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The Spillover Effect of Global Crude Oil Price Volatility on Iran's Basic Metals Market: A Kalman Filter Approach

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ABSTRACT

The present study examines the spillover effect of global crude oil price volatility on the basic metals market in Iran during the period from 1996 to 2024. Given the importance of oil and basic metals in Iran's economy—and their roles in export revenues and economic growth—the main objective of the research is to identify the transmission channels through which oil price volatility affects the export of mineral resources and basic metals, and to determine the magnitude and direction of these effects. To analyze the data, a state–space model using the Kalman Filter algorithm is employed, which enables the estimation of unobservable variables and time-varying parameters of the model. This method is particularly suitable for examining structural instability and the dynamic effects of market volatility. The findings indicate that crude oil price volatility, economic policy uncertainty, geopolitical risk, and energy consumption exert negative effects on basic metals exports, leading to reduced competitiveness and profitability in this sector. In contrast, capital and labor have positive effects on the export of basic metals, facilitating the enhancement of production and export performance. Furthermore, the effects of institutional quality and the economic complexity index in Iran appear to be limited and short-term. Based on the results, it is recommended that policymakers stabilize energy prices, reduce policy uncertainty, expand stable trade relations, invest in technology, and increase institutional transparency to support the sustainability and growth of basic metals exports. Using the recursive Kalman Filter algorithm, this study provides an accurate and dynamic portrayal of the interaction between global oil market volatility and the basic metals sector, offering valuable insights for policymakers and economic practitioners.

Keywords: Basic metals exports, oil price volatility, state–space model, Kalman Filter, Iranian economy

Introduction

The basic metals sector sits at the heart of contemporary industrialization, infrastructure development, and the green energy transition. Steel, aluminum, copper, and other base metals enter virtually every stage of value chains from construction and transport to renewable energy technologies and digital equipment, making their price dynamics and export performance critically important for both advanced and emerging economies (1). At the same time, crude oil remains a key strategic commodity that shapes global macroeconomic conditions, production costs, and financial market sentiment; the interaction between oil markets and metals has therefore become increasingly central to debates on energy security, decarbonization, and sustainable growth (2). As countries scale up investment in renewable and low-carbon technologies, the demand for industrial metals intensifies, while oil markets

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still influence the cost structure and financing conditions of these capital-intensive projects, creating a complex nexus between energy and metals under the emerging clean-energy paradigm (3). Understanding how shocks and volatility in global crude oil markets spill over into metal markets is thus essential for commodity-exporting economies whose fiscal stability, external balance, and growth prospects depend heavily on these intertwined sectors (4).

In recent years, a rich international literature has emerged analyzing volatility spillovers and connectedness within and across commodity classes, particularly between energy and metals. Studies of realized volatility and time-varying connectedness show that the direction, magnitude, and persistence of spillovers between energy and metal markets are far from constant over time and often depend on the underlying macroeconomic and financial regime (5). Using advanced joint connectedness and quantile-based approaches, research on precious metals and oil volatilities has documented asymmetric responses across the distribution of shocks, with stronger connectedness under extreme market conditions (6). Spillover analyses based on high-frequency data confirm that oil shocks transmit rapidly to non-energy commodities, including industrial metals, and that this transmission intensifies during crises and stress episodes (7). Complementary evidence from time-varying spillover indices suggests that metals and energy commodities form strongly interconnected networks in which oil often acts as a net transmitter of shocks, while metals can switch between net-receiver and net-transmitter roles depending on global conditions (8). More granular investigations of industrial metal markets further reveal that intra-metal spillovers themselves evolve over time, indicating that systemic risk within the metals complex cannot be treated as static (1). Extending this framework, time-frequency approaches to the energy–food–metal nexus highlight that connectedness differs across short-, medium-, and long-term horizons, underlining the need for methods that explicitly accommodate time variation in parameters (9).

Beyond average volatility, recent work has shifted toward systemic risk, tail dependence, and herding behavior in commodity markets. Research on systemic risk across commodities and emerging stock markets shows that simultaneous shocks in oil and metals can amplify financial fragility, especially in economies with shallow capital markets and strong resource dependence (10). Studies focusing on tail risk spillovers confirm that during crisis periods, extreme downside shocks can propagate from oil to commodities and metals in ways that standard linear models fail to capture (11). Evidence from high-frequency volatility spillovers between oil and non-energy commodities indicates that crisis episodes—such as global financial turmoil or geopolitical tensions—are associated with sharp increases in bidirectional connectedness, suggesting a tighter risk linkage between energy and real commodity markets (7). Analyses that distinguish between demand- and supply-driven oil shocks show that these shock types have heterogeneous implications for grain and commodity markets, reinforcing the notion that the transmission channels of oil volatility are multifaceted (12). At the same time, research on herding behavior in commodity and metals sectors demonstrates that macroeconomic shocks and monetary policy shifts can reinforce correlated trading and collective reactions across investors, thereby amplifying volatility spillovers beyond what fundamentals alone would predict (13). Complementary studies on financial connectedness in emerging markets stress that oil shocks can reshape cross-market linkages, altering portfolio diversification benefits and the transmission of risk across asset classes (14). A growing body of work on higher-order spillovers between crude oil, foreign exchange, and stock markets further underscores that oil is embedded in a broader web of macro-financial dynamics that ultimately feed back into commodity markets and export performance (4, 15).

