Since the first oil shock in 1973, researchers have focused on evaluating the impact of exogenous shocks to the price of oil on macroeconomic variables. To do so requires the ability to change the price of oil while holding all the other variables constant, which is difficult to do as prices reflect the changes in demand and supply. In addition, the demand shocks do not have the same effect on the price of oil, or vice versa, as a supply shock. To allow the changing of a single variable, while holding the others constant, and observe different effects of the shocks of macroeconomic variables on the price of oil, Killian (2009) proposed a structural Vector Auto-Regressive (VAR) model for the global oil market. He found that a shock to the precautionary demand for oil has an immediate, large, and persistent impact on the price of oil; a shock to the aggregate demand has a lagged, but sustained, increase in price. He also determined that a supply shock causes a small transitory increase in the price of oil. Killian (2009) used the VAR specifically to study the impact of exogenous shocks to the price of oil on the supply and demand, but such methodology can be used to study other commodities or monetary policies.

Using structural VAR models, the economic literature has focused on trying to explain the causes of price fluctuations in gold. On the one hand, Baur and Lucey (2010) found that the price of gold responds to increased uncertainty in the financial markets as gold acts as a “safe haven” for financial investors. On the other hand, Dooley, Isard, and Taylor (1995) found that exchange rate movements influence the price of gold. In fact, current literature has studied gold believing that its price is only affected by financial shocks, ignoring the fact that gold is used in the industrial manufacturing process, like electronics. To determine whether the industrial demand for gold might have a significant effect on the real price of gold, this paper proposes a similar structural VAR used by Killian (2009). The main findings of this paper provide some surprising results. A disruption in the supply of gold leads to a statistically significant and immediate increase in gold production, followed by a sharp decrease in production one quarter after the shock. A sudden increase in the demand for electronics slightly increases the global industrial demand for gold when the shock occurs and causes a growth in the S\&P500 index a quarter after the shock. However, this sudden increase in demand for gold has no statistically significant effect on the real price of gold, serving as evidence that the literature is correct in explaining changes in the price of gold due to supply and financial shocks. An increase in the volatility in the stock market leads to an immediate increase of the S&P500 index, seemingly a counter-intuitive response, and in the price of gold that disappears one quarter after. Lastly, a shock to the real price of gold has no significant effect on supply or demand but has a transitory, positive effect with a one-term lag on the S&P500 index.

Part I of this paper provides a description of the data and shows how the supply and demand for gold are determined from data provided by the World Gold Council and the United Nations Industrial Development Organization (UNIDO). Part II focuses on the construction of the VAR model and the ordering of the shocks. Part III delivers and explains the empirical results. The concluding remarks are in part IV.

\section{I. Building the Data}

The quarterly time series have been taken from three different organizations: the World Gold Council, UNIDO, and the Federal Reserve System from 2011Q3 to 2020Q4. The World Gold Council provides data that will be used to estimate the quantity of gold that is produced, and the data given by UNIDO will be used to build a proxy for the global industrial demand for gold, henceforth referred to as gold demand. The Federal Reserve System, through the Federal Reserve Economic Data database, gives the quarterly percent change in the S\&P500 index, the 500 largest companies listed on the US stock exchanges, and the Gold Fixing Price in the London bullion market in dollars per Troy ounce, approximately 31.10 grams. The following subsections explain how the data from the World Gold Council and UNIDO are used to estimate the gold supply and demand, respectively.

\subsection{Gold Supply}

The data provided by the World Gold Council contains the quantity of gold that is mined, recycled, and hedged by net producers. Net producer hedging measures the impact in the physical market of gold forward sales, loans, and options positions of mining companies. This paper considers the quantity of gold produced is given by the volume of gold mined globally. The quantity of gold that is recycled is dropped for this analysis as 90\% is recycled due to consumers selling gold for cash. Since consumers explain most of the recycled gold, it is impossible for gold producers to estimate future gold recycling, as gold is often sold as an alternative source of income during economic crises, nor can they contemporaneously respond to changes in the recycling of gold. In short, the mining of gold is largely unaffected by changes in the quantity of gold that is recycled. The gold that is produced by the net producer hedging is also dropped because it does not generate a net increase in the supply of gold according to the World Gold Council.

\subsection{Global Industrial Demand for Gold }

The price of a traded commodity is determined by multiple factors: the quantity supplied, the quantity demanded, and the precautionary demand for gold. Precautionary demand occurs, according to Killian (2009), when buyers are uncertain about possible interruptions in the supplies of a given commodity. The issue is that gold has two sources of demand: an industrial demand and a financial demand. Each of these demand shocks might have different effects, thus requiring two different equations in the VAR model. Since gold is a “safe haven” (author and jazz) to hedge against market volatility, the financial demand for gold will be impacted by the performance of the stock market represented in the VAR model via the S\&P500 index. However, there does not exist a measurement for the global industrial demand for gold, thus requiring the creation of such an instrument.

