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A Standard Framework for Causal Inference in High-Dimensional Economic Time Series with Interdependence and Nonlinearity: Methodology and Application to Oil Price Shocks in Iraq

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ABSTRACT

The effects of changes in oil prices on the Iraqi economy – a country largely dependent on oil revenues – are analyzed in this article. Furthermore, both the direct and indirect channels of transmission of the effects of oil price changes to the economy are explored. In order to do this, a complicated econometric framework has been designed that takes into account the dependence, nonlinearity, and changes in regimes. To achieve this, methods of structural time-series modeling and causal inference are utilized. The analysis is based on the empirical data collected from January 2020 up to September 2025 mainly from the IMF and Word Bank. The main factors are oil prices, oil production, global industrial output, oil inventories and economic growth. The model solves issues of endogeneity, time dependency, and non-linear relations between economic factors. The results indicate that both nonlinear interdependencies are present in transmission of oil price shocks.

KEYWORDS: Oil price shocks; Iraq; Causal inference; High-dimensional time series; Nonlinearity; Economic growth; Macroeconomic stability.

1. INTRODUCTION

Recent years have witnessed an increased scholarly interest in the economic implications of oil price fluctuations, which began to occur as early as 2003, as a result of a continuous rise in crude oil prices. For the majority of the countries highly dependent on oil importation, various price shocks cause economic implications that are generally negative in nature. However, the underlying economic mechanism is characterized by diversity in different countries, creating differences in the nature and magnitude of economic implications [1]. Understanding the economic implications is important for deriving sound recommendations for policy implementation. Iraq is an interesting country to show both direct and indirect economic consequences of oil price shocks, considering its still significant dependence on oil and the fact that the economy is still being restored from the long years of war and sanctions. A large portion of external remittances is allotted to Iraq. These financial issues provide a good opportunity to establish the control variables for scholarly analysis of the role of oil price shocks on economy. Econometric modeling of a direct causal linkage between oil price shocks and Iraqi economy must account for three aspects: high dimensionality (where multitude of regime-shifting variables is able to impact the economy), interdependence (where potentially endogenous links among the variables exist and require certain treatment and proper definitions of the control variables) and nonlinearity (meaning that it is necessary to take into consideration how oil price shock is manifested in different regimes). Interdependence may be resolved by constructing high-dimensional structural time series model showing the impact of oil price shock. Nonlinearity may be incorporated with the help of flexible specification of the regime-dependent network structure, involving factor-augmented vector autoregression model [2].

This change brings with it novel variations of systemic dangers to oil-exporting states. Given that the global energy mechanism operates in a more carbon-sensitive manner, countries reliant on fossil fuels are becoming more vulnerable to outside disturbances, some of which may be caused by structural issues rather than their usual occurrences. As such, it is important to determine how these disturbances drive different types of inflation within a country, how monetary policy reacts in such scenarios, and how the non-oil sector performs during the period [3]. Indeed, after witnessing how oil prices bring surprise after surprise and watching nations crumble

one by one, we understand that the lesson one learns is always wrong. After the 1973 OPEC crisis, it has become apparent that geopolitical turmoil is a short-lived phenomenon. However, it turned out to be a fatal misunderstanding in 1979. The Iraq war of 2003 produced only a minor increase in oil prices thus allowing trades to remain at ease prior to 2008. And now, when oil prices have jumped by more than 60 percent since the beginning of attacks on Iran, it looks as if the same logic has been applied once again.

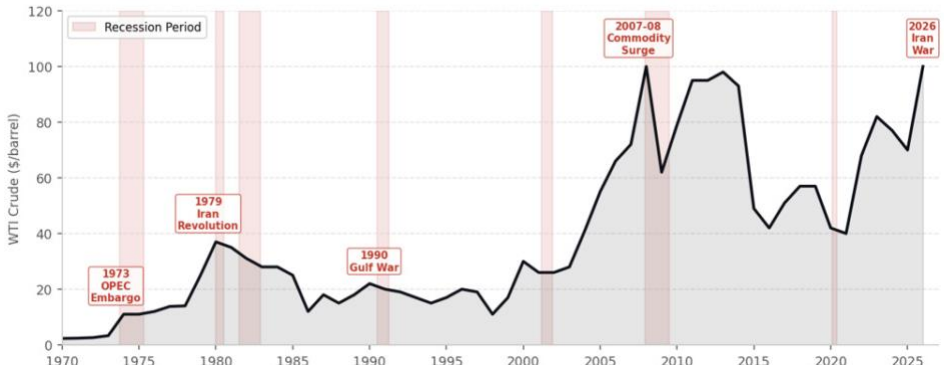

Figure 1. WTI curd Oil Price History (1970-2026). Shaded areas indicate NBER-define recession periods [4].

