lütkepohl et al., 2001). For these reasons, and for a more streamlined presentation of the results, this thesis uses only the trace statistical test, which is a maximum likelihood-ratio (LR) test comparing the null hypothesis of r_0 cointegrating vectors, against the alternative of n cointegrating vectors. The test statistic takes the following form:

$$LR(r_0) = -T \sum_{j=r_0+1}^{k} \log(1 - \lambda_j)\,,$$

where λ measures the eigenvalues obtained from the reduced rank form of model 4.1 (Johansen, 1995).

A necessary consideration before employing the cointegration test is to define the optimal lag order of the model. In fact, failure to do so may introduce significant biases in Johansen's test and lead to spurious results that incorrectly suggest a cointegrating relation (Cheung and Lai, 1993). Since at this stage the cointegration rank r is not yet known, a number of VAR models can be estimated downwards from a pre-selected maximum lag k. The final selection is limited to the model with the lowest information criterion (Lütkepohl, 2004). Here, both the the Schwarz Bayesian information criterion (BIC) and Akaike information criterion (AIC) are used for selecting the lag length.

Model specification

Another property of Johansen's methodology is the ability to include a deterministic term, D_t, in the model. Except for cases of seasonal dummies, the term may usually take the form of a constant, with or without a deterministic linear trend. Based on how restrictive its specification is, the term can famously cover five different cases. The most general case (for VAR or VECM processes) is $\mu_0 + \mu_1 t$, though its exact specification always depends on the nature of the data, as well as the theoretical underpinnings that support the model (Lütkepohl, 2004). Here, two cases are going to be tested: Case I, with just an unrestricted constant and no linear trend ($\mu_1 = 0$), and Case II, with an unrestricted constant and a restricted linear trend ($\mu_1 \neq 0$). In Case I, the constant is not bound to the cointegrating relation (hence, "unrestricted") and therefore captures a mean drift of the $I(1)$ variables X_t. On the other hand, Case II includes an unrestricted drift, as well as a deterministic linear trend that is restricted to the cointegrating relation. The new variations of model 4.1, for each respective case, are as follows:

$$I: \quad \Delta X_t = \mu_0 + \Pi X_{t-1} + \sum_{i=1}^{k-1} \Gamma_i \Delta X_{t-i} + \epsilon_t$$

$$II: \quad \Delta X_t = \mu_0 + \Pi^{(ii)} X_{t-1} + \sum_{i=1}^{k-1} \Gamma_i \Delta X_{t-i} + \epsilon_t \,, \qquad \text{where } \Pi^{(ii)} = \alpha(\beta' + \mu_1 t)\,.$$

VECM interpretation and the Fisher effect

After establishing the testing methodology, it is now time to define the empirical model that is going to be estimated, as well as the theoretical motivation behind its analysis. There are two endogenous variables included in the model: Precious

Metals (PM), which represents gold or silver prices, and the Consumer Price Index (CPI), which represents the general price-level (*note*: the term CPI is not used in a strictly technical sense, since older measurements rely on various estimations and assumptions). Assuming both variables are found to be $I(1)$ and that there exists exactly one cointegrating relation ($r = 1$) between them, then the Case I version of model 4.1 may take the following extended form:

$$\begin{pmatrix} \Delta PM_t \\ \Delta CPI_t \end{pmatrix} = \begin{pmatrix} \alpha_1 \\ \alpha_2 \end{pmatrix} \left(PM_{t-1} - \beta_0 - \beta_1 CPI_{t-1} \right) + \sum_{i=1}^{k-1} \Gamma_i \begin{pmatrix} \Delta PM_{t-i} \\ \Delta CPI_{t-i} \end{pmatrix} + \mu + \epsilon_t \,.$$

A better way to understand the distinct short and long-run dynamics of this model, is to isolate the *error correction term* (ECT). The idea is that, because there are no transitory deviations from the equilibrium point in the long-run, all past differences of the variables will be equal to zero, i.e. $X_{t-2} = X_{t-1} \Leftrightarrow \Delta X_{t-1} = 0$. Therefore, a deviation (shock) at time t will produce the error $\beta' X_t$. If the source of the error dissipates, then the pace in which it returns to its steady state is measured by α. The higher (lower) the value of α, the quicker (slower) it adjusts. Notice, however, that in the absence of a shock, if all $\Delta X_{t-j} = 0 \, (j = 0, 1, \ldots, k-1)$, then

$$\alpha\beta' X_t + \epsilon_t = 0,$$

or

$$PM_t = \beta_0 + \beta_1 CPI_t + \epsilon_t$$

If a restricted linear trend is also present (Case II), then the ECT will take the form:

$$PM_t = \beta_0 t + \beta_1 CPI_t + \epsilon_t \,.$$

The latter two ECTs represent the long-run equilibrium in the model, a relationship that is cited as the *Fisher effect*. This economic theory stems from Fisher's (1930) hypothesis, that nominal interest rates have accumulated all available information on expected inflation. Extending this hypothesis to risk-carrying assets suggests that the expected nominal returns of an asset may be equated to the inflation rate (Jaffe and Mandelker, 1976) — or without differencing: the level asset-prices to the CPI — and the empirical model may take the form of the aforementioned ECTs (Bampinas and Panagiotidis, 2015; Long et al., 2013). Consequently, if the asset-price of a precious metal incorporates all available information on future price-levels, then it is a full hedge against inflation and its price-changes match the changes in the CPI, i.e. $\beta_1 = 1$. Otherwise, the precious metal can be a partial hedge ($0 < \beta_1 < 1$), no hedge ($\beta_1 = 0$) or have superior performance ($\beta_1 > 1$).

4.3 Expected inflation measures

The previous literature has concluded that different nuances of inflation may yield different results when examining the gold/silver - relationship (see Literature Review). Since older data only capture the *headline* CPI (henceforth, HD), a few different methodologies and filters can be applied on it, so as to extract information on *expected* inflation. More specifically, two filters are used for smoothing out the expected inflation: the Hodrick and Prescott (1997) linear decomposition (henceforth, HP), and the Christiano and Fitzgerald (2003) asymmetric band-pass filter (henceforth, CF). For both filters, the result of interest is the trend component of the series.