To construct demand for gold, I will be using data from the Quarterly Index of Industrial Production (IIP) at the 2-digit level of the International Standard Industrial Classification (ISIC) Revision 4 provided by UNIDO. The IIP measures the quarterly growth of the volume of industrial production in real terms, free from price fluctuations, indexed to 2015. To be more specific, the data that is used to create the proxy for the demand for gold looks at the industrial production of goods of 96 countries that fall within ISIC code 26 and 27, i.e. computers, electronics & optical products, and electrical equipment, respectively. ISIC code 26 was chosen because the main components (i.e. PCBs, CPUs, …)\footnote{ Printed Circuit Boards, Central Processing Units, …} that are used in these products contain a significant amount of gold. Furthermore, there are no good substitutes for gold in these components meaning that a shock in the supply or price of gold should have, in theory, an impact on the global demand for gold, or vice versa. The inclusion of code 27 is debatable. According to the ISIC, code 27 includes the manufacturing of domestic appliances. Normally, domestic appliances do not contain a significant amount of gold, if there is any at all, but since the advent of “smart” appliances, these appliances have similar components as computers or electronics. Consequently, they also contribute to the demand for gold. The risk in including products in code 27 is that it might lead to an understatement of the impact of a shock to the supply or price of gold on the global demand for gold.

To create the demand, I have averaged the quarterly growth of volume of the industrial production for both codes across all 96 countries\footnote{ As UNIDO only had data from 96 states} across the 2011 to 2020 period.

\section{II. The Real Price of Gold}

In order to decompose the real price of gold, I will be using a VAR model similar to the model used by Killian (2009) based on quarterly data, where $\mathbf{z\_t} = (\Delta prod\_t, \Delta rea\_t, S\&P500\_t, rpg\_t)'$. $\Delta prod\_t$ represents the change in the supply of gold, $(\Delta rea\_t)$ is the change in the demand for gold constructed above, $S&P500$ represents the change in the S&P500 index and $rpg\_t$ is the real price of gold. The structural VAR representation is:

Where $\epsilon\_t$ is the vector of serially and mutually uncorrelated structural shocks. For the VAR to work, $\mathbf{A^{1}\_0}$ has to be a lower triangular matrix so that the Cholesky decomposition can be used to find $\mathbf{e\_t=A^{-1}\_0\epsilon\_t}$:

What this means is that there needs to be some short-run restrictions. The first short-run restriction is that the change in the supply of gold is contemporaneously unaffected by shocks to any of the other variables. This is valid for two reasons. The first reason is it takes time for supply to respond to changes in demand or in price due to slow adjustments of the mining process. The second reason is that shocks to gold production are often unpredictable, thus they cannot be affected by shocks in demand for gold, the S\&P500 index, or the real price of gold. The second short-run restriction is that the changes in demand for gold are not contemporaneously affected by variations in the stock market nor in the real price of gold. This is also due to a sluggish response from companies to respond to market signals as it takes time find a substitute for gold, if one exists, when the price increases.

The ordering of the last two shocks is debatable. Since gold is considered as a "safe haven" from uncertainty in the financial market, the price of gold would be contemporaneously affected by shocks to the financial market, thus placing the financial shock last. On the other hand, since gold is considered a "safe haven" for financial uncertainty, shocks to the gold price will contemporaneously affect the financial markets, thus shocks to the real price of gold should be placed last. Ultimately, it should not really matter as, theoretically, the impacts of the shocks will be the same.

For the first analysis, I decided to put the real price of gold in the last equation. My reasoning is that, although gold is seen as an alternative financial investment, there are many alternative investments in other commodities (i.e. silver, copper, etc.) or other financial instruments, such as bonds for which Baur and Lucy (2010) find evidence that gold is not a “safe haven”. Consequently, even though the shocks to the real price of gold might contemporaneously affect the stock market, they do so at a lesser extent than the impact of shocks to the financial market on the real price of gold, in theory.

