Modelling the gold market, explaining the past and assessing the physical and economical sustainability of future scenarios[1]

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ABSTRACT

By using an integrated dynamic model we are able to reconstruct the supply and gold price of the past (1920-2010) and this is used to predict the future supply of gold to the market and to make a forecast of the goldprice 2010-2100. The model was validated against field data for the period 1920-2010 and it performs well. The model GOLD is implemented in the STELLA® software and the model described in the article. The simulation results show that the market is fundamentally driven by supply and demand, but that derivates trade and speculations have affected the market significantly to create large short term variations in price. The investigations show that during 1930 to 1971, the price was set by the governments of the US and UK, that after 1971 it was a functioning market and that during 1990-2000, the gold price was artificially depressed by foreward and derivates trade. On the theme of long term supply the model predicts a shift from high-grade ores to low-grade deposits as the main virgin supply source in the next 50 years, but that recycling will become the most important source of gold to the market. The authors predict a significant tightening of the gold market, with rising prices and a decreased derivates trade as compared to trade in the physical commodity. It has been claimed that foreward and derivates trade would stabilize the markets and the price. However, the model shows clearly that this is not the case, but that foreward and derivates trade create less stability and increase price fluctuations, but that they cannot prevent the long term trend from basic fundamental factors to set the long term levels.

Keywords: Gold price, sustainability, commodity market,

Introduction

During 2008 and 2009, much of the world economic system is going through a major economic crisis, and one important contributing element is the fact that too many economic decisions lost contact with physical realities, inventing materials, values and resources that never have existed. Because of significant doubt about the security of paper money, inflation and actual coverage in real values, physical gold has received increased attention from private investors as a safe haven of a physical monetary entity. The oldest gold items are more than 7,000 years old, and since then, gold was always used as a symbol of great value. It was to be followed by silver in a dual currency system. This dual metal standard system was upheld from 550 BC until its final breakdown in 1971 (Kock Johansen, 2001). At times through history, rulers and governments have tried to monopolize the handling and possession of gold,

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[1] The predictions are to be seen as hypothetical predictions, based on our best available information at the moment of writing. These studies are predictions in the same way as weather forecasts, and do in no way constitute financial advice. Investors may use this material completely on their own risk.
[2] Guldcentralen AB in Solna, near Stockholm, Sweden, is a wholly owned company in the KA Rasmussen
[2] Guldcentralen AB in Solna, near Stockholm, Sweden, is a wholly owned company in the KA Rasmussen group, with it's headquarter at Hamar in Norway. K A Rasmussen is a refiner of precious metals and a trading house for physical metal (gold, silver, platinum, palladium and rhodium). www.ka-rasmussen.no, www.guldcentralen.se

however, in the long run they always failed. The father of King Kroisus (550 BC) of Lydia, King Alyattes (about 630 BC), was probably the first official authority to issue governmental money in gold and silver as coins (Kock Johansen 2001, Sear 1978). The coins counted for their metal value, these metals being the essence of money. Thus the standardized currency was born. The first international currencies were the Athenian owl, based on silver tetradrachms and the dual Persian system of gold coins called Darics and silver coins called Sigloi (Sear 1978). At several times in history (In China during the Han dynasty 200-400 AD, during the Yüeh dynasty 1340-1450 AD and in many European states 1700-present), man has experimented with paper money, however, most of the time these systems have collapsed after some time because of abuse of the system. The foundation of the system is the understanding that the paper money is only a proxy of value kept somewhere else (property, commodity, bullion metal), and that the issue of these proxies do not exceed the value behind it. Hyperinflation is the main cause for the collapses, resulting from abuse of the system by issue of uncovered paper. All governments are tempted at overprinting paper money to pay the bills when the state coffers appear to go empty. Many governments have succumbed to that temptation and have subsequently ruined their economies (Lietaer 2001, 2003, Lietaer et al., 2010, Muelbauer 2010, Borio et al., 2010, Bussiere et al., 2010). The unique thing with gold as a currency is that it is independent of the issuing authority, and there no way to cheat to create gold. Gold and silver coinage can be debased, but that is normally detectable even to the layman.

Objective
We will investigate the long-term sustainability of the gold market in terms of supply and stability of the price. We will do this by modeling the major fluxes and stocks in the world and connect this to price as determined by the presence of tradable in the official gold exhange. We assume that some gold is never visible at the metal exchanges, but are traded as over-the-counter trade with the official metal exchange price as a guide.

The scope of this study is to model and investigate the mechanisms of the gold market in a time period when the market changed from a politically governed price regime driven by governments and cartels, to a market at least to a large degree driven by market mechanisms of demand and supply driven by technical uses and investment needs. The intent is to explain and reconstruct the past gold price and quantify the metal fluxes in society. We will show that use of simulation models is important for understanding the market dynamics and the ability to predict. We intend to develop a dynamic simulation model for the gold market, in order to be able to predict gold fluxes and get an approximate estimate of the price to be expected as based on the resource availability situation in the market. The model is not expected to be able to reproduce short-term variations, but we do aim to try to capture the overall long-term trends.

Hypothesis
Gold is a limited resource, and the gold market is affected by the fact that it is a free market within set physical limits. Our hypothesis is that the price of gold and the physical availability can be modeled based on a systemic mapping of gold flows in the world gold trade system. Our hypothesis is that the derivates trade has distorted the price and disturbed the market system by increasing financial risks and inflated stock estimates.

Key assumptions and historical background
We apply the following fundamental assumptions:

1. The laws of thermodynamics are universally valid, the principles of mass energy balance apply everywhere with no exception.
2. We assume that the production statistics and recorded stocks and movements of the Central Banks largely been correct.
3. We assume that the official statistics on gold reserves in the ground have the correct order of magnitude.

Further assumptions and the set stage in this study are defined as follows from below;

1. The gold market is characterized thus:
    a. Before 1800, gold was the real money, and paper money was a rarity and rather unstable unless strictly backed by gold or silver.
    b. Between 1800-1932 it was a largely free, but unregulated market, and gold was treated the same way as money, paper money was gold or silver backed, and gold was the ultimate currency
    c. Between 1932-1971 the market was a command and control system, a governmental cartel, along with limited sub-regional black markets. Gold possession is prohibited in several countries for private persons, unless in jewelry. Gold was not easily traded over state borders during this period. However, in many countries, gold was seen as the only true kind of money.
    d. After 1971 it is for most practical purposes, a free market, and movement of gold is relatively unrestricted. However, for large transactions, the invisible hand of a central bank cartel was still at times seen there. Trade was internationally free, but fluxes are greatly influenced by central bank sales and purchases. Some countries, not being free trade countries and several countries with dictatorship have restrictions on moving gold across their borders: such countries are United States, Russia, India, China, Brazil, Cuba, North Korea, and in addition some countries have limitations on private ownership of gold: Russia, Cuba, North Korea. In many countries with weak, none or chaotic government and economy, gold, Euro and Dollars remained as the only true currencies.
2. Paper gold, which existed through the bank notes being gold certificates since 1830 to around 1935, and was available to the public along with minted gold in most of the great powers. The old paper gold was to a large degree backed by central bank physical gold holdings for most of the time. The gold monetary standard was abandoned in Europe in 1925 and in the USA in 1932, when paper monetary volume expansion made it impossible to back every banknote with physical gold. Gold was used as a clearing currency between national banks until 1971, when the United States cancelled that system. After 1971, US dollar was only pegged to global social trust, the gold backing being gone. Paper gold reemerged after 1973 as a separate market for gold certificates, being like banknotes with only a gold value printed on them, as well as metal accounts, metal loans and forward contracts for gold. This was originally not available to the public, but only to gold processing companies and financial institutions.
3. There is not full alternativity in the gold market, as only gold is the real magic money metal in the eye of the public, and beside silver the only money a government cannot corrupt and which also survives a governmental collapse
    a. There is a limited financial substitute in silver and in modern times by small amounts of platinum and palladium as bearers of monetary value in solid physical manifestation
    b. The total physical amounts of all gold, silver and platinum are very limited

4. Gold is sold as physical metal as well as paper gold, ownership to gold as shown on a metal bank account. The amount on the account is supposed to have a corresponding amount of physical metals somewhere if the trader is a serious trader.