The HP filter was originally designed to capture business cycle components, but has been found to be a good proxy for rational expectations on future inflation (Bampinas and Panagiotidis, 2015). It is based on the idea that a time series can be decomposed in a cyclical and a growth component, of which the cyclical component is on average zero in the long-run (Hodrick and Prescott, 1997). Here, the component of interest is the trend, or growth, which is a smoothed value close to the original observation, and is calculated by solving:

$$\text{Min}_{\{g_t\}_{t=-1}^{T}} \left\{ \sum_{t=1}^{T} c_t^2 + \lambda \sum_{t=1}^{T} [(g_t - g_{t-1}) - (g_{t-1} - g_{t-2})]^2 \right\}$$

where g_t is the growth component at time t, c_t is the cyclical component (measured as the deviation of the growth component from the actual series), T is the number of observations and λ is a positive penalty parameter for the variability of g_t. The higher the penalty, the more smoothed the series is, and the farther away from the original observations it stands. For annual data, as is the case here, it is a common practice to use $\lambda = 100$ (*note*: another common value is 6.25, though here it produces an $I(2)$ series that becomes fruitless in cointegration testing).

The CF is an asymmetric band-pass filter that similarly aims to decompose a time series x_t in a trend and a cyclical component. The main bottleneck, its creators argue, is that an ideal band-pass filter, a periodic filter that removes all unwanted frequencies from the data, would require an infinite number of observations. Therefore, they create an approximation of the optimal one, in the sense of minimizing the mean squared error of a linear projection of the data generated by the ideal filter (Christiano and Fitzgerald, 2003). For an infinitely long time-series x_t, the ideal band-pass filter $B(L)$ will produce

$$y_t = B(L)x_t,$$

the filter has the structure

$$B(L) = \sum_{j=-\infty}^{\infty} B_j L^j, \quad L^k x_t = x_{t-k},$$

and its weights are

$$B_j = \frac{\sin(jb) - \sin(ja)}{\pi j}, \quad j >= 1$$

$$B_0 = \frac{b-a}{\pi}, \quad \alpha = \frac{2\pi}{p_u}, \quad \beta = \frac{2\pi}{p_l},$$

where p_l and p_u are the lower and upper oscillation periods respectively. The Christiano and Fitzgerald (2003) approximation of the optimal band-pass filter ($\hat{B}(L)$) will produce a projection $\hat{y}_t$, which is the function

$$\hat{y}_t = \sum_{j=-f}^{p} \hat{B}_j^{p,f} x_{t-j}, \quad f = T - t, \ \ p = t - 1,$$

and where $\hat{B}_j^{p,f}$ is a solution to the minimum squared error

$$\min_{\hat{B}_j^{p,f}, j=-f,\ldots,p} E\left[(y_t - \hat{y}_t)^2 \mid x\right].$$

For each step of the process, the calculations at moment t are conducted using the whole data-sample, which makes the analysis both non-stationary and asymmetric; a fact that does not produce any significant problems, while simultaneously assisting in the minimisation goal (Christiano and Fitzgerald, 2003). The end-goal of the CF filter is similar to that of the HP one, to extract the trend or cyclical components of the business cycle, though the CF can additionally perform the same analyses for various data frequencies and various lengths of filtering. The latter is measured by p_l and p_u, which control the oscillation periods, i.e. the frequency-analysis under a set minimum and maximum time-interval (here the period of 2 to 8 years is used, representing the business cycle; Christiano and Fitzgerald, 2003).

Chapter 5

Results

The following section empirically tests whether gold and silver are hedges against inflation. Section 5.1 is an overview of data used in the analysis, including a quick summary of their time-series plots. Section 5.2 approaches the problem from a few different angles: how the real prices of precious metals acted during inflationary or deflationary periods, whether they have retained their value and have remained constant over time, and lastly, how they match up against other inflation-hedges. Section 5.3 presents the results of the cointegration analysis and compares them to the respective results of Bampinas and Panagiotidis (2015). Lastly, in Section 5.4 follows a small summary and discussion.

5.1 Data

The data consist of 231 annual observations ranging from 1792 to 2022; the starting date is determined by the availability of data for the US. The gold market price-series cover the aforementioned time span and, following previous literature (Baur and Lucey, 2010; Bampinas and Panagiotidis, 2015, among others), are converted to the domestic currency of each country (US$ and UK£), so as to reduce the valuation effects of exchange fluctuations. Both the series and the historical exchange rates are obtained from Officer and Williamson (2023). Historical data of silver prices are obtained from Kitco Metals Inc for the UK (via kitco.com), from the Bureau of the Mint (1965) for the US, and the London Bullion Market Association for prices after 1968 (via data.nasdaq.com). Lastly, the US inflation series is sourced through Carter et al. (2006), for dates preceding official measurements, and the official data by the US Bureau of Labor Statistics. Similarly for the UK, historical rates are obtained from O'Donoghue et al. (2004) and the official series of the UK Office for National Statistics. A complete summary of sources is available in the appendix (Table A.1). All data are transformed into logarithmic form.

Taking a look at the US data (Figure 5.1, left-side), it is clear that the nominal prices of gold have doubled in the span of just fifty years, mostly owing to sharp increases in the 1970s and around the 2000s. Historical prices are in line with the events described in section 2.2. The pegged gold-price was constant during bimetallism and the gold (-exchange) standard (until the late 1960s), except for a few disturbances caused during the Civil War (the "greenback" period). Similarly, silver prices had remained constant until the abandonment of the bimetallic regime (Act of 1873) and later followed a downward trend until World War II. In the wake of the Great Depression gold became unavailable to the general public, and the role of silver gained more importance in transactions and industry, especially after the war; thus silver-prices took a steady upward trend. Interestingly, the shock after Bretton Woods was short-lived for silver markets. Lastly, general price levels have been relatively lower in the US, with a slight deflationary trend in the 19th century.

