The asymmetric relationship between core macroeconomic variables and the stock market

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I hereby declare that the following work is my own and therefore does not include any other work that is a result of a collaborated effort. However, the methodological part that is used is inspired by a secondary paper, which I appropriately reference in the following pages. Moreover, this document is not like any other previous work that I have submitted in the effort of obtaining the master’s tittle at the International Hellenic University. It has been supervised by the school’s appointed professor and it generally follows the regulations set in the Student’s Handbook both in the structural and in the citations’ formatting levels. Finally, I understand that failure to correctly reference and responsibly give appropriate credit to other peoples’ work can and will give ground to question the credibility of this dissertation.

Abstract

This work is done as the final part of my studies at the International Hellenic University. It was written, among others, as an effort of developing an overall better understanding of the relationship between core macroeconomic variables and the stock market.

The role of the financial sector within any economic environment and the basic variables of aggregate economic activity, together with their respective interrelations with various stock markets around the globe have been thoroughly studied in the empirical literature. However, as it will be seen extensively below, most of the traditional or even slightly more advanced econometric models that have been used, fail to consider the non-linear and asymmetric interdependence between macroeconomic and financial variables. Taking into account that the economic policy decision-making and the portfolio asset allocation are both regime-varying processes, we develop an analytical framework for dealing with this asymmetry by using the measures of transfer and partial transfer entropy with particular focus on their asymmetric versions. Starting with an unrestricted VECM that is accompanied by a standard Granger Causality analysis, we find significant evidence of lead-lag relationships. Furthermore, the model-free assumption of the proposed direct causality methods seems to offer additional value when testing for the true causal links between the variables on top of the non-linear and asymmetric nature of the macrofinance data.

At this point, I would like to express my gratitude towards my insightful supervisor, Professor Catherine Kyrtsou, who has generously offered her knowledge and expertise while guiding me through all the years of my undergraduate as well as graduate academic career. Our thought-provoking discussions and her excellent advice have been very valuable to me and for that, I am truly grateful. However, there are two special people to whom I owe this achievement. To my wonderful parents, Dimitris and Sofia for their endless support, love, and trust.

Keywords: macroeconomics; stock market; entropy; asymmetry; non-linearity

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Introduction

Microeconomic theory, which has always been a logical starting point for the study of economics, deals with the decision-making process of individual economic units while trying to provide utility and profit maximizing solutions to the respective theories of the consumer and firm. In this dissertation, we primarily focus on macroeconomics, which is being perceived as the second pillar of economics and even though heavily rooted in the above, deals with the study of fundamental, aggregate measures, business cycles and price levels, while providing answers to their respective fluctuations. Overall, we acknowledge that at least in the short term, where behavioural characteristics, inefficiencies and irrational expectations together with the forces of supply and demand possess a vital role in the determination of asset prices, the relationship between macroeconomics and the stock market can be more often than not characterized as being "blurred". As one of the world's most successful and famous investors notoriously said, "even if you knew what was going to happen in the economy, you still wouldn't necessarily know what was going to happen in the stock market" *(Warren E. Buffet, 2008)*. In this respect, we believe that a sound understanding of the current state of the economy is deemed as critical both from an investing and policy implementation perspective even if the number of macroeconomic variables whose cyclical movements are of interest is tremendous and their actual modelling choice is subjective and research dependent.

Departing from the traditional Granger causality approach [11] and building upon basic information theory, in this dissertation, we attempt to shed light into the complex system of relationships between the stock market and the macroeconomy, by using the measures of Transfer Entropy (TE) and Partial Transfer Entropy (PTE) while particularly focusing on their asymmetric version. More specifically, by drawing upon standard macroeconomic theory as well as existing empirical work, we attempt to build a system that is composed of the economic activity as proxied by industrial production, inflation and the S&P 500 index, with the latter accounting for aggregate stock market movements. We have chosen to focus on the U.S market because of its significant size, strict regulatory provisions and increased ethical standards and overall awareness. However, we acknowledge that the empirical results can be market dependent. A higher number of industrialized and/or emerging economies should be examined in the effort of establishing common patterns of asymmetric causal relationships across different countries. In this front, the reader must understand that discrepancies can arise from any destabilizing factor that can cause valuation as well as structural differences (e.g. systematic factor and financial reporting standard differences). For example, even though the adoption of IFRS as the required reporting standard by many countries around the globe has advanced the goal of comparability and overall consistency of financial statements, there are still significant differences in the global capital markets' financial reporting level that can affect the security valuation mechanism and price development procedure. Nevertheless, determining in the most part two out of three main managerial decisions, namely the investing and financing ones, the macroeconomic variables that are under investigation can influence future expected cash flows and discount rates. Hence, considering that the latter are being extensively used in the determination of fundamental value, we expect our stated variables to have a strong and statistically significant relationship with stock market prices and returns.

Chapter I

I.1 Brief review of the basic macroeconomic dynamics

By defining economic indicators as variables that provide information on the state of the overall economy, a possible and intuitive causality direction of the dynamic relationship between core macroeconomic variables and the stock market can quickly become apparent. The latter is being perceived by many as one of the most pronounced leading indicators since corporate profits and investment capital constitute a large component of the overall economic output. It's even worth mentioning that stock prices are one of the components of the National Bureau of Economic Research's Index of Leading Economic Indicators. Thus, their aggregate movements are generally being thought of as having value toward predicting the economy's future state conditional upon the fact that market participants continuously discount future information in a rational way. On the other hand, acknowledging that core macroeconomic variables are among the basic factors that can influence discount rates and expected cash flows renders the relationship as unidirectional, with macroeconomic variables granger-causing stock returns.

Contradicting with the aforementioned perspective, *Shiller* [34] concluded that the latter can be too volatile to be simply explained by shocks to basic valuation inputs in every economic environment and time period (e.g. the stock market crash during late part of 1987). This is also evident by the results of *Cutler et al* [4], who via a vector autoregressive model, showed that macroeconomic news was able to explain about one third of the variance of stock returns. In our view, this should not be thought of as a strict "one-way relationship", or at the very least should be allowed to vary especially when the asymmetric and non-linear informational contents and relationships are considered alongside with the different regimes of the business cycle.

In more general terms, the aggregate economic activity should be perceived as a major determinant of stock market volatility at least in the long run, where information about the future events of the former are being reflected in stock prices well before it occurs. In an effort of providing a more detailed description and by using a build-up method that sets aside the liquidity premium, one could say that the rate that is used in the standard absolute valuation models in order to discount future risky expected cash flows, includes a virtually riskless interest rate, a component that considers the compensation for the expected inflation rate and a credit and equity premium. Hence, an unanticipated change in both the risk-free rate and risk premia that may be caused by a term structure slope fluctuation can influence pricing and therefore stock returns.