It is important that all paper gold must be backed by physical stocks somewhere, for the system not to be fraudulent. We will show that the world of gold has narrow physical limits and that the economic assumption of full substitutability is invalid for gold. Central Bank, investor and private transactions in the gold market was used as input data to the model for 1900-2040. The values are to a large degree derived from official statistics.

Methods and definitions

The methods are those of systems analysis and systems dynamics incorporating mathematical modeling of complex systems. We will analyze the system using flow charts based on box-arrow symbols, causal loop diagrams and mathematical modeling using the STELLA® system. We intend to use available published data sources (examples are USGS 2008, Gordon et al. 2006, Platinum Review 1996-2008, Strahan 2007, 2008, INSG 2008, Cross 2000, OCC 2009, Ragnarsdottir 2008), but also undocumented business information available to us at K A Rasmussen a/s, Norway, as part of the precious metal community, as well as different official and semi-official commodity statistics available in the internet. Many of these sources are not consistent between them and we will make expert judgment on what we think is the most likely figures when there are uncertainties. Paper gold is defined as any type of paper indicating ownership of gold without the actual physical possession of the metal. Thus as paper gold we count gold certificates, gold account statements, forward or short contracts and metal loans.

Table 1. *Data for gold. Financial significant precious metal stockpiles, production, recycling rate and estimated time horizons to scarcity for 2008.*						
Mining rate % per yr	Burn-off time yrs	Hubbert-decline to 10 %, yrs	2008 Estimate, available ton	2008 mining ton/yr	Re-use rate %	Approximate world inventory in tons 2000
6.0	17	37	40,000	2,400	90-96	146,000

The physical resource situation

Gold comes ultimately from mines, and approximately 160,000 tons have been produced on earth totally during the last 7,000 years. Of the amounts extracted, we have lost 13,000 tons, retaining approximately 147,000 thus long-term dissipative loss was 8.5% on the average for this time period. It is estimated that approximately 30,000 tons remain to be mined in known high-grade ore bodies (Table 1). We estimate that another 10,000 tons may potentially be available in ore bodies not yet discovered. Another 20,000 thousand ton remains to be mined from low-grade ores and as contaminant in copper, silver and zinc ores, or in gold ores that are only available if the gold price increases very significantly (the estimate of reserve base comes from USGS 2008 statistics at their website). We have added 50,000 tons of low-grade reserves as hidden reserves to be found by prospecting, which gives us a total estimate of 70,000 tons low-grade reserves. Likewise, we estimate that the reserves of ultralow-grade reserves are known to be approximately 10,000 tons and we have assumed that 50,000 tons lie hidden to be discovered by geological prospecting (Table 2).

Hence, we have known reserves of 120,000 tons and an estimated amount of 50,000 tons remaining hidden in 2010. This brings the global total ground reserves to 170,000 ton in 2010. Total inventory of gold on the planet before the end of the next ice age, reachable in some way for humans, is thus 350,000 ton. We have shown a flow chart of the world's gold market in Figure 1, indicating the approximate size of the major stocks in 2000. Gold is traded in banks and the price is set at the London, New York and Tokyo metal exchanges. Central banks have hoarded gold in periods, all depending on politics.
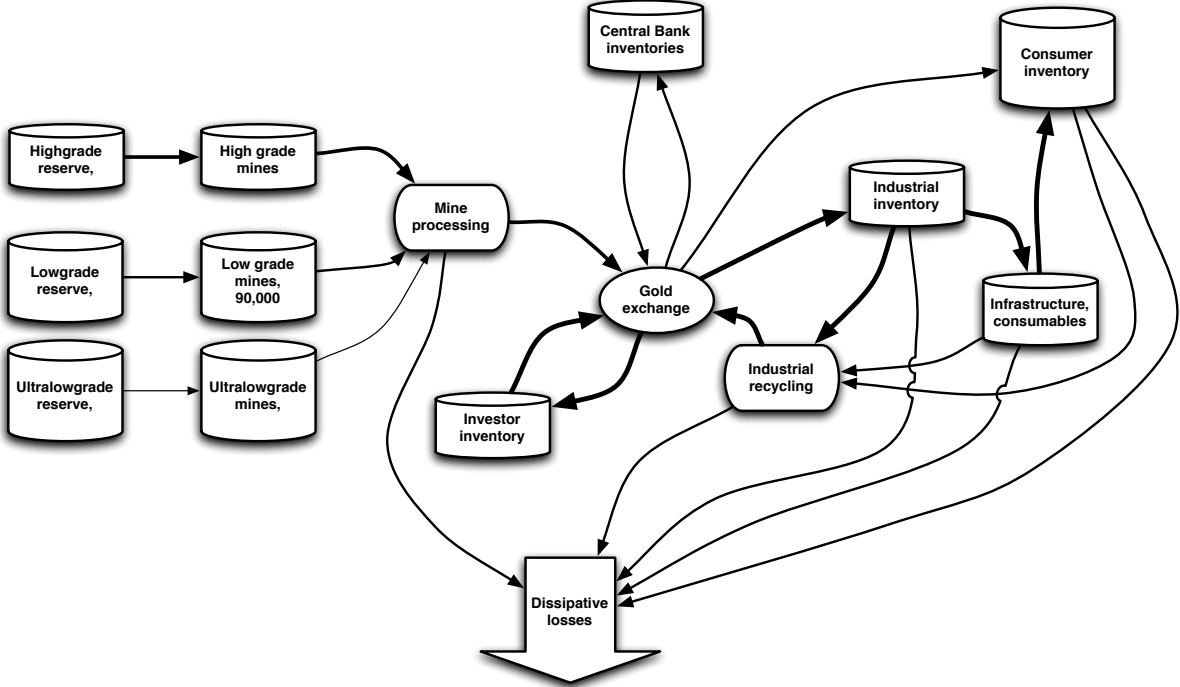
Figure 1. *Flowchart for world gold material fluxes. Most actors trade through the market, trade takes place geographically dispersed, but linked through the price systems at the London and New York Metal exchanges.*

In parallel, gold is traded on contracts and physical possession has been separated from ownership through metal accounts. However, there are suspicions that the system has been misused, and there are probably paper contracts for far more gold that actually can be matched by real metal. This remains as a significant problem with all kinds of paper money. There are three alternative ways to own gold:

1. Physical possession of coin, minted ingots, gold ornaments or jewellery
2. Gold on a metal account or a certificate at a bank, financial house, trader or metal processing firm
3. Gold on a forward contract that promises delivery or purchase in the future

When we later look at the market, we need to add up the amounts in all these three alternatives and then hold that up against what is physically available. With alternative 1, ownership and possession are the same. With alternatives 2 and 3, physical possession is

separated from legal ownership, just like it is with money in a bank. Alternatives 2 and 3 rest on the trust that the bank has coverage for its accounts and promises, either in contracts with

Table 2. *Gold stocks. Estimates of gold in different market inventories in tons, with uncertainty range for 2008. The availability of total market data is limited and the numbers are very rough estimates.*

Grade	Known reserves	Hidden reserves	Range of estimate	Sum
Estimate for calculation start 1900, thousand ton				
Highgrade	100	100	70-130	200
Lowgrade	0	80	50-100	80
Ultralowgrade	0	70	50-100	70
Sum	100	250		350
Estimated for year 2010, thousand ton				
Highgrade	10	20	15-35	30
Lowgrade	50	20	10-70	70
Ultralowgrade	60	10	30-70	70
Sum	120	50		170

someone who has physical possession of gold or that the bank has its own holdings to match the claims made on it. Several of the gold mining, processing, recycling and refining companies normally have metal accounts backed up by their own metal stock. They are, in general, very well covered and able to deliver promptly. It is also useful to remember that mining and recycling are, for practical purposes, almost the same. Physical gold is flowing into these operations from less tradable resources. Trading houses and banks have their own metal stock that they declare openly, but some do not. Here, transparency is small and the risks are as with other bank certificates. Several banks and trading houses back up their contracts with forward contracts and metal accounts with others, and the whole system becomes much less transparent.