Similar conclusions are derived from the graph depicting UK data (Figure 5.1, right-side). Notwithstanding a period of suspended convertibility in the 1810s (Napoleonic Wars), gold remained fixed for all of the classical gold standard. Though England was not in a bimetallic regime, silver prices also remained stable; as Jastram (1977) argued, other commodities were drawn by gold and converged at a more-or-less stable level. In the late 19th century, however, the latter took a downturn and followed an almost identical path to that of the US. After gold convertibility resumed in 1925, and during the much troublesome gold-exchange, gold prices gained in value against the pound sterling. Once again, this became more intense after the 1960s. A noteworthy observation is that, during most if not all periods, the dollar price of

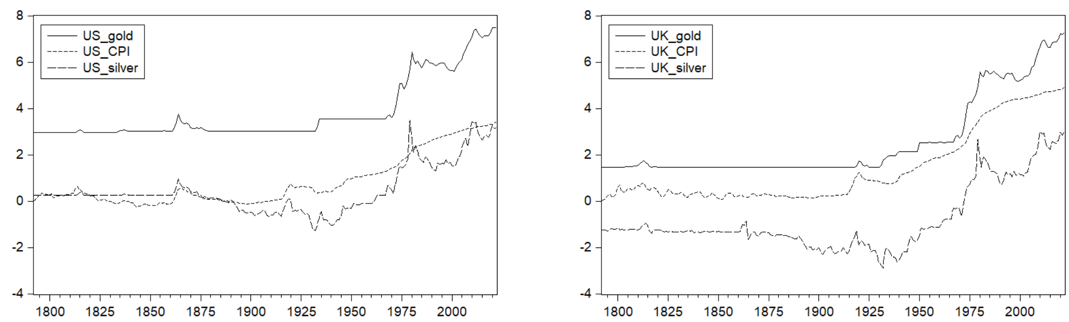

Figure 5.1: Gold, silver and consumer prices in the US (left) and UK (right)

gold was noticeably higher than that of the sterling-denominated one (before taking exchange rates into account), owing to a relatively undervalued dollar and partly due to higher convertibility rates in the US. Finally, general price levels have risen faster in the UK during most periods.

5.2 Purchasing power of gold and silver

The simplest of methods to determine whether precious metals have retained their purchasing power, is to directly compare their price trajectory with that of inflation. If the real price of an asset (i.e. inflation-adjusted price) remains at least constant during inflationary periods, then it can be said that it acted as a hedge against inflation. Jastram and Leyland (2009) and Erb and Harvey (2013) conduct such an analysis for gold, Jastram (1981) for silver, while Bampinas and Panagiotidis (2015) employ various stationarity tests as well. This thesis also follows a similar analysis, and, for comparison's sake, also recreates the analysis of Dempster and Artigas (2010), by comparing precious metals to other inflation hedges in the US.

5.2.1 Purchasing power: historical prices

The real prices of gold and silver are depicted in Figure 5.2, where different shades denote different CPI trends (dark grey: inflationary, light grey: deflationary, white: stable). The classification of the aforementioned periods as well as the specific dates are taken as suggested by Jastram and Leyland (2009); except for the years after the latter's publication which are at this author's discretion. The terms for classifying different CPI trends are used "in a sense descriptive of prices' behavior" (page 84), and not by following a technical definition (*note*: Leyland, in Jastram and Leyland (2009), considers 1980–2000 disinflationary and 2000–2008 inflationary, as a way of capturing general inflation expectations).

A close look at Figure 5.2 yields the following observations: real gold prices in the US have decreased in four out of seven inflationary periods, have increased in three out of four deflationary periods, and have moved without a particular pattern during "stable" times. The real price of gold has been on average 2.69 ($14.77), has had a peak of 3.925 ($50.65, in 1980; also $46.96 in 2012) and a low of 1.70 ($5.49, in 1970). Regarding the inflationary period 1933–1976, gold had been steadily losing the real appreciation caused by president Franklin Roosevelt's policy in the 1930s, up until the establishment of the two-tier gold market in 1968, after which it gained

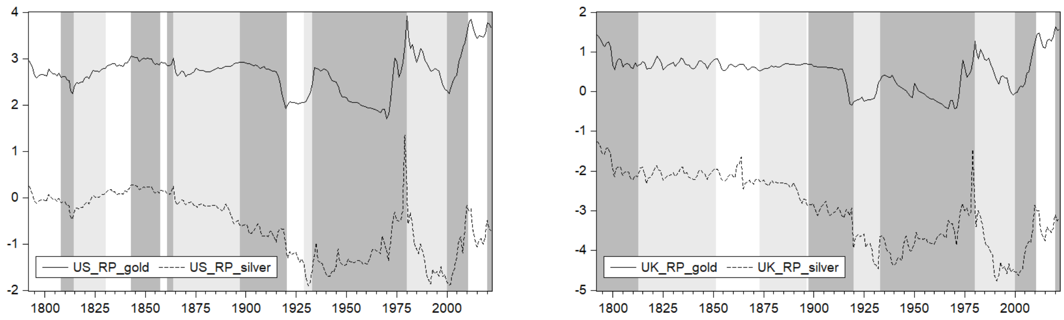

Figure 5.2: Real price of gold and silver in the US (left) and UK (right)

substantially in value. In fact, during the gold standard, the purchasing power of gold had persistently sustained losses during inflation and had gained during deflation, while the opposite became true subsequent to the collapse of Bretton Woods. Thus, gold has only been an inflation hedge during periods of floating gold markets — though as of writing this thesis, gold has lost real value in 2023.

On the other hand, silver markets in the US have been much more volatile. Silver has lost purchasing power in four out of seven inflationary periods and three out of four deflationary periods. Its real price has been on average -0.61 ($0.54), and has varied between -1.90 and 1.34 ($0.14 and $3.81, respectively). In the bimetallic standard, real silver prices matched the trajectory of gold, as was to be expected. After that, real prices have been erratic during all periods, and have shown clear trends only in the long-run. Although real silver has also appreciated during the last two inflationary periods, its abrupt corrections make it seem as a less reliable hedge.

As depicted in Figure 5.2 (right-side), gold prices in the UK seem to have a more or less similar dynamic with inflation. Before 1971, gold had lost purchasing power in all three inflationary periods, and had small to medium gains during most deflationary periods. Since 1971, gold has been able to hedge against inflation (except the last period where the result is still unclear) but has depreciated during deflation and periods following inflation. On average, real gold prices have stood around 0.51 (£1.66) and have had only slightly less variability than the US — between -0.43 and 1.62 (£0.65 and £5.05), a smaller interval by just 0.161 — while its low and peak values were recorded in 1970 and 2020, respectively.