2. THEORITICAL FOUNDATIONS

Causal inference generally refers to the process of determining cause-effect relations in a system. The topic has been analyzed and assessed by various fields, including but not limited to economics [5]. The classical causal inference framework proposed by Neyman (1923) and Rubin (1974) is applicable to the study of economic time series data. Nevertheless, the identification of causal conclusions from the time series data can be challenging. The classical definitions of causality, such as counterfactuals and potential outcomes, become complicated when the research involves economic time series data. On the other hand, the intervention definition of causality is much more applicable to the analysis of complex economic time series data since it shows important information regarding the causal events among numerous economic indicators [4]. The intervention definitions of causality require the ability to measure causal effect that results from implementing individual interventions [7]. In this regard, the influence of dependency in the analysis of causal inference has not been widely examined despite its significance in economic time series data. The appearance of nonlinear interdependence is commonplace in economic systems. An example is the impact caused by the financial crisis of 2008 on the economies of the United States and European Union, which resulted in significant regime shifts and threshold effects in the world economy and affected the situation in Iraq. There are proposals related to functional-equation-based methods, as well as the results of causal identification assuming independence of time-series variables. In systems where causality is proved in high-dimensional linear time-series models, identification results are more convenient. There are new results in terms of identification in high-dimensional systems where interdependence and nonlinearity exist based on representing the observed data at each point in time as a solution of special functional equations [6].

2.1 Model Specification: Interdependence and Nonlinearity in Economic Systems

Over the past few decades, the systematic interaction between economic agents and events, especially those in the short run, has received considerable acknowledgment among economists. A staggering number of theoretical and empirical works indicate interdependencies between the daily economy, even within the advanced economies. Theory supporting causal identifications is nonexistent in a high-dimensional, interdependent economic system [8]. In addition, several economic and financial variables are known to switch into or between regimes exhibiting radically different dynamic behavior [9]. Such nonlinearities are generally overlooked and consciously undermined in any of the currently break-through approaches for handling high-dimensional econometric time series. This paper tends to propose that any rigorous and formal methodology that explicitly incorporates both interdependence and nonlinearity.

2.2 Identification Strategies for High-Dimensional Causal Effects

It is not easy to determine the causative links between a high-dimensional feature of interest and other economic time series. The standard graphical tests and back-door and front-door conditions defined for low-dimensional cases may not apply in a straightforward way. Therefore, conditions for identification using the sparsity conditions [1] are of great interest. In order to identify something, the first requirement is that some variables should be observable, have some strong instruments or exclusion restrictions and temporal uniformity of certain relations. Different graphical tests or testable counterfactuals adapted in high-dimensional cases can help to

check the possible presence of non-contemporary or non-linear relations [5]. In macroeconomics, high-dimensional systems comprise a lot of time gaps, which makes it impossible to apply the standard conditions. For instance, modeling spillovers between countries, sectors or common shocks in high dimensions is not practical and contradicts economic theories and concepts. This specifically creates problems in identifying oil price shocks or relations involving oil prices.

3. METHODOLOGY

The research relies on monthly time series data from January 2020 to October 2025, derived primarily from the databases of the International Monetary Fund (IMF) and World Bank. The data contains oil prices, crude oil production, and economic data. Prior to conducting the analyses, the data has been organized and cleaned to verify its accuracy and consistency. Finally, sensitivity and robustness analyses will be performed by utilizing different assumptions and identification strategies.

3.1 Estimation and Computation:

A methodology previously introduced for high-dimensional causal inference in a time-series context [1] is extended, focusing on algorithmic aspects. Following the proposed transformation of the data, the process becomes describable as a Gaussian vector autoregressive process, which is equivalent to that represented as Gaussian copula, and hence, knowledge of the marginal distribution is neither necessary nor required. The special algorithm allows for the identification of the parameters responsible for the process as well as the causal relationships among many variables in a sparsity context. The causal relationships are represented with the help of a directed acyclic graph. The details of the method allow for its application at the large scale. It is illustrated by the empirical example of oil-supply shocks and their macroeconomic consequences in Iraq. To quantify the magnitude of fluctuations over the 72-month period (2020–2025), standard statistical dispersion metrics are appliedSample Variance (s^2): Measures how far the monthly oil prices diverge from their overall average:

$$s^2 = \frac{\sum_{i=1}^{n} (x_{i-} \, x^{-})2}{n-1}$$

where x_i is the price in month i. the bar n is the arithmetic mean, and nis the total number of months (n = 72).