Already after World War I, some large economies abandoned the gold standard. First was the German Weimar Republic that went bankrupt in 1922-1923 through hyperinflation and deficits. In 1925, the first larger breakdown in the gold/silver currency came with the abandonment of the right to exchange paper money to gold at will at any time in the National bank, first in most European countries, and in 1932 the United States followed with prohibition of private possession of gold and a forced state exchange of gold at a fixed price. The gold was purchased at $20.67 per troy ounce, and the dollar was subsequently devaluated versus gold to $35 per troy ounce. From that point in time, the paper currencies of the western world lack backing by gold for private persons who hold banknotes. The silver coins were still kept by many countries until the breakdown of the silver standard in 1965. After that, there is no real precious metal standard for the public for any currency. Just in case something big happens, several Central Banks still keep gold as a last safety resort. Before paper gold, money as gold was free of inflation. It does not tarnish with time, and is persistent over millennia. From that moment in 1925, the currencies of the world became based on social trust alone, and many fell an easy prey to inflation. Strict controls against inflation and overprinting did not arrive until 1996 with the European Union budget stability pact, forbidding state budget deficits in excess of 3%.

All this being said, we need to remember that half of the world's population live in countries with no proper government, with little or no democracy and a low degree of state financial accountability. Examples of countries with long lasting civil war, large-scale collapse of rule of law and/or severe economic mismanagement include but not limited to

Afghanistan, Haiti, Somalia, Myanmar, Pakistan, Iraq, Zimbabwe, while countries like Cuba, North Korea and Belarus can be considered as non-development-oriented dictatorships. It only takes one small revolution to make all paper money in a country worthless. Further, in cases of loosing any war, the currency may become worthless. For all these people living under these commonly occurring conditions, gold is the only real money.

Earlier assessments

Some assessments of gold supply sustainability has been made, but with no sufficient detail for gold (Meadows*, et al.*, 1972; Gordon*, et al.*, 2006). Meadows et al (1972) made dynamic runs, whereas Gordon et al (2006) used the simple term burn-off rate, a static measure. In an earlier study, we have made use of simple mass balances without the use of dynamic models (Sverdrup*, et al.*, 2009). The results of this investigation are shown in Table 1. It shows precious metal stockpiles, production, recycling rate and estimated time horizons to scarcity. However, whether we use the burn-off rate or the Hubbert curve (Hubbert, 1982), these are stiff estimates that leaves most of the system dynamics aside, missing adaptive responses in the system, tending to give underestimates of the times really involved.

Model description

We have built a dynamic simulation model for the gold market, based on mass balances phrased as differential equations. An overview of the model is shown in Figs 7-8. The differential equations are solved with a 4-step Runge-Kutta numerical integration routine with a time-step of 0.05 year. We employ the following reservoirs in the model:

- Central Bank gold stock
- Trading arena amount
- Amount locked in industrial processes
- World stock held on private hands, including short term investors
- Reserves in the ground
  - Reserves in high grade deposits
  - Reserves held in low grade deposits
  - Reserves held in ultra-low grade deposits
- Reserves held in mining processing plants

Metal from mines is moved to the market in the model, based on the gold price and the population numbers. Market demand is driven by per capita private consumption, private hoarding, investor demand, industrial use, but modified by price. Demand by central banks is driven by predetermined political decisions. Metal is recycled from public holding, depending on the gold price at any moment. Figure 2 shows the simplest price mechanisms as a causal loop diagram (CLD). It shows the causal loop diagram for a market with a supplier and a customer as we have modelled it, with investors, consumers, industry and central banks. The investors and the consumers have basically the same functionality of operation, whereas the central banks work on political decisions and partly outside pricing.

The gold price is depending on the gold amount physically present in the market. The price curve used has been shown in Figure 2. It was derived from gold price and availability estimates from the period 1971 to 2008.

Figure 3 shows the physical gold system. When paper gold is added to the model, the whole system becomes much more complex, as there are now two interconnected systems (Figure 4-5). The paper system is a proxy system, also depending on the social appreciation of the system and how much social trust there is in it.
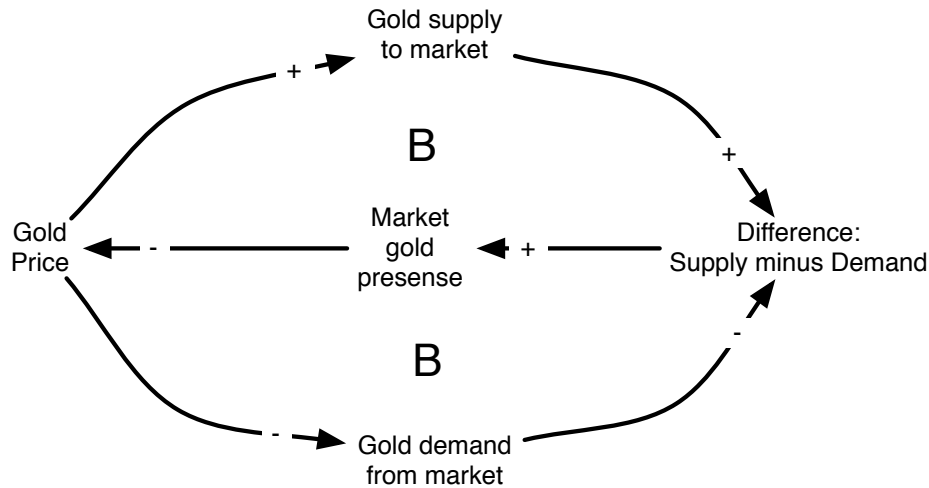
Figure 2. *The price mechanism at the COModity EXchange (COMEX) in London, New York and Tokyo. Causal loop diagram (CLD) for the basic price mechanisms as operated within the gold metal exchanges. Every day the demand and supply proposals are compared; when they are not equal in amounts, the price is increased, if the demand is larger than supply, or vice versa, and then the demand and supply changes. When supply matches demand, the price is fixed. Throughout the day, this is done repeatedly. In a model, supply would be related to price with a characteristic price-supply curve and demand with a price-demand curve. In Figure 2 these curves corresponds to the availability-price curve. Below, the dialog window of STELLA shows the price to market amount curve used in the model. The price curve used for the relationship between presence of gold in the market and price in $ per troy ounce*

The paper gold system is not really open to the public, but it is to some financial institutions, banks, companies and investors. The price is determined by the intensity of gold (G_I) in the market which is defined as a function of physical gold (G_T) in the trade market and the amount of paper market gold (G_P):

$$G_I = G_T + k_P * G_P$$

The coefficient, k_P, is initially 0.00 and increases with the derivate market to about 0.08, with an average around 0.05, but the weight of paper gold may vary depending on the market trust in the paper gold. The coefficient implies that about 5% of all paper gold has a presence in the market, equal to a virtual annual gold flux of 1,400 ton per year in 1975 increasing to 3,600 ton per year in 2007. Many more paper contracts do not pass through the COMEX market, and thus is not part of the price regulating mechanism. The gold demand was expressed as a function of the amount of gold in the market (G_T) times world population (P) plus the demand resulting from social stress levels, the stress index SI, plus the investor purchases I:

$$D = k_D * G_T * P + SI + I$$

Where $k_D = 0.0833$. The stress index is a function of the population size and the political stress index, scaled between 0 and 1 (Figure 3).
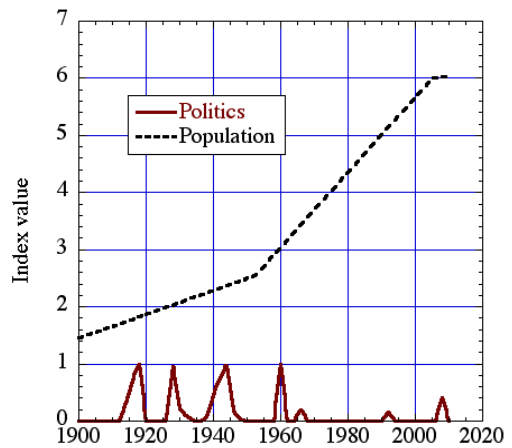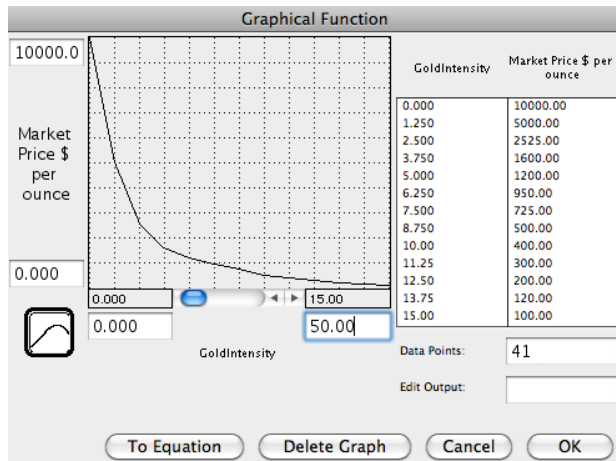
Figure 3. *The earth population stress estimates according to the Tilly equation was added into the overall stress estimate. This is a function of crowdedness, which has so far increased with increased population numbers and urbanization. The diagram shows political stress from great wars and crisis, along with the approximate population in billions.*

The population stress function was derived from data given by Tilly (2005; 2006, 2007) in his discourse on collective violence, the exponent 1.86 indicates that this has to do with kinetic encounters amongst people in a crowd. We have the expression

$$SI = P_S + k_S * P^{1.86}$$

The mining rate (r_G) was set as a function of resource left in the mine (m_G), times an annual production rate (k_M), in 2008 set at k_M=2,400 ton/yr, modified by the worlds populations (P) and a population proportionality factor (k_P):

$$r_G = k_M * m_G * k_P * P$$

where k_P=4.167 per billion person. There are delays in the system. The mining output is delayed for 5 years, due to the large amount of rock that must be moved and the difficulty in changing such a large system. This also mimics the fact that when a mine is opened, it takes 5 years before gold appear at the gate. The industrial delay for recycling was set at 2 months or 10 weeks refining time, not unusual in the market. Decreased social trust in the system will erode the value and decrease the impact of the paper gold on the gold price. Of the world stock only, 80% is really recoverable, and the recycling rate only if the price rise from 0 to 4% annually when the gold price rise from 0 to 1,000 $ per troy ounce. It has maximum at 6.5%. In the model a paper gold market is created when the Central Banks start lending out gold. In 1948-49, the federal reserved lent out 9,000 tons of gold to some of the National Laboratories for physics research and to certain banks in connection with the devaluation of the dollar and the necessary change in the official gold price. In 1973 when the gold market was liberated, a system with paper gold was initiated by the central banks and large private banks lent out the ownership of 23,000 tons of gold, creating a total metal loan market of approximately 29,000 tons. The additional amounts had little transparency in the market on how it was really secured. It is a possibility that a significant fractions of it never existed as it was short-contracts, that is gold that is sold first and then the seller buys it and somehow buys it back physically later. If careful track of how much gold has been sold short and is available in the market is not monitored, it will be possible to oversell into non-existing metal.
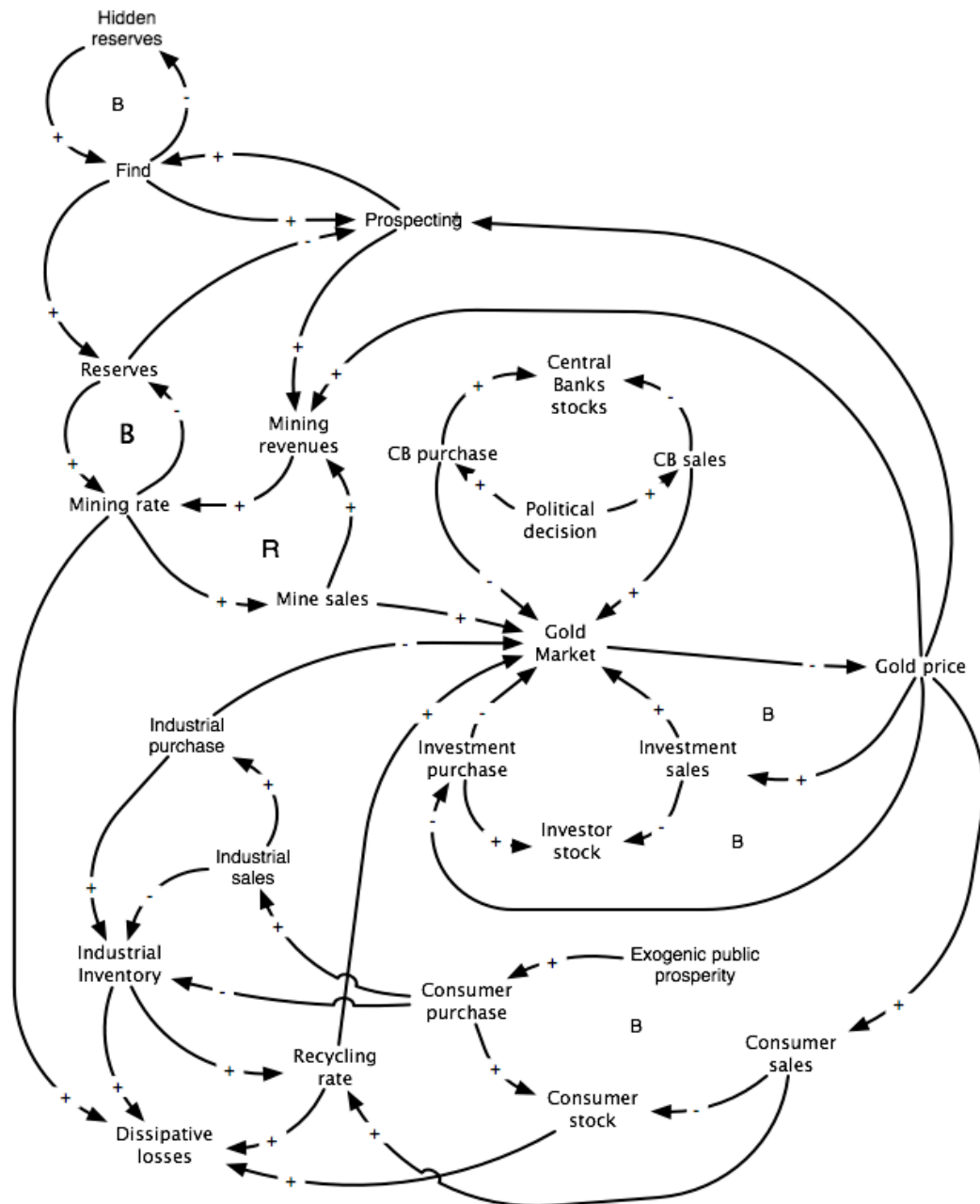
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Figure 4. *Causal loop diagram for the world's physical gold market, excluding the social dimension and paper gold. The market was modeled with 5 different actors: Mining industry, recycling industry, central banks, investors and consumers.*