Silver too has followed a similar path to that of the US, losing real value during most inflationary and deflationary periods. However, this is also where the difference in monetary regimes becomes more apparent. Though real silver prices largely followed gold prices, the short-term volatility was far more pronounced, meaning that price changes were sometimes bigger for silver prices (which were free during the gold standard). On average, the purchasing power of silver stood at -2.93 (£0.05) and varied significantly, from -4,76 to -1.27 (£0.008 and £0.28). It is worth pointing out, that silver has never reached anywhere near the same level of purchasing power since 1792, except for a brief spike in 1979 reaching 1.47. Also, during much of the 19th century real silver prices had a very slight downward slope (especially since a number of countries were abandoning bimetallic or silver standards) which did not fully materialize until after 1890. Overall, silver has acted as an inflation hedge in the UK, but only during flexible markets.

5.2.2 Purchasing power: (non-)stationarity of real value

Another way to determine whether precious metals have been good inflation hedges is to statistically test if their inflation-adjusted price has been constant over time. In theory, the inflation-adjusted price should be mean reverting, to a constant value, if gold/silver prices were indeed rising at the same pace as inflation (on average). This can be examined by employing the following three stationarity tests: the augmented Dickey and Fuller (1979, ADF) test, the Phillips and Perron (1988, PP) test and the Ng and Perron (2001, NP) test. The results are presented in Table 5.1.

Evidently, real prices of gold have not been constant in both the US and the UK, a finding which deviates from previously mentioned papers. Only the NP test with a constant finds gold in the US to be stationary at the 5% level of significance. All other results seem to suggest that real gold series are non-stationary processes with a strong trend-component. In retrospect, this seems intuitive when considering the analysis of the previous subsection. Gold prices have been surging ahead of inflation for the past 50 years, therefore it is safe to assume that gold returns have not remained constant against inflation, simply because they increase beyond general price-levels for a significant part of the sample — one fourth of the data.

The results for real silver prices are less consistent. First differences are indisputably stationary series, confirming the strong trend component of year-to-year changes. Level data, however, have mixed test results: the ADF and NP test mark them as stationary series only when assuming a deterministic trend in the process, while the PP has p-values very close to (and above) the 10% significance level. This conclusion seems out of order when looking at Figure 5.2, where both US and UK lines mostly have a distinguishable downward direction, indicating that the tests

Table 5.1: Tests of stationarity for real prices of gold/silver

	Stationarity tests					
	ADF		*PP*		*NP*	
Level	c	c,t	c	c,t	c	c,t
rp_gold_us	0.3053	0.6128	0.2731	0.5653	-8.4908	-9.1607
rp_silver_us	0.2748	0.0753	0.1601	0.1279	-3.7623	-17.5225
rp_gold_uk	0.2828	0.8150	0.1833	0.7093	-2.7565	-4.5244
rp_silver_uk	0.1299	0.0420	0.2043	0.1128	-1.1313	-15.9149
1st diff						
rp_gold_us	0.0000	0.0000	0.0000	0.0000	-68.4511	-70.4363
rp_silver_us	0.0000	0.0000	0.0000	0.0000	-62.7766	-62.9846
rp_gold_uk	0.0000	0.0000	0.0000	0.0000	-76.4073	-69.7964
rp_silver_uk	0.0000	0.0000	0.0000	0.0000	-68.1972	-64.3665

All tests compare the null hypothesis of a unit root. For NP, the MZa statistic is compared to the following 1%,5%,10% critical values: -13.8, -8.1, -5.7 with a constant; -23.8, -17.3, -14.2 with constant and trend. For ADF and PP the p-values are compared to the respective level of significance. ("rp": real price)

might be distorted from the noticeable spike in 1979. Indeed, when replacing the 1979 value with the average of the two adjacent observations, all three tests show significant evidence that real silver is a non-stationary process, both with and without a trend. Evidently, silver series are being heavily brought down by the consistent losses during a big part of the sample (after the late 1880s and up until the 1970s).

In short, both gold and silver prices have been more or less following an individual trend throughout a significant part of the sample, which got heavily distorted in the 1970s–1980s. Therefore, it would be erroneous to blindly consider either of the two as having consistently (not) retained their real value. The final result always depends on the time-span examined.

5.2.3 Precious metals versus traditional assets in the US

Whether the anecdotal belief that precious metals protect against rising prices is valid or not, it may still be interesting to examine if they have performed better in a given time-frame, compared to other "traditional" inflation-hedges. As evidenced from the previous subsection, gold and silver have been more reliable inflation-hedges in the periods after the Bretton Woods collapse, and since the cited indices were usually created at a later date, the time-frame is determined by data availability. This analysis is limited to the US, due to lack of data for the UK.

Dempster and Artigas (2010) conduct a thorough analysis of such kind, comparing New York gold prices to: Standard and Poor's - Goldman Sachs Commodity Index (GSCI; a production-weighted commodity-price index), Bloomberg Real Estate Investment Trust index (REIT; a capitalization-weighted index of real estate investment trusts) and the Barclay's U.S. Treasury Inflation-Protected Securities index (TIPS). Their final conclusion is that, gold has shown to improve risk-adjusted returns during low and medium inflation, its performance has been superior to that of the aforementioned assets and its price-trajectory has been erroneously regarded as a relatively volatile asset. A small part of their results is available for comparison in the appendix (Table A.2).

In an identical fashion, this thesis compares the performance of gold and silver against the same aforementioned asset-types (*note*: the Wilshire REIT total market index and the US TIPS market yield by the Board of Governors of the Federal Reserve System are being used instead). The goal is to add silver to the discussion of Dempster and Artigas (2010) and extend the period so as to include possible market corrections after the 2007 financial crisis. Now, the total periods (especially the longer ones) include environments of various investor-expectations, and can therefore give useful insight into how these assets perform in a long-run investment-horizon. The results of the analysis are presented in Table 5.2 and Figure 5.3, where real returns are the inflation-adjusted returns, and volatility is measured by the standard deviation.