\section{III. Empirical Results}

Figure 1 shows the responses of global mining production, global demand for gold, S\&P500 index, and the real price of gold to structural shocks. An unexpected gold supply disruption leads to a surprising an immediate increase in the global gold production, followed by a sharp decrease, erasing the immediate increase in production one quarter after the shock. This pattern can possibly be explained by small independent miners. Just like small independent oil producers, these small gold miners might be mining gold but are not immediately selling it as they are waiting for a higher price. Consequently, when there is a disruption in the supply of gold, these small miners take this opportunity to sell their gold, leading to a perceived increase in production even though the gold was previously mined. Since these small miners are unlikely to have huge reserves of gold due to the costs associated with mining and keeping a vast amount of gold, they might exhaust their reserves one quarter after the shock, explaining the sharp decrease in the “production” of gold. This explanation is supported by the effect of a shock to the supply of gold on the real price of gold. There is no statistically significant immediate effect on the price of gold which provides an incentive for small miners to immediately sell their gold reserves as they will not greatly affect the price of gold and are maximizing their profits. The real price of gold increases one quarter after the shock, reflecting the sharp decrease in supply.

Since the price of gold is determined by supply and demand, it is interesting to note that an unexpected increase in the demand for gold has no statistically significant effect on the price of gold. This provides evidence that current and future literature is correct in not including the industrial demand for gold when trying to forecast or explain the fluctuations in the price of gold. However, an unexpected increase in the demand for products in code 26 and 27 of the ISIC leads to a small but fleeting statistically significant increase in the demand for gold. This shock leads to a small statistically significant increase in the S\&P500 index one quarter after the shock. This is most likely due to the quarterly earnings report from companies that produce electronics, such as Apple, that occur at the end of the current quarter. Since there is a higher demand for electronic goods, it can be expected that the companies that produce these goods will see an increase in profits leading to an earnings report that beats expectations. If a company beats their predicted earnings, then investors will invest in that company, leading to an increase in the stock market index.

Counter-intuitively, an increase in the volatility in the stock market leads to a statistically significant increase in the S\&P500. Normally when there is an increase in volatility in the stock market there should be a negative effect, but it is not the case in this paper. The most probable reason is that the usage of the S\&P500 index as a proxy for the stock market might be flawed. The S\&P500 index represents the 500 largest companies that are traded in the stock exchanges in the United States. Therefore, it is very unlikely that the index will experience significant fluctuations in the performance of the index, barring financial disasters such as the 2007 financial crisis or COVID-19. This could mean that the S\&P500 index will act as sort of “safe haven” during times of relatively small financial instability, explaining the positive effect of a shock to the stock market on the S\&P500. In contrast to this counter-intuitive result, a shock to financial market leads to a statistically significant transitory increase in the price gold, reaffirming the financial demand for gold as a safer investment. This is compounded by the one-quarter lag effect of a shock to the real price of gold on the S\&P500 index. Initially there is sharp increase in the price of gold and there is no statistically significant effect on the index. However, as the price of gold decreases one quarter after the shock, there is a small increase in the index indicating that some gold investors are switching their investments back to the stock market.

The results of the VAR model where the stock market shock is last are significantly different than the results found in the first VAR model iteration. In Figure 1, there is a slight positive effect on the S\&P500 index one quarter after the shock to the price of gold that is not apparent in Figure 2. In fact, there is no statistically significant effect of a shock on the price of gold on the S\&P500 index in any quarter. Furthermore, a shock to the S\&P500 has no statistically significant effect on the real price of gold. This could be due to the fact that gold is not the sole “safe haven” during a time of uncertainty in the stock market.

\section{IV. Conclusion}

Although gold is used in the industrial process of manufacturing computer and other electronics, the structural VAR models proposed in this paper suggest that the changes in the industrial demand for gold is unnecessary to explain the variation in gold prices. Furthermore, the models provide evidence supporting the findings of current literature that the price of gold is affected in part due to shocks in the financial market. However, there are limitations to the parameters that were chosen for the VAR models.

The first major limitation is how the global industrial demand for gold is constructed. Though gold is abundant in products listed under code 26 of the ISIC (computers, electronics, \& optical equipment), the abundance of gold in 27 may not be representative of what is actually in said products. As stated in Part [Author], home appliances fall under the category of electrical appliances and most likely do not contain a significant amount of gold, even with the proliferation of “smart” appliances. Similarly, the global industrial demand for gold does not include the production of jewelry nor the demand from central banks to bolster their reserves.

The second major limitation is the use of the S\&P500 index as a proxy for the performance of the stock market. As mentioned in Part [author], the S\&P500 might not be greatly affected by increases in volatility in the stock market and can even be used as a “safe haven” when this shock occurs. This would mean that the S\&P500 is not an accurate representation of an investor’s portfolio. To see if there are any changes in the results, it would be interesting to simulate an investor’s portfolio and use its performance in order to estimate the impact of shocks to the price of gold, or vice versa.