In the years after that, metal traders and innovative bankers added another 24,000 tons of paper gold that probably never had any physical backing. This was estimated from statistics on inventories and depends on the honesty of those estimates. In the model, calls for physical delivery of contracts are taken from the trading market, private bank holdings and when the amount is insufficient, through Central Bank and market bailout. The central bank sales, investor and private consumer transactions have been reconstructed from the historical statistics, looking at changes in total holdings, year by year.
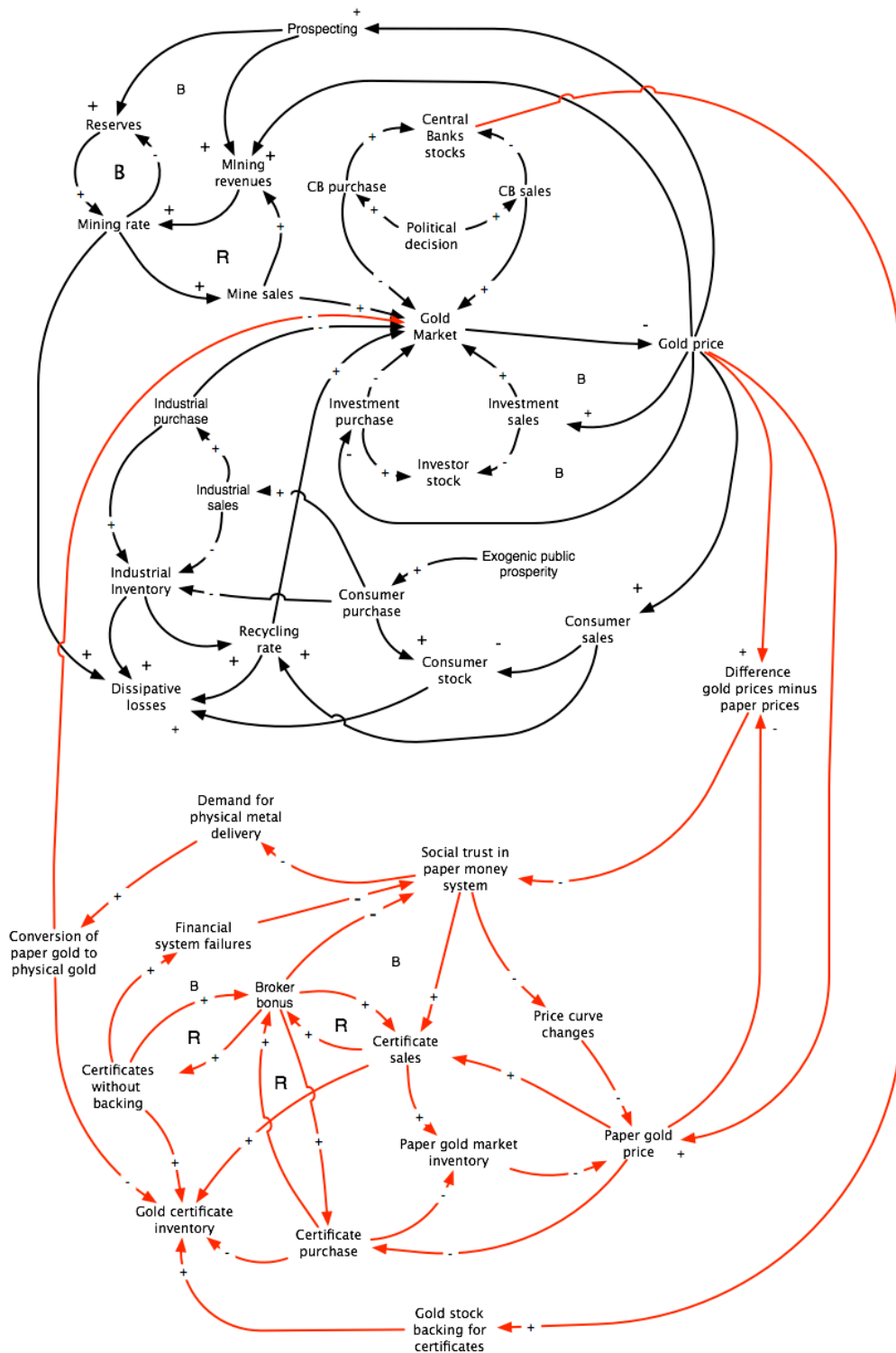
Figure 5. *When paper gold and the social interaction necessary in a virtual market is added to the model, then the whole system becomes much more complex. The paper system is a proxy system, also depending on the social appreciation of the system and how much social trust there is in it. The paper gold system is not really open to the public, but it is to financial institutions, companies and investors, which repackages the whole into different kinds of "structured products".*
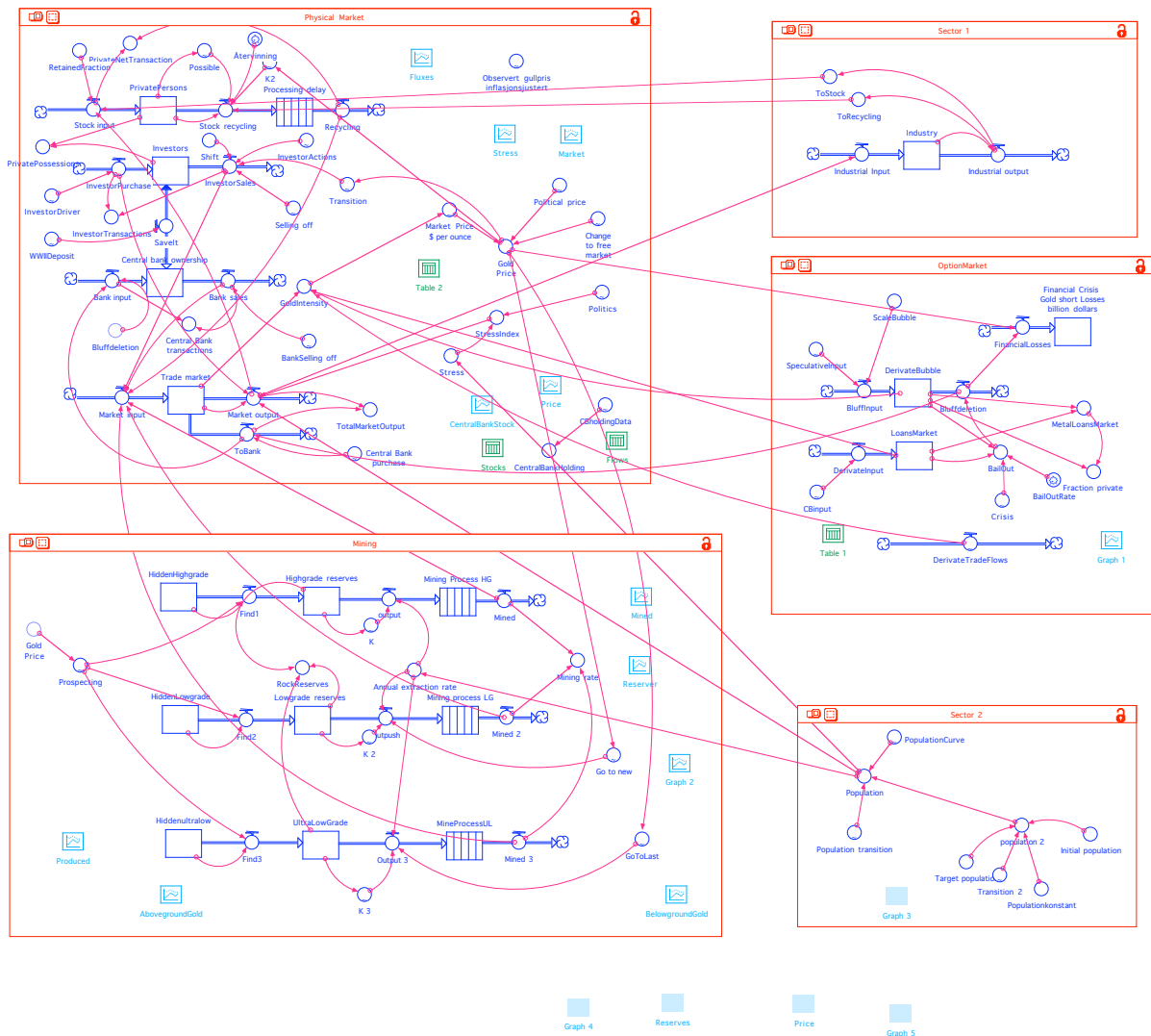
Figure 6. *The STELLA system diagram for the gold market. The model was used for the simulations in this. The model largely tries to capture the market illustrated with a flow chart in Figure 1.*