Evidently, market prices have progressed considerably and the previous conclusion of gold as a better performer, might not be valid anymore. Over the whole period (1980–2022), gold has appreciated by 2.4% yearly, on average; a higher return than the negative value of silver (-0.54%) but significantly lower than the 9.0% annualized real return of the WILREIT. The same stands true in the slightly smaller period (1986–2022), though in which silver had a much higher real return of 3.75%. In the period regarding the twentieth century only (2003–2022), gold (7.6%) and the GSCI (6.0%) were much closer to the WILREIT (8.9%), while silver (9.64%) enjoyed the highest real appreciation of the lot and TIPS (-1.6%) were the only depreciating assets. As for price-volatility, gold had the lowest during most periods and silver the consistently highest. Additionally, WILREIT had the highest return-to-volatility ratio during the whole period and gold for the remaining ones.

The above results make all the more sense when their historical background is

Table 5.2: Gold/Silver versus traditional inflation hedges*

Annualized Real Returns (%)					*(own results)*
Period	*GOLD*	*WILREIT*	*GSCI*	*U.S. TIPS*	*SILVER*
1980 – 2022	2.4	9.0			-0.54
1986 – 2022	2.8	7.5	2.4		3.75
2003 – 2022	7.6	8.9	6.0	-1.6	9.64
Annualized Volatility (%)					
1980 – 2022	19.4	16.0			28.0
1986 – 2022	13.1	16.0	17.7		25.0
2003 – 2022	13.6	18.7	20.5	2.0	30.0

*Compare to Table A.2
Sources: own calculations; data: for calculating real gold/silver returns see Table A.1; Wilshire US REIT total market (via fred.stlouis.org); Standard and Poor GSCI (via finance.yahoo.com); Market Yield on U.S. Treasury Securities at 10-Year Constant Maturity on an investment basis (Board of Governors of the Federal Reserve System, via fred.stlouis.org)

taken into consideration. First, after the 1970s gold and silver markets were still recovering from the period of the two-tier gold system, hence their downward price-trajectory in the 1980s is reflected in the real returns. This effect is so strong, that if the silver prices of just the year 1979 were to be added to the analysis (a 423.49% real return), its annualized real return would amount to 9.09%. Thus, it is very important to acknowledge that the results will (almost) always carry the bias of selecting the time-period. Second, the real estate market has recovered and significantly grown since the 2007 financial crisis, a period which was at the end-point of the analysis from Dempster and Artigas (2010). Even though the main index is somewhat different, it is still to be expected that the results in Table 5.1 are vastly different from the negative percentage of the aforementioned authors (appendix, Table A.2).

To summarize, most assets have been able to hedge against inflation, on average (Figure 5.3). However, the REITs are the ones that have consistently offered higher returns than inflation, while gold and silver have been closer to it the further markets move away from Bretton Woods. It is famously cautioned that past performance may not guarantee future results, but the relatively low historical volatility of gold and modest real returns might indeed make it a valid consideration for US investors; though the same cannot be said about silver which is a very unstable asset.

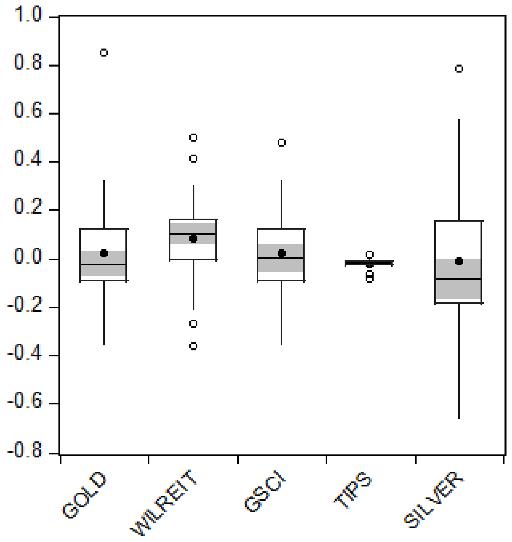

Figure 5.3: Real returns boxplot of potential inflation-hedges

5.3 Cointegration results

5.3.1 Johansen-test results

The first step towards testing for cointegration is to confirm that the variables in question have a unit root present (Chapter 4). Similarly to a previous analysis (Section 5.2.2), the ADF, PP and NP stationarity tests are employed. For the ADF the lag order is tested downwards by choice of the lowest BIC, and the PP and NP are both employed using the Bartlett kernel and Newey-West bandwith selection. The testing results are presented in the appendix (Table A.3) for both countries. Overall, all variables are non-stationary at levels and stationary at first differences; thus, they all are included in the cointegration analysis. The only results that suggest otherwise are for the HP and CF measures, where the ADF with a constant fails to identify them as $I(1)$ variables and all other tests accept the null of a unit root but at lower significance levels. This pattern is present for both countries, suggesting a small disturbance caused by the processing of the original CPI series.

The cointegration results are presented in Table 5.3, though before presenting individual results, it is worth mentioning that both countries have similar results on long-run relationships, and will therefore be presented together.

First, regarding headline inflation, the null hypothesis of no cointegrating relation with gold is rejected at a moderate significance level. Case I tests with the AIC

Table 5.3: Johansen tests for cointegration (US and UK)

US	**Johansen Test**					
	AIC			BIC		
	Case I	Case II	lags	Case I	Case II	lags
Headline Inflation						
gold, HD	**	-	7	*	-	2
silver, HD	-	-	3	-	-	2
Expected Inflation						
gold, HP	***	**	11	*	-	5
gold, CF	***	***	10	***	***	10
silver, HP	-	-	6	-	-	5
silver, CF	*	**	10	*	**	10

UK						
	AIC			BIC		
	Case I	Case II	lags	Case I	Case II	lags
Headline Inflation						
gold, HD	**	*	10	**	-	2
silver, HD	-	-	3	-	-	2
Expected Inflation						
gold, HP	***	**	7	*	*	6
gold, CF	***	***	11	***	***	11
silver, HP	-	-	6	-	-	6
silver, CF	**	*	12	*	-	11

*,**,*** denote rejecting the null hypothesis of no cointegration at the 1%,5%,10% respectively. All cases compare the trace test-statistic (Doornik's gamma-approximation p-values) against the level of significance.

present stronger evidence than any other combination, while the BIC has overall weaker results, especially for the UK. In contrast, silver has no long-run relation with headline inflation. *Second* comes expected inflation, where the results are more promising. There is a noticeably stronger connection between gold and expected inflation that is true for both filters. The CF-measured expected inflation is cointegrated with gold at the 1% level, for all cases, criteria and countries; an intriguing observation that may invite questions on the integrity of the results. On the other hand, the HP inflation has strong results with the AIC but not with the BIC so much so, that the US relation fails to reject the null.