Furthermore, by simply considering that the general price stability is the goal of most central banks around the world, one can understand the importance of inflation both in the economic and stock market fronts. Even in an imaginary, frictionless world where the general price level is assumed to be fully anticipated, market participants would still adjust their behaviours accordingly and thus, the price variability would impact nominal cash flows and interest rates. Of course, there would be no fluctuation in real values assuming "non-sticky" wages (or any other contract that can potentially influence a firm's revenue or cost structure). However, taking into account the risk premia influence of unanticipated inflation and the wealth transfers between borrowers and lenders that it can cause, together with the fact that input prices should adjust faster to inflationary pressures than output prices in the real competitive world that firms operate in, can exaggerate the assumed relation between inflation and stock returns.

The importance of the macroeconomic-stock market relationship can quickly emerge even in the case of commodities. By following a standard aggregate demand and supply analysis or by studying the intuitive correlation of oil with disposable income, *~we mention oil as it is one of the most widely followed commodities and as such its price movements should always track inflation~* one can notice its impact on consumption levels and subsequently on aggregate demand. More importantly however, by being one of the two biggest components of the cost structure of corporations, especially in the manufacturing and transportation sectors, alongside with wages, oil can influence stock returns and cause significant cost-push inflation. Further discussion of the above variables is provided in section two but in a more simple and theoretical manner, considering that they constitute the main sources of systematic risk in a world where investors generally hold an averse behaviour toward their co-movements and fluctuations, we expect them to have a significant role in determining asset prices since as theory suggests, non-diversifiable risk should indeed by priced.

Overall, the fundamental interrelation that is under investigation stems from the financial system's role within an economy. It basically consists of markets and other financial intermediaries (e.g. brokers, dealers, financial institutions) that facilitate the connection of users ~*households, corporations and governments*~ who are in need of transferring financial assets and various forms of financial risks, with others that are willing to forgo and substitute current for future consumption and receive a required rate of return. Thus, its working-state both in the informational and operational level is assumed to be closely related to the aggregate wealth fare, with its well-functioning leading to wealthier nations. For example, within an imaginary informationally inefficient financial system, market participants would be unwilling to participate in the capital allocation process through equity purchases or at the very best would require a higher risk premium for their equity contributions. Thus, because the savers' capital funds are usually being perceived as scarce, some of the investments that should have been only marginally accepted in an efficient market environment will end up being rejected due to their higher discount rates and subsequently negative NPV profiles, reducing the overall output level. Of course, the regulatory and ethical standards of an economic system that guarantee an orderly and fair market in which market participants can trade at prices that accurately reflect intrinsic values and all publicly available information without incurring excessive transaction costs in the form of elevated bid-ask spreads also possess a vital role. However, implicitly assuming them as given renders the discovery of the rate of return that equates aggregate savings with aggregate borrowings as well as the allocation of capital to its best uses as two of the most important functions of the financial system that can aid toward achieving a higher wealth fare.

Taking a shift to the investing implementation and especially for global investors who choose to follow a "top down" investing strategy, estimating the sustainable rate of economic growth ~*defined as the economy's productive capacity or potential GDP*~

and comparing it with the aggregate output level will aid toward understanding the current phase of the business cycle, which in turn can determine the asset allocation and security selection decisions. Note here that a "top down" strategy is being defined as one that analyses aggregate economic data and industry and security information in this specific order, as opposed to a "bottom up" one that primarily focuses on the micro-security specific level. Also note that even if a country's potential GDP cannot be directly observed, it should be reasonably estimated, when its respective labour productivity is calculated. Thus, by following a standard aggregate demand and supply (AD-AS) model, inflationary and recessionary gaps can be approximately identified with the associated asymmetric causality relationships being established.

For example, corporate profits and commodity prices should be elevated within any economic environment that is characterised by a rightward shift of the AD which indicates toward an expansion phase. In such cases, an investor could deliberately deviate from his portfolio strategic policy exposures and in an effort of adding value through the tactical asset allocation procedure, increase his investments to cyclical companies, commodities and commodity-oriented equities and reduce his respective fixed-income investments while avoiding the high duration ones. Overall, knowing if an economy is overutilizing (or underutilizing) its resources can provide a picture of the future general price level and hence, should increase the wealth of macro-investors in almost all economic regimes. However, as history repeatedly has shown, structural movements of the aggregate supply that lead to stagflationary regimes can be characterised as an exception. In such destressed economic environments, the majority of commodity-unrelated investment opportunities most of the times have an unattractive risk-return profile.

The pre-described procedure should not be confused with market timing strategies. The only thing that is predictable about cycles and general macroeconomic events is their inevitability, since they tend to be recurrent but not periodic in nature. Moreover, it apparently contradicts with both "buy-and-hold" and "factor" investing philosophies. The former is characterised by an effort of finding good investment opportunities and holding them for the long-run while ignoring short term fluctuations of any kind while the latter can be defined as a form of index investing that specifically focuses on getting exposure to certain well-established factors that influence future expected returns (e.g. size; value; profitability; momentum). As Marks wisely suggested in his insightful book [20], future economic and stock market events are by no means knowable and most of the times not predictable without wide margins of error, but since nothing is more dependable than the recurrence of certain macroeconomic events, investors should at least try to grasp the current state of the economy in order to get a sense of the direction that it is headed.

In the economic policy front and by focusing more on the monetary rather than fiscal instruments because of the severe recognition, action and implementation lags as well as the political dependency of the latter, one could say that there is least agreement about the role that they can and should play in achieving the well-established economic goals of price stability, economic growth and prosperity and high employment [9]. On the contrary, the fact that different economic policies are being implemented in different business cycle regimes is intuitive and widely accepted and thus studying the interconnections between aggregate economic activity variables and stock market movements in an asymmetric and non-linear environment should indeed offer value ~*at least in the short term where the money neutrality concept is ambiguous*~ conditional upon its ability of providing a better answer to the "how should the economic policy be conducted to contribute the most" question. Especially in cases where national central banks hold substantial power, it can help monetary authorities to "prevent money itself from being a major source of economic disturbance" [c, p.12] and thus to avoid any destabilizing mistakes. Finally, the inefficiency of any economic policy that focuses only on one variable within the non-linear and extremely complex structure of the economic reality renders a multidimensional policy as extremely efficient. Of course, in its effort of controlling the overall economic activity with actions that are doomed to have results only several months after, the monetary policy will still be unable to ultimately control both the amount of credit that is extended by banks and the amount of money that households and corporations choose to deposit. As the Executive Director of Bank of England once remarked, "steering the economy has been linked to driving along a winding road looking only in the rear-view mirror and in practice, there are times when it seems as if it is a great deal more difficult, for that mirror itself is misted up" (*Charles Bean, 2007)*. Nevertheless, the reinforcement of its transmission mechanism and the overall better understanding of the above critical variables' regime-dependent movements are the best that we can hope for, considering that the highest sustainable economic prosperity can be achieved in a highly stable environment.

This work is divided in two main parts which in turn include separate sections. Following this brief review, section two provides an overall picture of the literature that documents the observed relationship between the macroeconomic and stock market movements in different time horizons. A rather extensive explanation of the chosen methodological approach is presented in section three while being accompanied by the description of the S&P 500 index returns and aggregate economic activity data. In the fourth section, the empirical results are outlined, together with the associated discussion and finally, conclusions are being presented in the final section.