Results and discussions
Model simulations

The simulations were done for the time period from 1900 to 2040, in order to be able to assess the performance on past, as well as predict for the future. The results of our modelling are shown in the Figures 7-14. Figure 7 shows simulation results for the time period 1900-2040 for simulated total mine outputs from different categories, Fig. 8 the remaining reserves, Fig. 9 shows the central bank holdings as metric ton of pure gold. Prominent in the simulations are that present mines run empty after 2030, when the supply from low-grade mines becomes quite restricted. Figure 10 shows the flux from recycling is as large as the mining rate at present. Most gold come today from high-grade reserves, but these are coming to an end within the next decades. Then gold must come to a larger degree from low-grade reserves. The gold price is at present not sufficiently high for inducing mining of ultra-low reserves. Table 2 shows the distribution of mined gold per year from high-grade reserves, low-grade reserves and ultra low-grade reserves. Figure 9 shows the estimated stocks in different parts of the system. The paper gold market amount to 60,000-70,000 tons in 2008 and there is no certainty that this gold ever existed outside the imagination of creative gold dealers.
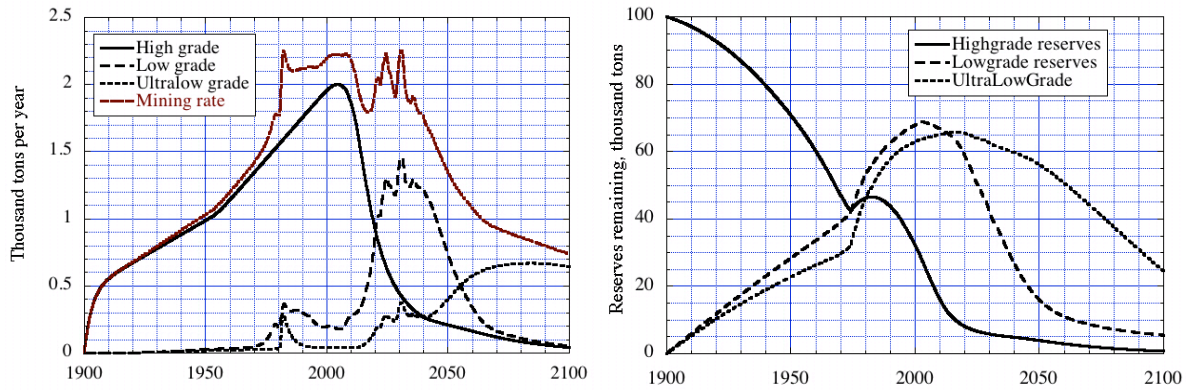
Figure 7. *Simulated total output from gold mines.* Figure 8. *Simulated remaining known reserves.*
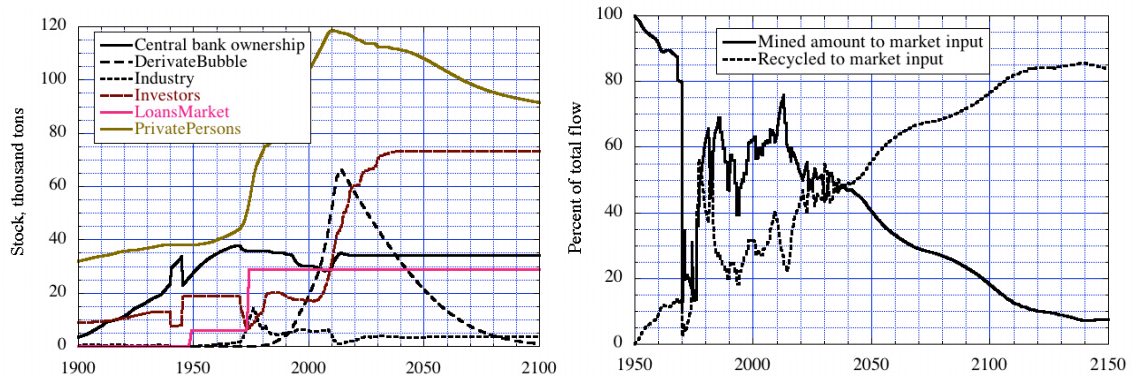

Fig. 9. *The stocks at central banks, private consumers, investors, trade market, industry as compared to the paper gold stock. Further details of the paper gold market are shown to the right. During 2008, paper gold with no documented metal support reached 62 % of the total gold market available for trade.* Figure 10. *The total mining rate as compared to recycling rate.*
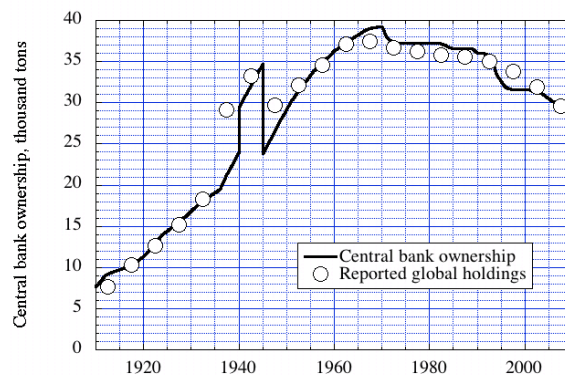

Figure 11. *Simulation of central bank holdings for the period 1900-2040.*

Fig. 12 shows the inflation-adjusted gold price in $ per troy ounce, and the degree of fit with observed data. After 1971, recycling became a major part of market supply. At present, recycling is about 55% of supply, and this will increase. The predictions of Central Bank holdings are not a real test of model performance, as it is based on the actual central bank transaction statistics being true, the total stock estimate is based on official estimates. There have been very consistent rumors in the market for the last 5 years that possibly, half the gold in the Federal Reserve may physically not present. A significant amount of gold from Federal Reserve may have been swapped for paper gold.
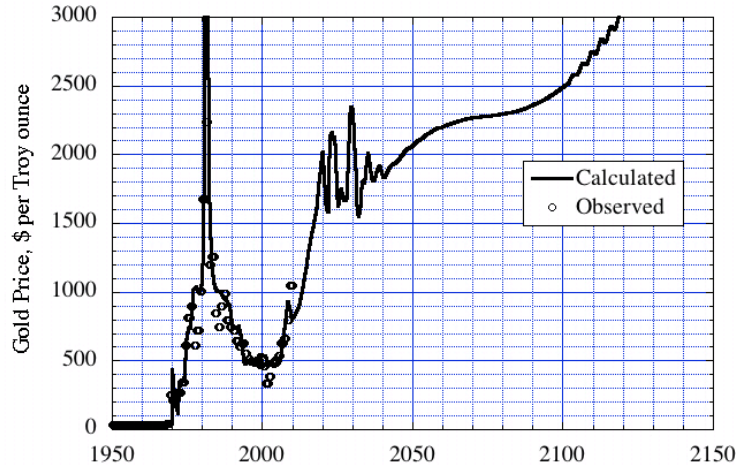
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Figure 12 *Simulation of past and future gold price in $ per troy ounce, adjusted for inflation with anchor point 2008, for the period 1900-2040. The circles show reported price for gold.*

Possibly as much as 15,000 tons may have been swapped for paper gold in the different national treasuries, however it is not possible to get this formally confirmed. However if the national bank sales statistics is indeed correct, then the central bank ownership is indeed intact. The fractions of supply coming from mines sink abruptly after 1971, when recycling increase significantly, reflecting a more fair market price. This also freed up metal for increased industrial use. A fraction of gold is lost by dissipation into the world, this is probably lost forever, with modern use, dwindling new gold from mines, this is increasing.

Recycling is a kind of mining
Recycling often offer an excellent opportunity for a high-grade substrate, many types of waste have higher contents of desired metals than the ore they are originally extracted from. With recycling in mind, parts and alloys may also be designed for facilitating metal recycling from the very beginning, increasing the price of the commodity, but to be offset by the increased end-of-life value. Further more, product design with recycling in mind may make the recycling task much simpler. The implications of recycling can be large. For gold it would imply that at present we use 2,500 t/yr new gold and recycle approximately 2,000 t/yr, a flux of 4,500 t/yr. Increasing recycling to 90% would shift this to 4,000 t/yr recycled, requiring a net extraction of 500 t/yr. For gold, 95% recycling is not utopian but business standard, and that would push the time to scarcity estimate to several centuries.