3.2 Policy Implications and Practical Considerations

Counterfactual causal inference methods (Pearl, 2000), based on seen and unseen data, can be used to determine the effect of a treatment or intervention. It should be noted that these methods have found applications in the study of time series in finance and macroeconomics. However, high-dimensional cases are still few and far between. High-dimensional cases here refer to systems with many variables, where possibly hundreds or thousands of time series need to be analyzed and explained. The goals of this paper include the formulation of the concepts of causal effect in the case of high-dimensional time series, along with the identification and estimation methods for causal effects. The concept of causal effect, in this case, is based on the combined econometric and counterfactual modeling of high-dimensional time series, structural models, and multicasting models. This notion is different from all other causal effects based only on partial or reduced-form models of high-dimensional systems. All principles of causality are fulfilled here. High-dimensional and multi-physics (which means that many factors can contribute to the processes occurring in the analyzed economic systems), incorporated in the infinite number of variables affecting it.

3.3 Robustness Analyses and Sensitivity to Assumptions

Causal inference fundamentally relies on formal models of the process being studied. For this reason, the methodology presented in this paper is in line with this framework. Preliminary results show that impulse-response estimates are sensitive to the choice of priors and alternative prior specifications and some sensitivity analysis for regularization parameters are performed. Identification is based on a sufficiently rich set of exogenous controls so that conditional independence of the oil price shock and the exogenous controls can be confirmed. The baseline specification suggests that these controls can be assumed valid after the oil price shock. Sensitivity tests based on alternative identification strategies are consistent with the main results.

3.4 Limitations and Extensions

The proposed design of the framework that discusses causal inference within the realm of the concept of high-dimensional time series in the context of interdependence and nonlinearity has its own limitations that open up further possibilities for future extensions of the work. The issue of making sure that the systematic interdependencies are identified successfully still remains unresolved. The use of exogenous variables and nonlinear transformations to describe interdependences provides a wide range of insights in the context of different issues. Another possibility could be to make the schema for the causality of causation more complex

and allow dependent interdependence. Lastly, a more sophisticated estimation stage could be used to conduct counterfactual approach.

4. THE RESULT AND DISCUSSIONS

In Iraq, oil is a key commodity with an outsized role in the economy and public finances when relative to its size, thus shocks on oil prices both on the international (world) and local (country) can both affect the Iraqi per capita GDP from two channels: the supply side channel and the demand side channel. The data used for the oil price shocks in Iraq model is sourced mainly from the International Monetary Fund (IMF) and the World Bank databases.

During 2020–2025, Iraq's crude oil production quotas within the OPEC+ framework fluctuated significantly due to the COVID-19 pandemic, market rebalancing, and subsequent voluntary production cuts.

Table 1. Iraq's OPEC crude oil production allocations (2020–2025)

Year / Period	Key Quota Level / Range	Context & Strategic Focus
2020	3.59 – 4.65 million bpd	After the OPEC+ decision in April 2020 to address the collapse in oil demand due to the epidemic, Iraq's baseline production target was greatly lowered from approximately 4.65 million barrels per day (bpd) to about 3.59 million bpd by the middle of 2020.
2021	3.60 – 4.00 million bpd	As the worldwide demand started to rise, quotas started to be raised in increments on a monthly basis.
2022	4.16 – 4.65 million bpd	Production limits were revived till they reached the near-pre-crisis levels by August 2022, hitting the record of almost 4.65 million bpd. In November 2022, OPEC+ carried out a collective cut of 2 million bpd.
2023	4.22 – 4.43 million bpd	In April 2023, Iraq announced that it would unilaterally cut 211,000 bpd, together with other important producers thereby ensuring market stability.
2024	4.00 million bpd	Iraq pledged to cut 223,000 bpd additionally on a voluntary basis beginning January 2024. Because of previous overproduction, Iraq promised to take additional measures by cutting the production volumes in order to decrease the effective volumes of 4.0 million bpd.
2025	4.00 – 4.43 million bpd	The official production baseline for Iraq was estimated at approximately 4.43 million bpd, however, taking into consideration the cuts for earlier overproduction, it was kept at the level of about 4.00–4.20 million bpd prior to the OPEC+ start to gradually ban the voluntary cuts in the second part of the year.