I.2 Literature review

With even the slightest glance at the existing academic papers, one can realise that the empirical literature that has documented the relationship under investigation until today, across a number of different countries and over different time horizons is surprisingly extensive, with the traditional econometric and more advanced models providing results that are far from univocal. Even when strong evidence is found, some contradicting results can be obtained within different market environments or data frequencies suggesting otherwise, making it extremely difficult to determine which macro-variables (if any) have truly meaningful relationships with the stock market prices and returns.

Starting from a basic linear relationship, one of the most conventional ways of linking macroeconomic variables with stock market returns is through simple OLS regressions. In their effort of explaining stock returns' variability, these models often include various basic macroeconomic and other behavioural and microeconomic risk factors. Hence, even with a simple CAPM estimation that factors in the market beta, one of the most well-known risk factors in the academic literature, a researcher can notice that the systematic variables that vary according to country specific events can help towards explaining a part of stock variation. There have been a lot of "breakthroughs" in the asset pricing literature that propose several different risks that consistently explain the differences in realized asset returns due to the market beta's inability of fully explaining the observed empirical discrepancies. Of course, the higher the number of true independent risk factors, the higher proportion of asset pricing differences can be explained, and the better coefficients of variation estimated by multifactor models ~*models that allow different factors state variables to influence asset returns*~. A well-known case is the arbitrage pricing theory (APT) of *Ross* [30] which even though extensively used in pricing individual assets, could be potentially estimated using indexes to proxy for aggregate stock exchange movements.

I.2.1 The controversial relationship between the stock market and inflation

The first wave of empirical work, with researchers studying asset classes in order to find nominal returns that among others continuously compensate for expected inflation and thus present a positive and statistically significant correlation coefficient started with the high inflation rates that have been observed in the latest part of nineteen century. They have been mainly cost-push in nature and have basically changed the notorious "safe-heaven" perception of cash, with investors factoring in the loss of purchasing power in their asset allocation decisions. In a simple OLS framework, *Fama* [7], was among the first that empirically recognized the negative relationship between stock returns and both the unexcepted and expected components of inflation. He provided evidence that contradicted both with the up-until-then common way of thinking of common stocks as providing a natural hedge against inflationary pressures, representing claims of ownership of real assets and with the famous Fisherian theory of interest. Based on the quantity theory of money, he viewed this puzzling finding as being spurious in a sense that it is proxying for the more fundamental and positive relationship between common stocks and real activity, with the latter being negatively related with inflation.

Several other explanations have also been offered in an effort of explaining the above controversial conclusion. Among the authors that have based their findings on basic corporate finance theory, *Lintner* [19] suggested that both the expected and unexpected inflation increase the cost of external financing of corporations and subsequently their real cost of capital. Thus, he concluded on impaired equity values by assuming that working capital accounts do not cover the cost of capital. *Modigliani et al* [22], in a theory that apparently contradicts with the efficient market hypothesis, even suggested that due to the so called "money illusion" [21, p.25], investors should be unable to appropriately price equities because of their inability of seeing through nominal accounting statements. In an attempt to provide further evidence, *Geske and Roll* [10] argued that stock returns signal changes in the inflationary process due to the government's deficit fluctuations that are in part influenced by some "uncontrollable" expenses and are monetized by printing additional currency. As the authors note, even in cases of non-monetization, the elevated supply of debt securities should eventually crowd out private borrowings and subsequently cause an increase in real interest rates. Using a reverse causality model, they found that interest rate levels ~*proxying for* *inflation*~ as well as their change cause fluctuations in stock prices. By estimating several bivariate log-linear models, *Hashemzadeh et al* [13], further noted that causality seems to run from interest rates to stock prices and not the other way around. On the contrary, via a standard VAR analysis, *Lee* [18] found no bidirectional causal relationship between inflation and stock returns.

I.2.1 Stock market returns and aggregate economic activity

When it comes to economic activity, the choice of research is binary since the academic literature provides evidence based on either industrial production or gross domestic product (GDP) data. Starting with the former, by simply regressing stock returns on production growth rates for the 1953-1987 period, *Fama* [6] found that the future growth rates of the latter seem to explain a fraction of the variance of a value-weighted portfolio of NYSE stocks. More importantly however, he showed that the relationship between industrial production and stock returns becomes stronger for longer time horizons and that it remains intact when the variables chosen to track expected returns and shocks to expected returns are included in the regressions. *Schwert* [33], in an effort of investigating the stability and the explanatory power of Fama's estimated results used an additional 65 years of data and provided further evidence about the strong positive relation between real stock returns and future production growth rates. *Lee* [18] shifted his attention to the direction of the causality of the above relationship. He concluded that stock returns seem capable of explaining a substantial fraction of variance of industrial production, proving that the stock market rationally signals changes and granger causes real economic activity. Moreover, *Chen et al* [3], provided positive evidence by using the Fama-MacBeth technique. Focusing on the industrial production, term, and default spreads and the (un) expected inflation, the authors suggested that these variables systematically affect stock market returns and hence, are significantly priced. On the contrary, investigating the predictive ability of macrovariables in several industrialized countries, *Rapach et al* [26], via a set of in-sample and out-of-sample tests found limited evidence on the industrial production's front. Even when testing for its potential effects on conditional return volatility or trading volume within a traditional GARCH framework, *Flannery et al* [8] concluded that no significant relationships exist.

In the absolute gross domestic product (GDP) or per capita front, as explained above, well-functioning financial markets should eventually lead to wealthier nations due to higher liquidity and subsequent productivity improvements. Setting aside this intuitive conclusion, there is a considerable debate in answering the question of who enjoys the associated benefits. Of course, consumers, the aggregate workforce and the general population of a country that enjoys a higher GDP growth rate will eventually be "better-off" due to the increased national income levels and the associated higher standards of living that they can cause. However, results seem to be far from intuitive in the case of equity capital providers even when the relationship between growth in corporate earnings and GDP growth has been shown to be statistically significant and positive ~*a well-established phenomenon*~. Even though one would expect countries with higher GDP growth rates to have increasing stock prices and thus deliver higher stock returns, *Ritter* [29], using more than a century's worth of data for both developed and developing countries has shown that the cross sectional correlation between the compounded real return on stocks and the compounded real growth rate of per capita GDP is negative. Among others, one of the possible explanations that he offered is based on market participants' expectations and on the way that they are built into asset prices. In reality and on aggregate, investors seem to be "overpaying for growth" in all cases that are characterised by a lower realized level of GDP growth than the one that had been initially expected. On a more theoretical ground, *Bernstein et al* [2] explained that the growth in earnings per share should be the variable of interest when measuring equity returns. They have shown that during the 20th century, new share issuances in many nations almost always exceeded stock repurchases and hence concluded on existing shareholders' earnings dilution due to the higher number of companies raising more capital in higher growth economic environments.