Overall, gold is cointegrated with expected and mostly Case I headline inflation, while there is weak-moderate evidence of a cointegrating vector between silver and expected inflation as measured by CF. The number of null-rejections is almost identical between Case I and Case II, with the exception of Case II tests when using the BIC. In comparison to the time-invariant cointegration tests of Bampinas and Panagiotidis (2015), the results presented here are not far off; US and UK tests are slightly stronger here but by no surprising margin. The only noticeable difference is the consistently higher statistical significance of the CF-measured inflation, and especially the fact that silver and CF yield better cointegration results here. Nevertheless, silver fails to be cointegrated with headline and HP inflation for both countries.

5.3.2 VECM results

The results of the VECM estimations are presented in Table 5.4 for the US and Table 5.5 for the UK; each country is to be examined separately and compared to the respective time-invariant results of Bampinas and Panagiotidis (2015). Based on the methodology (Section 4.2), the analysis focuses only on the first equation corresponding to the Fisher-effect, including the loading matrix. As a reminder, a precious metal hedges fully against the respective inflation-measure, if it rejected the null in the Johansen cointegration-tests and if the threshold of $\beta_1 \geq 1$ is reached within the ECT.

Starting with the US, it is clear that gold has been performing significantly better than inflation, with returns much higher than needed for it to be deemed a hedge. The long-run beta (the slope coefficient of the cointegrating vector) is consistently above 1.27 and statistically significant at the 1% level. Though mostly expected inflation-measures have reached this point of estimation, the Case I gold-

Table 5.4: US VECM. Own results, and Bampinas and Panagiotidis' (2015) results

US		**Own results**		**Bampinas and Panagiotidis (2015)**	
	Series	Cointegrating vector	Loading	Cointegrating vector	Loading
AIC					
Case I					
	gold, HD	$g_{us} = 2.73 + 1.29^{***}$HD,	a = 0.062 ***	$g_{us} = 2.58 + 1.24^{***}$HD,	a = 0.004
	gold, HP	$g_{us} = 2.66 + 1.38^{***}$HP,	a = 0.085 ***	$g_{us} = 2.86 + 1.31^{***}$HP,	a = -0.0006
	gold, CF	$g_{us} = 2.64 + 1.41^{***}$CF,	a = 0.075 **	$g_{us} = 2.80 + 1.37^{***}$CF,	a = 0.0002 *
	silver, CF	$s_{us} = -0.79 + 1.47^{***}$CF,	a = 0.044 **	-	-
Case II					
	gold,HD	-	-	$g_{us} = -0.002t + 1.28^{***}$HD,	a = 0.012
	gold, HP	$g_{us} = 0.001t + 1.31^{***}$HP,	a = 0.078 ***	-	-
	gold,CF	$g_{us} = 0.005t + 1.27^{***}$CF,	a = 0.048 **	$g_{us} = -0.004t + 1.61^{***}$CF,	a = 0.00002 ***
	silver, CF	$s_{us} = 0.008t + 1.43^{***}$CF,	a = 0.024 **	-	-
BIC					
Case I					
	gold, HD	$g_{us} = 2.73 + 1.30^{***}$HD,	a = 0.050 ***	$g_{us} = 2.89 + 1.39^{***}$HD,	a = -0.004
	gold, HP	$g_{us} = 2.55 + 1.51^{***}$HP,	a = 0.046 ***	-	-
	gold, CF	$g_{us} = 2.64 + 1.41^{***}$CF,	a = 0.075 ***	$g_{us} = 2.80 + 1.37^{***}$CF,	a = 0.0002 *
	silver, CF	$s_{us} = -0.79 + 1.47^{***}$CF,	a = 0.044 **	-	-
Case II					
	gold, CF	$g_{us} = 0.005t + 1.27^{***}$CF,	a = 0.048 ***	$g_{us} = -0.004t + 1.61^{***}$CF,	a = 0.00002 ***
	silver, CF	$s_{us} = 0.008t + 1.43^{***}$CF,	a = 0.024 **	-	-

Source: own results (left), Bampinas and Panagiotidis (2015), Table 5, p. 23 (right)
*,**,*** denote statistical significance at the 1%, 5% and 10% level respectively.

HD relation also yields promising results. A similar significance is also present for the loading coefficient. In all cases, coefficient α (the adjustment vector) of the ECT is statistically significant; the cointegrating relation is meaningful to the VECM. Following a shock and a deviation of $\beta' X_{t-1}$ from the equilibrium point, gold prices are going to compensate for inflation at time t at a speed of 100 times α, percent. Thus, the positive sign means that when inflation rises, gold prices will rise as well, effectively keeping its real value at least constant. This correction is more persistent for expected inflation, an observation that makes intuitive sense considering that investors may look further into the horizon and compensate for possible inflation-losses (e.g. gold-hoarding; Adrangi et al., 2003). Regarding the silver-CF relation, its beta is higher than that of gold in three out of four cases, its statistical significance is indisputable, and the loading vector has a significantly positive sign (though slightly smaller values). The part that stands out, however, is the negative intercept in Case I models.

The arithmetic mean of all betas is 1.38, a mere hundredth shy from those of

Bampinas and Panagiotidis (2015), which they find to be 1.39 (only their HD, HP and CF betas are included in this calculation). The authors' peak is very high at 1.61 (gold, CF), while here it is lower at 1.51 (gold,HP). However, the extended time-frame of this thesis allows all gold-relations and at least one silver-relation to be captured. Also, the loading coefficient is much bigger and consistently significant at high levels. The latter observation suggests that, price-adjustments in the VECM of this thesis are much faster and have a stronger pull towards the "equilibrium point". Lastly, the coefficient of each restricted trend is positive, meaning a small but upward direction over time.