World extraction rates, reserves and estimated times to scarcity have been estimated in Table 1. The burn-off rate is a crude measure, and is a rough estimate of the time to scarcity. The same apply in some economies where economic liberalists removed most regulations, installing trader bonus and incentive systems, creating something close to a "tragedy-of-the-commons" economic model (Hardin, 1968). However, for exploitation of common goods outside national legislation or with no ownership or diffuse common ownership, such as ocean fisheries, the burn-off rate estimate is very relevant, as the individual exploiter does not care about whether the resource runs empty or not (Ainsworth and Sumaila, 2003; Klein, 2007; Lövin, 2007). For financial use a high price is not use limiting, such as it is for physical use in the industry (Hubbert, 1982; Hirsch, *et al.*, 2005). Within 20 to 100 years, many strategic metals like platinum and gold will enter into the range where they no longer will be readily available, and the price will become prohibitive for their present use. Alternatives are available for some, but not all applications. That is the reality of a world of limits. For gold

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there are no reason to expect any new substantial finds of unexploited resources, simply because the whole globe was searched out.

Table 3. *Estimates for unreal gold stocks. Physical and imagined precious metal amounts and associated paper metal volume estimates in 2008.*		
		Ton of gold
Metal accounts and loans	15,000	5,000-25,000
Gold certificates	6,000	3,000-10,000
Forward contracts	16,000	3,000-10,000
Shorted contracts	16,000	3,000-10,000
Estimated undisclosed contracts	10,000	3,000-15,000
Sum estimate of paper gold	63,000	25,000-95,000

Paper gold, how real is it?

In international trade, metal and commodities for that sake, are traded as physical entities with actual physical delivery of the commodity. The internet is full of very critical accounts, but as with many articles, their substance is difficult to assess (Ash 2002; Butler 2008-2009; Ash 2009; Persson 2009; Chapman 2000, OCC 2009, Duffie 2010, Emery et al., 2009). According to contract overviews conducted by the , at the date of writing, some major American and British banks have big volumes of forward contracts of silver and gold (Estimates run from 40-60% of an annual production of silver and maybe more in gold, but we have not been able to verify nor deny this), it is unknown how much of those contracts there are actual physical coverage for, or for how much the contract holders have declared to want physical delivery. However, there is also a banking system where metals are traded based on ownership but not actual physical possession. The system works perfectly, as long as there are physical amounts equivalent to and associated with the bank accounts. A significantly larger volume has been traded, than what is actually physically available or in existence in total on the globe. Getting estimates for the categories is very difficult, but an attempt has been made in Table 4:

Table 4. *Precious metal overview*						
Metal	World above-ground content	Market stocks estimate	Paper metal estimate	Bedrock resource estimate	Mining rate	Value of paper metal as times annual mining
	ton				ton/yr	
Gold	145,000	20,000	63,000	42,000	2,400	26
Silver	28,000	20,000	40,000	400,000	20,000	2
Platinum	12,000	3,500	5,000	6,600	230	22

The estimates of amounts on metals account, we have very little information in terms of open sources to work from, the same applies to the amount of metal loans, and the exact degree of physical backing of those loans and accounts and we must use expert judgment and what we can learn from asking. We estimate that readily available tradable gold is about 10,000 ton in the markets (jewelry, industrial materials, coins, privately held ingots), in addition approximately 20,000 ton is held by Central Banks worldwide. How much of this that is lent out against gold certificates and is used to back up metal loans, is unknown. Gold held by Central banks is not readily physically tradable, and require political action for sale or purchase. The biggest holdings are United States (reported at 8,100 ton in 2005), Switzerland, France and Great Britain (about 1,000-2,000 ton each in 2005, in 2009, China increased their

stock to more than 1,000 tons, other nations have purchased at least as much annually during 2009-2011). Other individual Central Bank stocks are significantly smaller and run in the range of 50-100 ton. Several emerging economies are slowly building up their gold stock, and some deeply indebted counties are selling off their gold. The COMEX (COMmodity EXchange), has its own stocks of about 100-200 ton, but is backed by contracts with others holding physical amounts. Forward contracts in excess of 100 tons already may jeopardize the COMEX system. We estimate that it is realistic to set the principally freely tradable volume to be 30% of world holdings (40,000 ton), but that only 10,000 ton are available on command in the market without longer delay. Including the remaining 30,000 ton would require time-consuming recycling before it would be available. The privately held gold mostly goes through recycling before being available to investors. The model predictions have to get the fluxes and amounts to obey mass balances. From those calculations we get the following picture (OCC 2009):

Central Bank backed metal loans and contracts:	29,000 ton
Market backed metal loans and contracts:	41,000 ton
Total derivates markets	70,000 ton

The remaining 100,000 tons in society trade only partially and the Central Bank holdings are off limits for daily trade, thus only 15,000 ton are counted as readily available. When we compare paper gold volumes against physical amounts, it appears that the necessary check against the real physical commodity stockpiles and inventories were not made, whereby this often ended up as promises that cannot be fulfilled.

It is all based on the underlying assumption that there is full alternativity in the world for these commodities, and that the world is essentially endless as compared to the actual traded volumes. Neither of these assumptions is true. From Table 4 we can see very approximate estimates of the amounts of money possibly at stake in international metals trade. We seem to be falling short of the existing supply contracts by perhaps as much as 40,000 ton. The net gold production from mining is only 2,100 ton/yr. Gold recycling adds a flux of 2,500 ton/yr. Supply from gold mining alone will require 30 years to fill the hole. Possibly, the some American banks holds gold derivate products for something in the order of 3,000-4,500 ton of gold each alone, at least one major British bank seems to be exposed. The alternative to physical delivery is to supply the gold account holders buyers with replacement money instead, however, that would kill the credibility of the system and discontinue the forward metal trading for quite a while. Then the trust that once was inherent to the system will be gone. The shortfall in money caused by a hypothetical default on paper gold has been estimated in Table 4. The gold derivatives only represent a fraction of all the derivatives these banks have. The precious metals shortfall may be enough to possibly default several of the large gold trading banks and metal trading houses in the world, and large enough to limit the possibility of a state bail-out (OCC 2009, Moessener and Allen 2010, Shin 2010, Sikka 2009). If a sufficient number of actors decide to demand physical delivery instead of rolling their metal positions on paper forward, then the paper gold could break down. Much of the information about the paper gold trade is not readily available, a major market failure of that system. This implies that the insiders have better information than their customers, and thus it is not a fair market, nor can proper controls for honesty, security or actual paper coverage by physical entitles be made. Thus, the paper gold market does not meet the requirements of a transparent and free market. For gold, it would take 25 years of the present production to replace the paper gold deficit, for silver, more than 6 years, for platinum maybe 21 years.