I.2.3 Oil prices, the macroeconomy and stock market movements

Finally, the oil-macroeconomic relationship and the associated stock market impact have experienced an increasing focus in the empirical research since the first oil shock of 1973. The general belief seems to be that an increase in the oil price level signals an energy shortage and hence causes a leftward movement of the aggregate supply curve, increasing the general price level while decreasing output. The academic literature has on aggregate confirmed the above intuitive inverse relationship between the oil price levels and aggregate economic activity, with the seminal study of *Hamilton* [12] providing the initial foundation. In a six-variable system environment that was first introduced by *Sims* [35], he showed that all but one US recessionary regimes up until

1975 have been preceded by steep oil price increases, but more importantly the author further concluded that none of the additional macroeconomic variables that have been additionally included in his study could account for these recessions, since none of them were found to granger-cause oil prices. However, in order to provide an extension of the above results and to assess whether the relation persists in periods of oil price declines, *Mork* [25] found evidence of asymmetric behaviour by documenting that results become insignificant in such price plummeting regimes. Moreover, using a reduced-form macroeconomic model with bivariate and partial correlation statistics, *Mork et al* [24] found evidence of asymmetric effects in most of their study's examined countries. All in all, the absolute effect of oil seems to be dependent upon the examined national regime, with the overall oil consumption-production levels and net exports' participation being potential sources of differentiation.

The existing literature is not as extensive when it comes to the relation between the oil and stock market prices. The variation of the latter can be a result of systematic as well as non-systematic factors and other speculative dynamics and hence the oil impact is most of the times assumed to be security dependent. Nevertheless, numerous studies point to a statistically significant relation between oil and aggregate financial market movements. By making use of the impulse responses in a standard VAR model, *Sadorsky* [31] showed that oil price movements are important in explaining the variation in stock returns, with their relation exhibiting a negative coefficient. *Kyrtsou et al* [16] deployed a rolling-window approach in order to assess the direction of the observed causality. The authors observed a consistent lead-lag relationship between the S&P500 and the market participants' expectations for crude oil at least for a period that ranged from 2004 to 2009. Furthermore, *Papapetrou* [27] focused on the Greek economy. More specifically, by using a VAR methodology, the author tried to determine how the economic activity, oil prices and unemployment rates respond to shocks of each other. Oil price changes were found to explain a significant portion of the output growth while negatively affecting the industrial production. There was statistically significant evidence for a unidirectional causality relationship. Namely, a positive shock in the industrial production was shown to have a positive effect in real stock returns for an upcoming 3-month period.

Besides the causality studies that have been already outlined, the rest of empirical research seems to be focused on case study methodologies (for example, see *Brahmasrene et al* [1]; *Pradhan et al* [28]) that on aggregate perform correlation and

Granger-causality tests as well as unit root and cointegration analysis. Of course, simple correlation significance does not imply causation and hence, even though some of the previously mentioned literature concluded on significant co-movements between the stock market and core macroeconomic variables, we have to keep in mind that "even if two variables are highly correlated, one does not necessarily cause the other in the sense that certain values of one variable bring about the occurrence of certain values of the other" [5, p.336]. Moreover, one has to be cautious about the nature of the observed relationship in order to prevent results from being spurious since interdependence between variables can arise either due to their underlying relationship with a third variable or because of simple chance.

Nevertheless, the aforementioned research presents an interesting (but rather traditional) spectrum of methodologies with almost all of academic papers basing their findings on linear correlation and symmetric causality measures. In this work, we attempt to fill this gap based on an asymmetric causality approach. *Kyrtsou et al* [17] suggested that the heterogeneity of believes between market participants can quite often lead to inefficiencies in the price behaviours, with the presence of rumours and non-authenticated information exaggerating the above. Even though some of the most well-known financial theorems (e.g. Modern Portfolio Theory) assume homogenous beliefs, we argue that the far opposite has been evident in the real-world financial transactions. Hence, we believe that the nature of macroeconomic and financial data together with their conditional interactions can be too complex and synergistic to be captured by linear and symmetric causality measures and that the constant coefficient models and statistics generally impose too much structure on the data. Considering the spectrum of speculative dynamics, heterogenous believes and behavioural inefficiencies, via the following methodological approach, our ultimate goal is to investigate any potential interdependences and to provide a more precise and coherent picture regarding their regime-varying behaviours.

Chapter II

II.1 Data & Methodological approach

In this section, we present the dataset, and our methodological approach based on the asymmetric version of the transfer and partial transfer entropy statistics, introduced in *Kyrtsou et al* [15]. In this recent and quite innovative paper, the authors, through a simulation study, tried to establish the non-linear and asymmetric relationships between the S&P500 index, VIX and volume. By using the asymmetric partial transfer entropy statistic *~from now on, ATPE~* and by further focusing on the observations that lie on the tails, they were able to provide further empirical evidence regarding the noise trading behaviour of market participants. In this dissertation, we are going to use the ATPE statistic alongside macrofinance data and this constitutes one of our empirical contributions to the literature. All in all, considering that there has been a wide range of causality tests that attempt to identify causal relationships among cross sectional and time series data, with the Granger causality approach [11] being the seminal concept, this chapter's secondary purpose is to help the reader understand the key advantages of such a model-free approach.

II.1.1 Direct causality tests

The measure of transfer entropy (TE) dates to the seminal work of *Schreiber* [32]. By taking into account the flow of time, the author develops a measure that defines statistical coherence as the transfer of information within a bivariate system. Due to its ability to quantify both linear and nonlinear causal effects, TE has a wide range of applications in many scientific fields and can be thought of as the starting point for the empirical research that followed. In order to quantify the strength and direction of potential dependencies between two observed variables, X_1 and X_2, assuming their past values to be known, we can calculate the following

$$TE_{X2 \rightarrow X1} = \sum p\,(x_{1,t+1}, x_{2,t}, x_{1,t}) \log \frac{p(X1,t+1|X1,t\,,X2,t)}{p(X1,t+1|X1,t\,)} \qquad (1)$$

Note here that past values of both X_1 and X_2 are being used to calculate the above bivariate measure of causality. Also note that $x_{1,t} = (x_{1,t}, x_{1,t-\tau}, ..., x_{1,t-(m-1)\tau})'$ and $x_{2,t} = (x_{2,t}, x_{2,t-\tau}, ..., x_{2,t-(m-1)\tau})'$ are delay vectors of the bivariate time series $\{x_{1,t}, x_{2,t}\}$, while m and τ are defined as the embedding dimension and time delay, respectively. The above bivariate entropy measure renders the existence of causality as significant by examining each pair of variables in isolation and thus, its limitations on measuring the information transfer in multivariate environments should be apparent. Overall, the need of developing a measure that quantifies all available information and thus, “prevents from spurious results that may be derived when constraining the analysis on couples and ignoring information from the remaining of the variables” [15,p2] comes to light.