The inflation-hedging results for the UK are milder compared to the US, though gold still manages to fully hedge against inflation (Table 5.5). All long-run betas of the UK stand around the same level, a result that neutralizes the dominant edge of gold against expected inflation. The highest slope coefficient is equal to the lowest of the US, which surprisingly is for the silver-CF and gold-HP relations. Nevertheless,

Table 5.5: UK VECM. Own results, and Bampinas and Panagiotidis' (2015) results

UK		**Own results**		**Bampinas and Panagiotidis (2015)**	
	Series	Cointegrating vector	Loading	Cointegrating vector	Loading
AIC					
Case I					
	gold, HD	$g_{uk} = 0.82 + 1.21^{***}$HD,	a = 0.073 ***	$g_{uk} = 1.09 + 1.12^{***}$HD,	a = 0.018
	gold, HP	$g_{uk} = 0.81 + 1.22^{***}$HP,	a = 0.071 ***	$g_{uk} = 1.09 + 1.15^{***}$HP,	a = -0.0006
	gold, CF	$g_{uk} = 0.83 + 1.21^{***}$CF,	a = 0.086 ***	$g_{uk} = 1.08 + 1.17^{***}$CF,	a = 0.00001
	silver, CF	$s_{uk} = -2.64 + 1.27^{***}$CF,	a = 0.045 **	-	-
Case II					
	gold, HD	$g_{uk} = 0.002t + 1.15^{***}$HD,	a = 0.065 ***	$g_{uk} = -0.001t + 1.15^{***}$HD,	a = 0.03 *
	gold, HP	$g_{uk} = 0.001t + 1.18^{***}$HP,	a = 0.066 ***	$g_{uk} = -0.001t + 1.19^{***}$HP,	a = 0.0004
	gold, CF	$g_{uk} = 0.001t + 1.16^{***}$CF,	a = 0.077 ***	$g_{uk} = -0.021t + 1.24^{***}$CF,	a = 0.00001
	silver, CF	$s_{uk} = 0.002t + 1.23^{***}$CF,	a = 0.039 **	-	-
BIC					
Case I					
	gold, HD	$g_{uk} = 0.79 + 1.24^{***}$HD,	a = 0.049 ***	-	-
	gold, HP	$g_{uk} = 0.75 + 1.27^{***}$HP,	a = 0.054 ***	$g_{uk} = 1.09 + 1.23^{***}$HP,	a = 0.0008 *
	gold, CF	$g_{uk} = 0.83 + 1.21^{***}$CF,	a = 0.086 ***	$g_{uk} = 1.08 + 1.17^{***}$CF,	a = 0.00001
	silver, CF	$s_{uk} = -2.48 + 1.16^{***}$CF,	a = 0.048 **	-	-
Case II					
	gold, HD	-	-	$g_{uk} = -0.002t + 1.15^{***}$HD,	a = 0.045 **
	gold, HP	$g_{uk} = 0.002t + 1.18^{***}$HP,	a = 0.047 **	-	-
	gold, CF	$g_{uk} = 0.001t + 1.16^{***}$CF,	a = 0.077 **	$g_{uk} = -0.021t + 1.24^{***}$CF,	a = 0.00001

Source: own results (left), Bampinas and Panagiotidis (2015), Table 5, p. 23 (right)
*,**,*** denote statistical significance at the 1%, 5% and 10% level respectively.

gold is a full hedge against both expected and headline inflation, silver is a good hedge against expected inflation, and all CPI measures are statistically significant in the cointegrating vector. The latter also applies for the loading matrices, which have a sizeable, strongly-significant impact in the adjustment dynamics of the VECM. Similarly to the US, the intercept of the Case I silver-CF relation is negative, while restricted trends are low and positive. Compared to the 1.18 beta of Bampinas and Panagiotidis (2015), the arithmetic mean of all betas here is 1.20. The loading matrices continue to be considerably higher, while restricted trends are positive. It is worth noting that Bampinas and Panagiotidis (2015) find that silver in the UK is not a hedge against any inflation-type in their time-invariant VECM analysis.

5.4 Discussion

Based on the aforementioned analyses no clear-cut conclusion can be reached regarding the long-run hedging abilities of precious metals. Looking at historical prices, gold managed to more or less keep its real price constant during the gold and bimetallic standards, but suffered in credibility during the Bretton Woods system. Silver lost its inflation hedging ability once its currency value subsided, and has been struggling to be a reliable hedge ever since. Clearly, public gold markets revamped the significance of both precious metals and gave them the necessary momentum to overcome loss of value during some inflationary periods. Whether this achievement will happen more often than the few documented times, however, remains to be seen. Note, that the definition of "inflationary" periods is at the discretion of Jastram and Leyland (2009), therefore a strict, technical definition might render both metals useless as inflation hedges. The same result can be argued about the stationarity of real prices, which also relies on the discretion of choosing which time-period to examine and whether to include explosive peaks or not.

Comparing gold and silver to other inflation-hedges is also a tricky process. Both of them have exceptional real annual returns, while gold also has relatively low annualized volatility, especially in periods that are further away from the 1970s market-turmoil. It is a reasonable assumption then, to suppose that they could be a valid consideration for an investor's portfolio, if the choice of competing assets is small. A capable investor, though, can have multiple other instruments at their disposal, many of which may prove more fruitful than a very broad or whole-market index, or a non-productive commodity.

Turning to the cointegration analysis, VECM estimators deem gold as a hedge against inflation, better so for the US than the UK and at higher levels against expected inflation. The higher than 1 long-run beta suggests that gold is an asset that compensates in excess of inflation losses. The same conclusion is not true for silver, however, since it can only hedge against expected inflation and only through the measurement of the CF filter. Nevertheless, loading coefficients are high and significant for both metals and countries, indicating that the Fisher effect is quick to counterbalance inflationary shocks.

Chapter 6

Conclusion

The goal of this thesis was to try and give an answer to whether gold and silver are able to hedge against headline or expected inflation in the long-run, by examining a time-period covering 231 years (1792–2022), and passing it through the historical lens of multiple monetary regimes and legal-tender policies. The optimal result would be an analysis that carefully interprets the market nuances of each historical period, successfully incorporates and extends the work of Bampinas and Panagiotidis (2015), and provides food for thought questioning the anecdotal belief that gold/silver are reliable inflation-hedges.