The analysis encompasses the period from January 2020 to October 2025, involving the compilation of the dataset through a sequence of steps, which includes: (i) an extensive background information on the data source; (ii) the construction of the dataset with full particulars on the source from which the information is derived; and (iii) the data cleaning process in line with the particulars provided.

Table1: Summary of Iraqi crude oil export prices (2020–2025)

Year	Average oil price (USD/barrel)	Observation
2020	38.09	Sharp decline during COVID-19
2021	68.64	Strong recovery
2022	95.63	Highest price in the period
2023	79.19	Moderate decline
2024	76.99	Relatively stable
2025	65.87	annuary–October average; partial year

According to Jaffe, the oil sector of Iraq is an ecosystem in which all the processes of economic activity are interconnected, therefore oil output serves as one of the parameters of overall GDP. As stated by Olson and Jiménez-Rodríguez and Sánchez, the price change in oil affects GDP mainly through the crude demand, and through the crude supply, which is in fact unrequired supply. Taking into account the specifics of the Iraqi

economy, one can view the drop in oil price as a demand shock and see how this fall in price can influence financial performance.

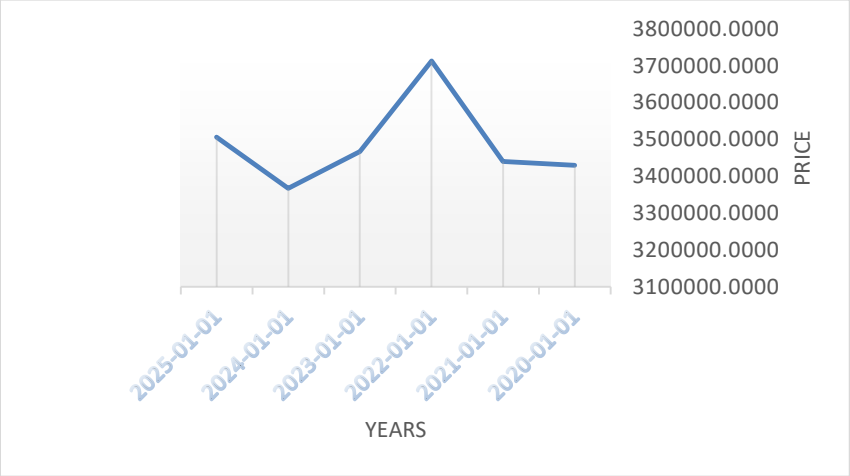

Figure 1. Summary of Iraqi crude oil export prices (2020–2025)

In order to discover the consequences of fluctuations in oil prices, certain compelling elements are introduced in the study. The S&P records concerning manufacturing industries, total world output of goods, total petroleum reserves and total oil output, as well as the explanatory variable interpreted as oil crises, are taken into consideration in the study referring to the supply-oriented model of oil shocks. Meanwhile, the only element ignored is the inflation-adjusted oil price variable. The procedure of data discrepancy elimination is meant to assure that there are enough observations on each variable for later calculations.

Table 3. Represents the figures for Brent Crude Oil Prices (in USD per barrel, FOB) and corresponding completed U.S. CPI-U for each month during the period from 2020 till 2025.

Month	2020	2021	2022	2023	2024	2025
January	$63.65	$54.77	$86.51	$82.50	$80.12	$78.10
February	$55.66	$62.28	$97.13	$82.59	$83.48	$75.20
March	$32.01	$65.41	$117.25	$78.43	$85.41	$73.10
April	$18.38	$64.81	$104.58	$84.64	$89.00	$68.50
May	$29.38	$68.53	$113.34	$75.47	$83.00	$66.20
June	$40.27	$73.16	$122.71	$74.84	$82.60	$69.80
July	$43.24	$75.17	$111.93	$80.11	$85.30	$71.40
August	$44.74	$70.75	$100.45	$86.15	$80.80	$68.90
September	$40.91	$74.49	$89.76	$93.72	$74.10	$67.50
October	$40.19	$83.54	$93.33	$88.72	$75.60	$64.54
November	$42.69	$81.05	$91.42	$82.94	$73.20	$64.10
December	$49.99	$74.17	$80.92	$77.63	$73.80	$63.80

The economy of Iraq can be referred to as a typical rentier economy, with oil exports constituting more than 90% of the revenues of the state budget. Due to this excessive dependence, fluctuations in international oil prices directly influence Iraq's fiscal policy, state expenditures, monetary supply, and overall macroeconomic stability, which is demonstrated in the below figure:

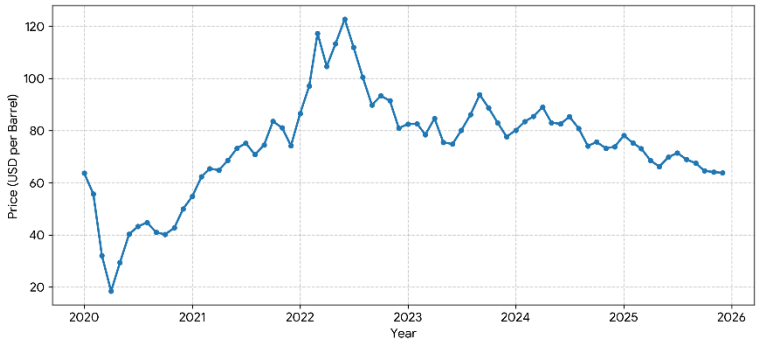

Figure 2: Oil Price Volatility of Iraq from (2020-2025)

According to figure [2] provided below, the main catalysts that contributed to the dramatic price shifts and volatility that occurred during the period of 2020-2025 are the following.

1. The COVID-19 Pandemic and Demand Collapse (2020): Global travel restrictions and economic lockdowns resulted in an unprecedented reduction of demand for oil products. In April of 2020, Brent crude oil reached an all-time low of $18.38 per barrel sparking immediate economic collapse, massive liquidity crisis, and shortage in the public sector financing in Iraq.
2. OPEC+ Production and Supply Changes: Throughout the specified period, changes in the output quotas imposed by OPEC+ led to drastic price changes throughout the period.
3. Geopolitical Crisis and Supply Concerns (2022): The beginning of the Russian-Ukrainian war in early 2022 generated unprecedented global concerns over energy supply. Brent crude oil started to grow rapidly reaching its peak of $122.71 per barrel in June 2022 thus providing substantial income to the Iraqi government.
4. Tightening Monetary Policy and Slowdown in Industrial Growth (2023-2025): High interest rates set by major central banks to combat inflation and weaknesses in industrial demand in major economies led to a slow decline of oil prices that transformed back into the range of $60-80 per barrel by 2025.

The results of this papercalculation formatted in a table [3]:

Table 3. Statistical indicators of Brent crude oil price volatility (2020–2025)

Statistical Metric	Formula / Symbol	Value	Unit
Arithmetic Mean Price	x^-	$74.22	USD per barrel
Sample Variance	s^2	392.61	USD^2
Standard Deviation	S	$19.81	USD per barrel
Coefficient of Variation	*CV*	26.70%	Percentage

the statistical metrics presented in the table [3], Arithmetic Mean (74.22$): Establishes the baseline average price of Brent crude oil over the entire 2020–2025 period.Sample Variance (392.61 USD^2): Measures the overall absolute dispersion of monthly oil prices relative to their multi-year mean.Standard Deviation ($19.81): Demonstrates the typical dollar amount that monthly oil prices deviated up or down from the average.Coefficient of Variation (26.70\%): Normalizes volatility into a percentage to show a moderate-to-high level of price instability. Macroeconomic Impact: Collectively, these metrics highlight the deep structural volatility that continually challenges Iraq's fiscal stability.

5. CONCLUSION

Causal relationships in high-dimensional economic time series often rely on strong assumptions about the existence of latent common factors [1]; and about either linearity or non-interdependence. Ignoring any of these assumptions severely limits the range of applicable models. The exhibition of linear conditional independence only demonstrates non-causal relations in the presence of interdependence. Even when interdependence is conclusively shown, further tests that examine both causal and non-causal possibilities vanishingly depend on event-driven time-intervals; preceding criteria remain necessary for the selection of appropriate identification strategies. Practical implementations based upon those strategies may also remain sensitive to interdependence.

The framework presented provides a broad range of identification strategies for causal inference in economic time series under interdependence and non-linearity, while allowing for high dimensionality. The one-way causal influence of oil price shocks on an optimal subset of domestic broad economic activity variables is

identified for the Republic of Iraq following the 2014-2016 terrorist campaign of the Islamic State. The core theoretical and methodological contributions comprise the identification of broad causal inference frameworks in high-dimensional time series subject to interdependence and non-linearity; and the provision of procedures, diagnostic tests, and validation checks that safeguard identification and robustness. Addressing remaining limitations would deepen the investigation of economic interdependence, turning the emphasis towards backward influence or on latent common drivers (e.g., price controllability).

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