Hence, the partial transfer entropy statistic (PTE) has been developed (see *Vakorin et al* [36]) in order to be able to perform causality studies within both stochastic processes and dynamic systems, with the interactions of the remaining variables being also taken into consideration in their true form. To grasp its advantages without the use of any complex mathematical formulations, let us consider an interacting system that encompasses all variables of interest. In such a system, all possible indirect relations can influence the ‘‘true’’ causal effect both in a positive (reinforce) and negative (weaken) way and thus, in order to estimate the strength of the unbiased observed relationship of interest, all secondary possible influences have to be disposed of the system. In the probability theory front, we can quantify the above by using the conditional mutual information that is proxied by the letter *(I)*, as

$$PTE_{X2 \rightarrow X1} = I\,(x_{1,t+1};\, x_{2,t} \mid x_{1,t},\, z_t) \qquad (2)$$

Note that $Z = X_3, X_4, \ldots, X_L$ and z_t are used to consider all the confounding variables within the interacting system of interest and the delay vector of the L-2 variables that remain, respectively. Even though the PTE statistic clearly advances on the TE one by expanding its usage to multivariate environments and by capturing the direct couplings of their variables, the question of whether or not the causal relationship of interest is still intact when conditioning on a subset of the original sample remains unanswered if we limit ourselves to the sole usage of the above statistics.

It should be apparent by now that through our methodology, we are not only interested in testing whether a variable precedes another. Consistent with the view of *Hatemi-J* [14], who introduced a linear extension of Granger-causality, stating that positive and negative shocks can have different causal effects, we have chosen to depart from the rather conventional use of a simple vector autoregressive model (or of any of its variations) and only present it for comparison purposes, while basing our findings on the asymmetric version of PTE.

In this front, by allowing positive and negative causal effects to cancel each other out and by focusing on the signs of the macroeconomic variables under investigation that define inflationary and deflationary gaps, we use the ATPE statistic in the same formatting level as in *Kyrtsou et al* [15]. Hence, we allow an observation $x_{2,t}$ of the X_2 variable (or alternatively $x_{1,t}$ of X_1) to be included in the estimation of the ATPE statistic, only if it satisfies certain assumptions [e.g. $x_{2,t} \geq 0$ or $x_{2,t} < 0$ ($x_{1,t} \geq 0$ or $x_{1,t} < 0$)]. Of course, further analysis can be done to identify the interrelations of the variables when conditioned upon observations that lie on the tails of the respective probability distributions (or on any other value above or below the sample's mean statistic). Even though such an analysis is thought of as being out of the scope of this dissertation, it can provide a possible topic for future macrofinance research. As a model-free approach, the ATPE basically incorporates the time coefficient by answering to the "what is the probability of occurrence of $X_{1,t}$, given that another variable's value, $X_{2,t}$ will occur'' question, as the measures of TE/PTE do.

However, we expect the former to offer more precise information on the nature of the relationship between our chosen macroeconomic variables and the U.S stock market index, by providing a significant answer to the statistical inference question of whether or not to reject the null hypothesis that states that non-asymmetric causality is apparent.

II.1.2 Data description

The dataset consists of the monthly, seasonally adjusted closing prices of the S&P 500 index, industrial production and inflation for a period that ranges from January 1947 to August 2020. The macroeconomic and stock market index data were derived from the FRED and Thomson Reuters databases respectively and the monthly frequency was chosen in order to follow conventional empirical macroeconomic research practices as well as to have a large sample and therefore obtain meaningful and statistically significant results. Note that the specific macroeconomic time series data are market dependent. For example, we base our findings on the core consumer price index (CPI) for all U.S urban consumers, which by construction excludes food and energy prices due to their excessive empirical volatilities while using specific weights to calculate the aggregate cost of a typical basket of goods. In this front, it is worth mentioning that our chosen metric is consistent with wide industry practices. Even though policymakers try to control headline inflation, which reflects the actual cost of living, they ultimately focus on core inflation in their effort of not overreacting to short-term fluctuations that may not have significant long-term impact on the overall economic activity.

Additionally, the industrial production series (INDPRO), which is being used to identify expansionary (or contractionary) periods, measures the specific movements of the aggregate production output of the U.S economy and highlights its structural developments. In order to provide an illustrative description of the approximately 900 datapoints, we present the plot of each of the variables of interest in the following collective figure.

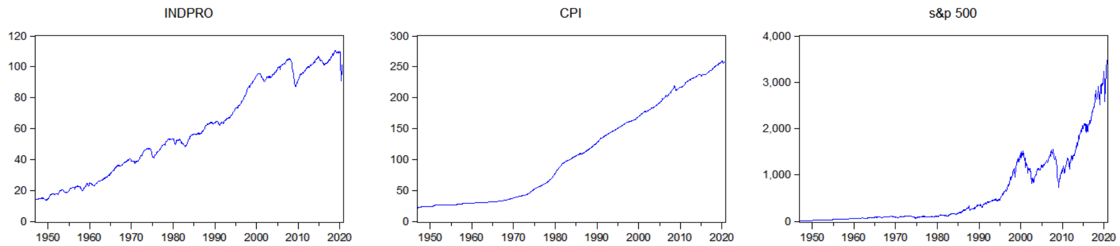

Figure II.1.1: Monthly values of S&P500 index, CPI, and industrial production

Unless otherwise stated, the empirical findings that are being presented below, were estimated using the monthly returns of the series which have been calculated by taking the first logarithmic differences. The descriptive statistics and the plots of the latter are presented in table II.1 and figure II.2 respectively and with even a slight glance, we can notice that the non-stationary price series have now been converted to stationary processes without any deterministic or stochastic trend. By subjecting all variables to augmented Dickey Fuller tests, we found strong evidence of stationarity since all three variables led to the rejection of the null hypothesis that supports the existence of a unit root.

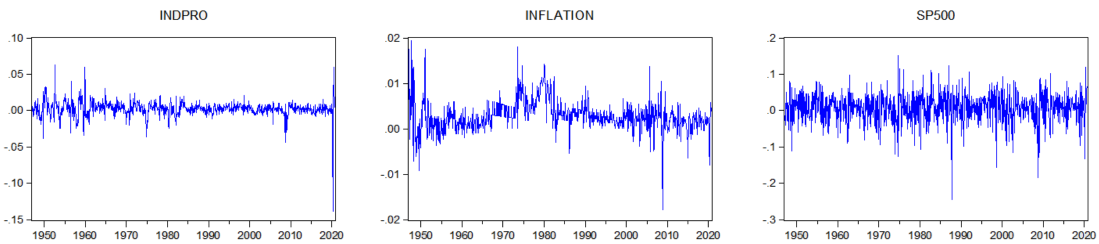

Figure II.1.2: Monthly returns of S&P500 index, CPI, and industrial production

Table II.1: Descriptive statistics of monthly return series

	INDPRO	INFLATION	SP500
Mean	0.002236	0.002823	0.006126
Median	0.002544	0.002436	0.009274
Maximum	0.062325	0.019452	0.151043
Minimum	-0.138451	-0.017864	-0.245428
Std.Dev.	0.010854	0.003430	0.041758
Skewness	-2.229209	0.569035	-0.656554
Kurtosis	38.37820	7.170562	5.313176
Jarque-Bera	46780.41	687.5918	260.3024
Probability	0.000000	0.000000	0.000000
Observations	883	883	883

Excluding the large and negative inflation value of 2010 that is apparent in Figure II.2, we can see that inflationary and disinflationary periods clearly outnumber the deflationary ones. In fact, excluding the Great Depression (not included in the dataset) and Great Recession periods where inflation rates were highly negative, there have been no consistent deflationary regimes in the history of U.S data. Conversely, inflation rates seem to have been very high in the late 1970s and early 1980s. Moreover, with a closer look on the 2020 industrial production values, one can notice the large drop that resulted from the world-wide pandemic and the subsequent shutdown of the economy. Finally, by closely looking at the S&P500 graph in Figure II.1, we can notice the dot.com and real estate bubbles together with their associated market collapses in the 2000 and late 2009 periods, respectively. Note that the above are related to global crisis episodes. As such, they offer interesting descriptive information and thus, should not be excluded from the sample even if they do not follow the same distributional assumptions.