Validation and Uncertainties

Validation of models used for prediction is an absolute must. The field test is the ultimate verdict, if a model fails in a field test, then the underlying theory is probably faulty and normal scientific practice it to either declare it dead or revise it throughly. We have subjected our model to field tests in Figures 13. In Figure 13, we have evaluated the accuracy of our gold price predictions. The diagram shows the spread in observed values for the observed gold price according to the London Metal Exchange archives. The fit is good, $r^2=0.92$. The amount of paper gold, trade contract volume including commodity exchanges, trading houses, banks and metal houses has been notoriously very difficult and the uncertainty range in our estimates are very large. We have conducted several interviews to further elucidate the numbers, but the real sizes remain elusive. The estimates of amounts of paper gold vary widely in the estimates, may be anywhere from 15,000 to ½ million ton, we simply cannot properly verify it with scientific standards. However, estimates average around 50,000-90,000 tons. Food for thought is that these assumptions lead to a very good reconstruction of the past gold price. The gold amounts simulated for the different stocks are a result of the available information on mined gold and Central Bank traded volumes and we can only speculate to why our mass balance numbers differ from official statistics on Central Bank holdings. The diagram to the right shows that we are able to model the gold price under the assumptions taken with an accuracy of +/- 5% on the value. The price between 1900 and 1971 was regulated by governmental law, regulated by the United States and some European central banks. The system broke down in 1971, and after that the gold market works nearly as a free currency or commodity market.
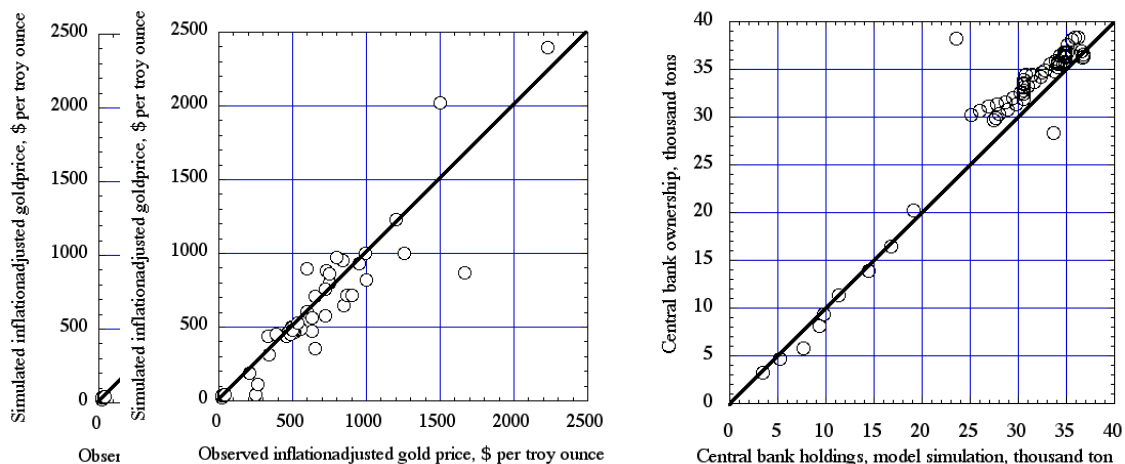

Figure 13. *Validation of the GOLD model. The diagram shows the spread in observed values for the observed gold price according to the London Metal Exchange archives. The fit is good, $r^2=0.92$. The Diagram to the right shows that we are able to model the gold price under the assumptions taken with an accuracy of +/- 5% on the value.*
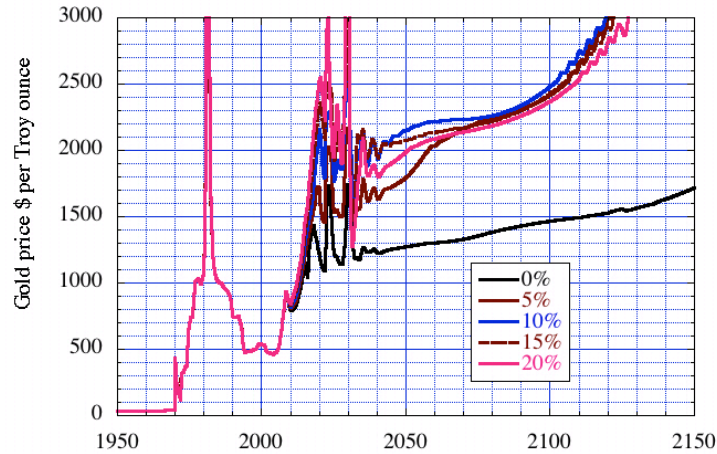
Figure 14. *Sensitivity analysis on the effect of size the effect of changing the derivates bailout rate, showing the effect on the gold price the reading effort e. Line 1-5: 0%, 5%, 10%, 15%, 20% per year, The graph shows that the derivatives market creates major disturbances in the gold price in the market and provides a potential vehicle for manipulating the market. The prediction was made in 2009*

Sensitivity analysis

A sensitivity analysis was made on the degree of recycling, bailout rate and price weight of paper gold in the gold price, with respect to the gold price, market supply and availability of gold in the market. Figure 15 shows a sensitivity analysis the builddown rate of the overdraft on paper gold on the gold price. Steps are 0, 5, 10, 15, 20% unwinding of the forward positions per year. An unwinding rate of 5% is already more than the annual mining rate, and must be taken from the public stock. Free in the market is about 15,000-20,000 ton, or $^1/_3$ of the derivates bubble. It is not known how elastic this amount is and how much it will increase per increase in gold price. Beyond the total available 15-20,000 ton in the market, there is a much more immobile stock of maybe 80,000 ton on private hands. At present, we can see a turbulent world gold market, we think this will continue for some time. At present, there have been established two markets in gold. One that runs the traditional way through the COMEX, which trades in paper gold and to a lesser fraction in physical gold. Beside this market, there are the local markets where the price of physical gold is higher. Bullion coins are now sold at LME Fixing +5% to +20%, all depending on the availability of physical metal in the market.
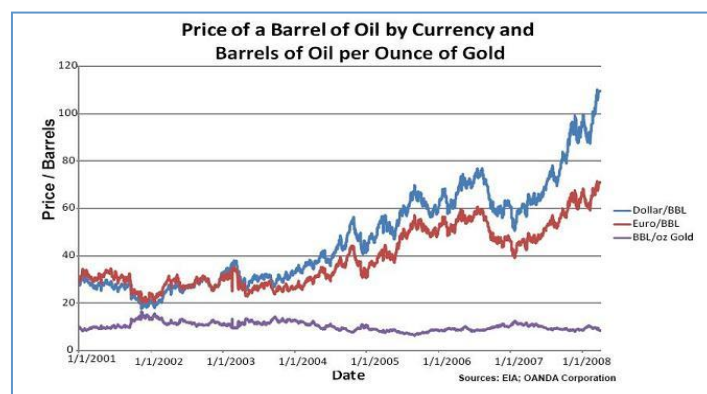

Figure 15. *The oil price calculated as grams of gold per barrel for 2001-2011.*

Conclusions

The gold price in the market can be explained using the available estimates of metal supply to the market and the actions of free market mechanisms. However, the occurrence of gold in the world is physically limited, and this puts a strong mark on the market behaviour.

- Efficient recycling is essential for the functioning of the market for physical gold, and will be even more important in the future. Today recycling accounts for 60% of the flux, and this can be predicted to increase

The effect of the large amount of uncovered paper metal contracts remains to be fully investigated before we can make more firm statements of its effect on the trade and the supply situation. Metal trades will need to pay attention to the fact that only fully backed future contracts will have real value, and forget some of the axioms valid in markets backed by commodities with full alternativity, because those principles are not necessarily valid in the gold markets. Physical limitations to when possession is possible will permanently have to be watched. It seems to us that the system of metal accounts, gold certificates and forward contracts lack in transparency and thus verification of whether the metal coverage really exists. Due to the lack of transparency, the risk for under-coverage seems significant, and the room for misuse is significant. For the security of the metals trade, we can see that some safety measures are needed:

- For derivatives and forwards contracts traded in the official stock exchanges, a complete inventory of all contracts must be kept. When the sum exceeds the physically available amount has been reached, trade must stop and further trade must be classified as fraud. Banks have very poor control of this today, and possibly a poor understanding of the risk, despite being "experts" in their own eyes.
- The market is only a fair market as long as all parties have equal levels of information, thus the system must be more transparent than today, including derivatives volumes, major positions, market size, holding sizes and governmental transactions and holdings.
- Penalties for breaking rules for forwards and derivatives trade. What we have taken on to model is not unique to gold, these conclusions are also valid for other commodities; nickel, aluminium, copper, silver, platinum, grain, etc……

Gold for humanity will last for several millennia, but will eventually run out, the timing depend on the human population development into the future. Under the most probable scenario, we estimate that humans will have gold available from mines for the next 4,000 years. Under the low population scenario, gold will last approximately 10,000 years, approaching sustainability. Thus, gold was our first money, and it may also well be our last.

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