Chapter 2 provided a brief history of the monetary regimes in the US and the UK, and acted as a guideline on how to interpret the price swings of precious metals. The historical period covers a de facto silver, bimetallic, de jure gold and gold-exchange standard, when gold and silver prices were part of currency policy and not publicly traded commodities. As evidenced by the analysis in Section 5.2, legal tender convertibility and credibility played a key role in the hedging-effectiveness of gold/silver; an ability that clearly depends on the time-period examined and the chosen point of comparison. The latter analysis found that gold retained its purchasing power in the long-run and in both countries, though at a volatile state when outside of a gold standard. Silver, on the other hand, proved to be an inconsistent inflation-hedge, losing much of its real value and relying on sporadic peaks or high-momentum markets. From an investor's perspective, both metals are valid considerations compared to other assets, but may not be optimal for someone with a wide variety of other choices.

From the perspective of a cointegration analysis, as per the VECM (Johansen, 1995) and the theoretical background of the Fisher effect (Fisher, 1930), gold is a superior hedge against inflation, better so for the US and slightly better against expected inflation (measured by the Christiano and Fitzgerald, 2003, and Hodrick and Prescott, 1997, filters). Its long-run beta and equilibrium speed-adjustment are considerably high, meaning gold-prices are usually over-correcting upwards. The respective results for silver are much more modest, considering that only the CF filter captures such a dynamic.

In summary, US gold markets are more probable to hedge against expected inflation in the long-run, though an unequivocally presented verdict would be erroneous. The aforementioned analysis lacks the non-linearity that previous authors have cautioned against (e.g. Wang et al., 2011), as well as the time-varying element (Bampinas and Panagiotidis, 2015). Seeing as inflation hedging is a vital part of financial planning, the two metals should be also put through rigorous financial analyses and treat the dynamic as a purely financial one (e.g., Erb and Harvey, 2013; Dempster and Artigas, 2010; McCown and Zimmerman, 2006). Finally, both methodology and assumptions ought to be critically reviewed in order to complete the mere representation of results.

Appendix

Table A.1: Summary of data sources

	Series	Time Period	Description	Source
Gold				
	us_gold	1791–2022	New York market prices	Officer and Williamson (2023)
	uk_gold	1791–2022	London market prices	Officer and Williamson (2023)
Silver				
	us_silver	1792–1967	New York market prices	Bureau of the Mint (1965)
		1968–2022	LBMA market prices	LBMA (via data.nasdaq.com)
	uk_silver	1791–1967	London market prices	Kitco Metals Inc (kitco.com)
		1968-2022	LBMA market prices	LBMA (via data.nasdaq.com)
Inflation				
	us_cpi	1791–1913	Consumer Price Index	Carter et al. (2006)
		1914–2022	Consumer Price Index, all urban consumers	Bureau of Labor Statistics
	uk_cpi	1791–1947	historical composite price index	O'Donoghue et al. (2004)
		1948–1987	Retail Price Index, all items	Office for National Statistics
		1988–2022	Consumer Price Index, all items	Office for National Statistics

Table A.2: Gold versus traditional inflation hedges (Dempster and Artigas, 2010)*

Annualized Real Returns (%)		*Dempster and Artigas, 2010*		
Period	*GOLD*	*BBREIT*	*GSCI*	*U.S. TIPS*
Jan 1974 – May 2009	2.0		2.8	
Dec 1993 – May 2009	3.6	-2.1	2.1	
Mar 1997 – May 2009	5.9	-3.8	-0.2	3.7
Annualized Volatility (%)				
Jan 1974 – May 2009	19.5		20.1	
Dec 1993 – May 2009	14.7	21.4	23.0	
Mar 1997 – May 2009	16.0	23.4	25.0	6.1

*Compare to Table 5.2

Source: Dempster and Artigas (2010), exhibits 1 and 2

Table A.3: Tests of stationarity for US and UK series

US	Stationarity tests					
	ADF		*PP*		*NP*	
Level	c	c,t	c	c,t	c	c,t
gold	0.9996	0.9901	0.9996	0.9885	3.5074	-0.3084
silver	0.9367	0.9298	0.9566	0.9521	0.2427	-2.3877
HD	0.9992	0.9656	0.9970	0.9806	2.8946	-0.1673
HP	0.9978	0.9551	0.9996	0.9774	2.8327	-0.2304
CF	0.9890	0.8396	0.9997	0.9806	2.8946	-0.1673
1st diff.						
d_gold	0.0000	0.0000	0.0000	0.0000	-85.0442	-68.5690
d_silver	0.0000	0.0000	0.0000	0.0000	-88.4486	-77.9193
d_HD	0.0000	0.0000	0.0000	0.0000	-75.8550	-70.8905
d_HP	0.1357	0.0245	0.0444	0.0402	-13.9952	-15.2317
d_CF	0.1230	0.0035	0.0081	0.0186	-13.8906	-16.5672

UK						
	ADF		*PP*		*NP*	
Level	c	c,t	c	c,t	c	c,t
gold	0.9990	0.9919	0.9999	0.9946	3.6765	0.3999
silver	0.9864	0.9604	0.9951	0.9780	2.2150	-0.9687
HD	0.9992	0.9708	0.9999	0.9865	2.7390	0.0288
HP	0.9995	0.9662	0.9998	0.9813	2.6462	-0.1640
CF	0.9997	0.9444	0.9988	0.9797	2.4666	-0.1389
1st diff.						
d_gold	0.0000	0.0000	0.0000	0.0000	-94.2376	-92.8749
d_silver	0.0000	0.0000	0.0000	0.0000	-98.2429	-94.0820
d_HD	0.0000	0.0000	0.0000	0.0000	-87.9029	-72.1268
d_HP	0.1360	0.0568	0.0908	0.0977	-8.9218	-10.3184
d_CF	0.3051	0.1764	0.0011	0.0023	-33.2258	-34.9218

All tests compare the null hypothesis of a unit root. For NP, the MZa statistic is compared to the following 1%,5%,10% critical values: -13.8, -8.1, -5.7 with a constant; -23.8, -17.3, -14.2 with a constant and trend. For ADF and PP the p-values are compared to the respective level of significance. (return to section 5.3.1)

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