II.2 Empirical findings

Before progressing to the more complex analysis, we present simple correlations for each of the variables, both contemporaneous and at lag 12 in panel A and panel B of Table II.2.1.A, respectively, since there are a couple of features worthy of note.

Table II.2.1.A: Simple cross-correlations for variables, contemporaneous and at lag 12

Panel A: Pair-correlation at lag 0			
	INFLATION	INDPRO	SP500
INFLATION	-	0.066754	-0.070323
INDPRO	-	-	-0.016692
SP500	-	-	-
Panel B: Pair-correlation at lag 12			

	INFLATION	INDPRO	SP500
INFLATION	-	0.002872	-0.072316
INDPRO	-	-	0.0001
SP500	-	-	-

First, the pairwise correlation between inflation and the S&P 500 index does not appear to wear off. On the contrary, even after one calendar year, it seems that it becomes more negative. Secondly, there is a negative and positive linear relationship between the industrial production and the stock return and inflation series, respectively, although in both cases, the coefficient becomes economically insignificant at the twelfth lag.

II.2.1 A basic VECM approach accompanied by a standard bivariate Granger-causality test

As already introduced in Section II.1.2, a VECM is used as a part of a comparison framework. The degree of significance of the information contained in the lagged values of the pre-described variables in explaining the variation in the stock index returns, within this generalization of univariate autoregressive models' approach, will be compared with the results of the proposed asymmetric entropy method. The secondary goal of the unconstrained VECM is to consider the long-run cointegration relationship of the examined tri-variate system. It should be seen as an extension of a simple VAR approach that would have been run on the differences of the selected variables and hence as a way of avoiding the misspecification of both the underlying model dynamics and of the associated Granger causality statistics. A mathematical representation of the simplest form of a VECM(1), with x_t, y_t and z_t being the S&P500, industrial production and inflation time series, respectively, would be the following

$$\Delta x_t = \mu_X+\alpha_X(b_1x_{t-1}+b_2y_{t-1}+b_3z_{t-1}+b_3)+\lambda_{XX}\Delta x_{t-1}+ \lambda_{XY}\Delta y_{t-1}+ \lambda_{XZ}\Delta z_{t-1}+u_t \quad (3)$$

$$\Delta y_t= \mu_Y+\alpha_Y(b_1x_{t-1}+b_2y_{t-1}+b_3z_{t-1}+b_3)+\lambda_{XY}\Delta x_{t-1}+ \lambda_{YY}\Delta y_{t-1}+ \lambda_{YZ}\Delta z_{t-1}+v_t \quad (4)$$

$$\Delta z_t= \mu_Z+\alpha_Z(b_1x_{t-1}+b_2y_{t-1}+b_3z_{t-1}+b_3)+\lambda_{XZ}\Delta x_{t-1}+ \lambda_{ZY}\Delta y_{t-1}+ \lambda_{ZZ}\Delta z_{t-1}+\eta_t \quad (5)$$

Note that we have chosen to include an intercept in both the cointegrating and VAR terms since all of the logarithmic series appear to have stochastic trends that drift upwards. Also note that u_t, v_t and η_t are being specified as white noise innovations.

Even if the number of lags to be included in any standard VECM can be chosen in a variety of ways, we have decided to be guided by the minimization of the multivariate generalizations of the information criteria within a VAR model that is specified on the logarithms of the respective time series. As it can be seen in Table.II.2.1.B, the Bayesian and the Hannan-Quinn information criteria both choose a VAR(2), while the Akaike one selects an optimal lag of thirteen.

Table II.2.1.B: VAR lag order selection criteria

Lag	LogL	LR	AIC	SC	HQ
0	-1058.21	NA	2.498763	2.515191	2.505048
1	8121.166	18328.19	-18.62036	-18.5547	-18.5952
2	8292.304	339.5248	-18.99266	-18.87766*	-18.94866*
3	8305.185	25.46688	-19.00157	-18.8373	-18.9387
4	8313.077	15.54774	-18.99903	-18.7855	-18.9173
5	8318.724	11.08738	-18.99133	-18.7285	-18.8908
6	8328.518	19.1597	-18.99315	-18.681	-18.8737
7	8339.386	21.18698	-18.99744	-18.636	-18.8592
8	8348.945	18.58012	-18.99873	-18.588	-18.8416
9	8354.923	11.57201	-18.99179	-18.5318	-18.8158
10	8362.195	14.02661	-18.98782	-18.4786	-18.793
11	8378.645	31.61615	-19.00493	-18.4464	-18.7912
12	8382.051	6.520799	-18.99208	-18.3842	-18.7595
13	8410.721	54.70765	-19.03725*	-18.3801	-18.7858

Considering that all criteria seem to indicate a different number of optimal lags, a choice based purely on subjective judgment could be easily disputed. Nevertheless, we have decided to be guided by the Schwarz's stricter penalization factor in order to stay consistent with industry practises. In this front, it is also worth mentioning that it's superiority in suggesting the most parsimonious model has been well established in the literature (for example see *Wang and Liu* [39]; *Medel and Salgado* [21]). Moreover, based on the Wald lag exclusion test, the null hypothesis of joint insignificance could only be safely rejected until the second lag inclusion, with the rest of the joint coefficients (expect the twelfth and thirteenth lag specifications) offering no explanatory power. Thus, in the process of determining which model is able to capture the dynamics of the system, the loss of degrees of freedom materially over weighted the associated inclusion benefits. However, the heteroscedasticity that is apparent in the residual terms, together with the non-normality characteristic, are thought of as important limitations of this multivariate time series technique since the estimation of the endogenous equations is performed with OLS. These remaining structures can be effectively taken into account by the APTE as explained in the simulation experiment of *Kyrtsou et al* [15]. Of course, the number of lags to be ultimately included in the VECM will be *(p – 1)*, with *(p)* being specified as the general VAR lag order.

As a first step, we present the Johansen's cointegration test in order to establish the maximum number of long-run relationships *(r)* in the system. We can safely conclude that there is exactly one cointegrating equation at the 5% significance level based on both the Trace and Maximum Eigenvalue statistics.

Table II.2.1.C: Johansen Cointegration Test with linear deterministic trend

Unrestricted Cointegration Rank Test (Trace)				
Hypothesized No. Of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.
r=0	0.089755	96.78521	29.79707	0.0000
r≤1	0.009929	13.84083	15.49471	0.0874
r≤2	0.005698	5.040060	3.841466	0.0248
Unrestricted Cointegration Rank Test (Maximum Eigenvalue)				
Hypothesized No. Of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.
r=0	0.089755	82.94437	21.13162	0.0000
r≤1	0.009929	8.800773	14.26460	0.3031
r≤2	0.005698	5.040060	3.841466	0.0248

Furthermore, we present the initial VECM output in Table II.2.1.D to examine both the short-run as well as the long-run dynamics of the cointegrated series. Starting with the industrial production, the series' own past values seem to be able to explain about 35% of its future evolution, with the equity market also leading the business cycle in the short run. More importantly however, we can confidently state that approximately 0.6% of departures from the long run-equilibrium are corrected in each period, ceteris paribus. On the contrary, equilibrium does not seem to be retained in the inflation series, with the speed of adjustment being statistically significant and positive at the 1% level. We attribute this unconventional result to both the presence of autocorrelation in the residuals and to the dynamic instability of the specific equation. Note that the above are not evident in the rest of the equation specifications. Overall, the U.S stock market index returns' variation does not seem to be explained by almost any of the lags included, with the only exception being the negative, short-run impact of the inflation series. As explained above, standing up to their leading nature and interpretation, the stock markets' monthly returns seem to have significant value in determining the future movements of the inflation and industrial production series, since the short-run coefficients are statistically significant at the 1% level. In both cases, recent past movements of the stock market index seem to be positively influencing the future values of both macroeconomic variables. A possible explanation for this, is the well documented wealth effect of macroeconomics that is associated with the household consumption behaviour [23]. More specifically, it states that higher equity prices, and thus positive stock returns will shift the aggregate demand curve to the right due to their positive impact on household wealth, with the latter further increasing consumer spending while reducing the amount saved out of the current income.

Table II.2.1.D: VECM estimation output.

	Δlindpro	Δlinflation	Δlsp500
E_{t-1}	-0.005998** [-2.46216]	0.005655*** [8.67255]	0.006238 [0.61522]
Δlindpro $_{t-1}$	0.357628*** [11.4614]	-0.001362 [-0.16304]	0.0072578 [0.55888]
Δlinflation $_{t-1}$	0.180429 [1.60376]	0.458200*** [15.2169]	-1.038973 [-2.21894]
Δlsp500 $_{t-1}$	0.031386*** [3.85110]	0.007947*** [3.64321]	0.029125 [0.85868]
Constant	0.000734 [1.56773]	0.001480*** [11.8164]	0.008743*** [4.48757]
Co. Equation	lindpro = 1lindpro $_{t-1}$ -0.080490linflation $_{t-1}$ -0.371644lsp500 $_{t-1}$ -1.547223		
Adj. R^2	0.147875	0.388112	0.002536
F-statistic	39.22161	140.7017	1.559892
Akaike SC	-6.361852	-8.998021	-3.509901
Schwarz SC	-6.334742	-8.970911	-3.482791

Note. Values in [ ] are t-statistics. ***, ** and * indicate statistical significance at the 1%, 5% and 10% levels, respectively. Δlindpro, Δlinflation and Δlsp500 represent the change rates of the s&p500, industrial production and inflation series respectively; E_{t-1} is the error correction term.

As a final note and in order to provide confirming evidence about the lead-lag interactions between the macroeconomic and stock market series, we present basic pairwise Granger-causality tests in Table II.2.1.D. The results show that there is causality running from the S&P 500 returns to both macroeconomic time series at the 1% significance level. Moreover, there is, weak evidence of causality from inflation to the equity returns and hence, it could validly be stated that bidirectional causality is found at the 5% level. Overall, even when apparent chronological ordering is found in the data, industrial production does not seem to lead any of the variables in the tri-variate VECM and hence, univariate causality between the equity market and the general output level fluctuations can be concluded. Finally, the fact that inflation generally adjusts to business cycle fluctuations with a lag can be confirmed. The linear Granger causality dynamics that have been established above can be visualized in Figure II.2.1.A.

Table II.2.1.E: VECM Granger Causality/Block Exogeneity Wald Test

Dependent variable: D(LOGINDPRO)			
Excluded	Chi-square	df	Prob.
D(LOGINFLATION)	2.572060	1	0.1088
D(LOGSP500)	14.83097	1	0.0001
All	17.19996	2	0.0000
Dependent variable: D(LOGINFLATION)			
Excluded	Chi-square	df	Prob.
D(LOGINDPRO)	0.026581	1	0.8705
D(LOGSP500)	13.27297	1	0.0003
All	13.32266	2	0.0013
Dependent variable: D(LOGSP500)			
Excluded	Chi-square	df	Prob.
D(LOGINDPRO)	0.312345	1	0.5762
D(LOGINFLATION)	4.923695	1	0.0265
All	5.071042	2	0.1900

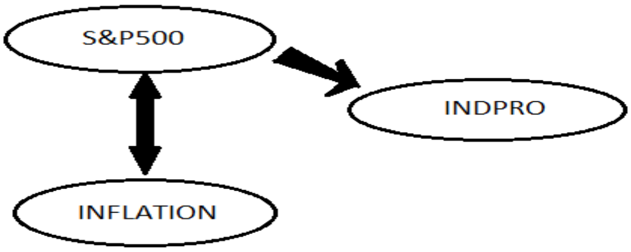

Figure II.2.1.A: Path diagram of the tri-variate system's indirect causal relationships

II.2.2 The application of the proposed Kyrtsou et al [15] test

With the aim of focusing on both the direct couplings and on their asymmetric behaviour, the PTE and APTE measures are being presented in Table II.2.2.A and Table II.2.2.B, respectively. Their performance is evaluated by the percentage of rejection of the null hypothesis of non-causality at the 10% significance level while the associated p-values are being displayed. We assess the above by using a time-shifted surrogate resampling technique that is established with 100 surrogates and without any initial distributional assumptions. Furthermore, even if there can be different types of estimators for the aforementioned measures, we have chosen to base our results on the nearest neighbour method, since it is specifically effective in cases of high-dimensional data and able to provide robust estimations regardless of the choice of k [37] (for this work, the number of neighbours is five). In order to filter out any of the previously established linear causality and cointegration links, the VECM residuals of the SP500 (X), industrial production (Y) and inflation (Z) series have been extracted (Figure II.2.2.A).

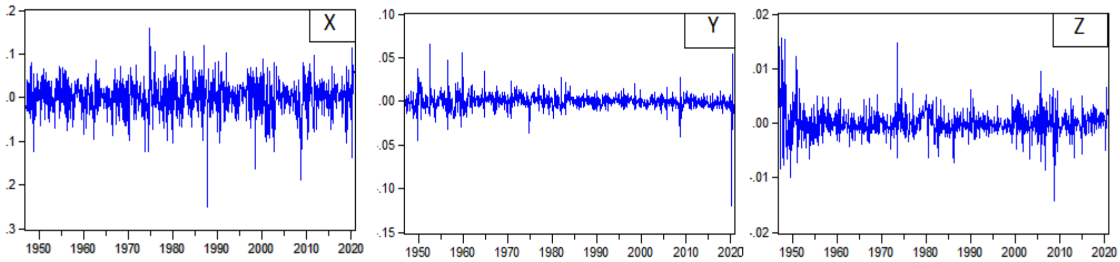

Figure II.2.2.A: VECM residuals of the S&P500 (X), industrial production (Y) and inflation series (Z)

Applying the PTE measure, where each coupling is conditioning on the remaining variable of the tri-variate system, we can conclude that X→Y|Z (i.e. S&P500→INDPRO) and Z→Y|X (i.e. INFLATION→INDPRO). Advancing on the Granger causality test, it seems that the PTE measure does not detect any direct causal relationships between inflation and the equity market when nonlinearity is taken into account (Table II.2.2.A). Furthermore, the leading nature of the equity market is once again verified, since and the S&P500 index seems to be leading the aggregate economic activity series. The reader can visualize the estimated true dynamics in Figure II.2.2.B and compare them with the ones presented in Figure II.2.1.A.

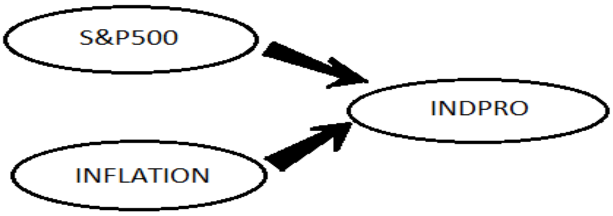

Figure II.2.2.B: Path diagram of the tri-variate system's direct causal relationships

The obtained results seem to materially change when conditioning on the different impact of positive and negative shocks of the driving variables. When asymmetry is allowed to influence the lead-lag dynamics of the tri-variate system, we end up with $X_+ \rightarrow Z|Y$ (i.e. $S\&P500_+ \rightarrow INFLATION$).

Table II.2.2.A: p-values for the significance test based on the PTE

X→ Y |Z	Y→ X |Z	Y→ Z |X	Z→ Y |X	X→ Z |Y	Z→ X |Y
0.0264**	0.1744	0.1744	0.0757*	0.4901	0.5493

Table II.2.2.B: p-values for the significance test based on the APTE conditioning on positive/negative signs of the driving variables

$X_+ \rightarrow Y \|Z$ 0.4408	$X_- \rightarrow Y \|Z$ 0.4309	$Y_+ \rightarrow X \|Z$ 0.6480	$Y_- \rightarrow X \|Z$ 0.7171
$Y_+ \rightarrow Z \|X$ 0.5592	$Y_- \rightarrow Z \|X$ 0.8256	$Z_+ \rightarrow Y \|X$ 0.2632	$Z_- \rightarrow Y \|X$ 0.1744
$X_+ \rightarrow Z \|Y$ 0.0559*	$X_- \rightarrow Z \|Y$ 0.9341	$Z_+ \rightarrow X \|Y$ 0.9341	$Z_- \rightarrow X \|Y$ 0.5789

II.2.3 Discussion

Overall, investors seem to have been rationally gauging the future direction of price levels, even before the last decade, where they are well under control. Of course, the fact that certain goods have been extracted in order to arrive at the core inflation series (i.e. energy and food prices) should not be neglected, since causality estimations seem to be materially affected by changes in the information set. The above, together with the model-free nature of the PTE measure may be potential explanations for the insignificant direct causality finding. As mentioned in chapter one, most of the causality studies seem to conclude on a significant Granger causality relationship between inflation and the stock market (e.g. *Geske and Roll* [10] and *Hashemzadeh et al* [13]) and hence, a multivariate approach that is conditioned on the VECM residuals is shown to offer additional information. Furthermore, when the causal effects of the S&P 500 returns to the industrial production series are taken into account, fluctuations in the general price level seem to lead the cycle. Thus, we can somewhat "tip the scale" in favor of the rather unconventional monetary tactics of inflation-targeting central banks, based upon the aforementioned detected causal channel. Considering that money neutrality does not seem to hold in the short-term, they should continue monitoring this nominal variable in order to ensure that certain qualities of money stay intact (e.g. a medium of exchange that has a relative stable value).

Moreover, our results seem to be in line with the rest of the literature when it comes to the coupling of the S&P 500 and industrial production. As mentioned above, equity returns lead the cycle even when a multivariate causality measure is used. Based on the established dynamics, investors should keep an eye on extreme stock return deviations from the long-term upward trend in either direction. After all, increasing stock prices and therefore returns should signal positive expected earnings and overall fundamentals that are not based on bubbly liquidity or unrealistic and irrational expectations.

Finally, we characterise the asymmetric causal link between the positive subset of the S&P 500 returns and inflation as "intuitively appealing". Apparently, APTE is able to provide further insights by estimating specific dynamics that may be undetected in the original sample that is used by the PTE measure. Of course, since the former is supposed to advance on latter by testing whether the direct couplings hold when conditioning on particular values of the dataset, we would expect $X \rightarrow Z|Y$ (i.e. S&P500→INFLATION) to be significant as well. A possible explanation for this, is that positive and negative values of the S&P 500 index have equal impacts and hence end up cancelling each other out. However, as it can be seen in Table II.2.2.B, the $X_- \rightarrow Z|Y$ (i.e. $S\&P500_- \rightarrow INFLATION$) is strongly insignificant as well. In view of the equity returns' negative skewness value and conditional upon statistically significant asymmetric causal findings, the negative subspace of the original sample should dominate, since the average magnitude of negative deviations from the mean is in this case higher than its positive counterpart.

Conclusions

The relationship between the stock market and the macroeconomy has been one of the most controversial topics in the macrofinance literature until today. In this work, we have attempted to provide clearer and more precise answers by using the most recent innovations of information theory. By considering the asymmetric and non-linear nature of real macrofinance data, the PTE/APTE statistics that were used, detected true causal links and shed light into the tactical asset allocation and monetary policy decisions, conditional upon their regime-depended characteristics.

Starting with an unconstrained VECM, we have been able to study the short- and long-term dynamics of the tri-variate system, composed of the S&P500, industrial production and inflation series. A long-run equilibrium equation with a 0.6% speed of adjustment has been found in the case of industrial production and leading-lag relationships between the series were established (i.e. S&P500→INDPRO, INFLATION→S&P500 and S&P500→INFLATION). However, the estimation of the PTE on the VECM residuals, where linear causal linkages have been filtered out, revealed further interesting couplings. More specifically, by taking into account all available information, the inflation and equity index causal link is not apparent, while both series appeared to lead industrial production. Finally, a rather compelling result emerged when positive and negative observations were allowed to have different impacts on causal relationships (i.e. $S\&P500_{+}$→INFLATION). Considering that the APTE is able to detect the asymmetric dynamics of the system, we characterise this result as "intuitively appealing". However, we would expect the S&P500→ INFLATION and/or the $S\&P500_{-}$→INFLATION couplings to be significant as well.

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