Despite this extensive international literature, several gaps remain, particularly with respect to real-sector outcomes and the position of resource-dependent emerging economies. Most existing studies focus on price and return spillovers in global financial and derivatives markets rather than on the export volumes and competitiveness of specific commodity-exporting sectors (2). Moreover, evidence is heavily concentrated on advanced economies or large diversified emerging markets, with far fewer contributions analyzing the experience of oil-dependent economies where fiscal revenues, exchange rates, and investment cycles are tightly linked to commodity prices (14). The metals–oil nexus has been examined from the standpoint of portfolio risk and market connectivity, but less from the perspective of how oil price volatility shapes the long-run trajectory of export diversification, structural transformation, and industrial upgrading in producer countries (3, 8). This omission is particularly important for economies that seek to use their mineral and metals endowments as stepping stones toward more complex, knowledge-intensive export baskets yet remain highly exposed to oil-driven macroeconomic uncertainty (9). There is therefore a need to bridge the gap between high-frequency spillover metrics and the medium- to long-run performance of strategic export sectors in oil-dependent economies.

The Iranian economy offers a salient case for examining these issues. On the one hand, Iran is endowed with substantial oil and gas reserves that have historically underpinned its export revenues and fiscal capacity; on the other hand, it possesses significant mineral and metals resources that could support diversification away from crude oil if developed under stable and supportive macro-institutional conditions (16). A large body of research has explored the "natural resource curse," Dutch disease, and the growth implications of resource abundance in Iran and other oil-producing countries, documenting how terms-of-trade booms can lead to real exchange rate appreciation, de-industrialization, and volatile growth trajectories (16, 17). Comparative studies of Iran and Norway, for example, highlight how differences in institutional frameworks and economic governance shape the translation of natural resource wealth into sustainable growth (17). Further work on oil-producing countries emphasizes that the relationship between resource abundance and per capita income is mediated by the degree of economic freedom and the quality of governance, suggesting that institutional and policy environments are central to determining whether resource wealth becomes a curse or a blessing (18, 19). Analyses of oil revenues and good governance indices in OPEC economies similarly underline that reliance on hydrocarbon rents can weaken incentives for institutional reform, transparency, and accountability, thereby reinforcing volatility and macroeconomic vulnerability (20).

Within this broader literature, institutional quality, governance, and macro-financial stability consistently emerge as key determinants of how oil-dependent economies manage external shocks and pursue diversification. Studies on resource abundance, governance, and growth stress the complementary role of information and communication technologies, transparency, and effective regulatory frameworks in enhancing the growth impact of natural resources (21). Empirical work focusing on oil dependence and institutional quality shows that weak institutions amplify the negative growth effects of oil price volatility and hinder the development of non-oil tradable sectors, whereas stronger institutions can dampen volatility and support more resilient trajectories (22). In the Eurasian and Iranian contexts, research on institutional quality and financial development indicates that better rule of law, stronger property rights, and reduced corruption foster deeper, more efficient financial systems capable of channeling resources toward productive investment, including in non-oil export sectors (23). At the same time, analyses of natural resource abundance and growth in Iran demonstrate that institutional reforms are essential for breaking the link between resource booms, macroeconomic instability, and long-run underperformance (19, 24). From a fiscal and macro-stability perspective, the sustainability of public finances is also crucial: when oil revenues are volatile and fiscal systems are weak, governments may struggle to smooth expenditure and shield strategic sectors such as metals from external shocks (25).

A growing strand of Iranian empirical work applies time-varying econometric techniques to capture structural instability and evolving relationships in resource-dependent settings. In particular, state–space models estimated via the Kalman filter have been used to study how institutional quality interacts with resource abundance and growth, revealing that the impact of natural resources on economic performance can change over time as institutions evolve (24). These approaches are well suited to contexts where parameters are unlikely to remain constant over long horizons due to shifting geopolitical conditions, policy regimes, and sanctions environments. At the global level, dynamic connectedness and time-varying spillover models have become standard tools for analyzing oil–metal linkages, but they typically focus on financial returns and systemic risk rather than on sectoral export flows (5, 8). By contrast, there is still limited empirical evidence on how global crude oil price volatility, together with domestic factors such as economic policy uncertainty, institutional quality, economic complexity, and geopolitical risk, shapes the export performance of Iran's basic metals sector over extended periods (11, 12). Existing studies on volatility spillovers, tail risk, and systemic risk provide a conceptual foundation but rarely incorporate real-sector trade variables, sector-specific production inputs (capital, labor, energy), or indices such as economic complexity into an integrated, time-varying analytical framework (2, 4, 10, 15).

These gaps are particularly consequential for policy in Iran, where the basic metals and mineral sectors are expected to contribute to export diversification, employment, and industrial upgrading, yet remain exposed to oil-driven macroeconomic shocks, domestic policy uncertainty, and institutional weaknesses (20, 22). Policymakers need empirical evidence on whether oil price volatility primarily affects metals exports through production costs, exchange-rate movements, demand conditions in trading partners, or shifts in financing and investment, and how these channels are moderated by institutional quality and the broader structure of the economy. Capturing the dynamic nature of these relationships requires models that allow parameters to evolve over time and can accommodate unobservable components such as cyclical factors or time-varying sensitivities to global shocks. State–space models estimated with the Kalman filter provide a flexible framework for this purpose, enabling researchers to extract hidden states representing cyclical spillover effects and to trace how the responsiveness of metals exports to oil volatility, energy consumption, geopolitical risk, and policy uncertainty has changed across distinct historical episodes (1, 9, 24).

Accordingly, the aim of this study is to investigate the time-varying spillover effects of global crude oil price volatility, economic policy uncertainty, geopolitical risk, institutional quality, and economic complexity on Iran's exports of basic metals and mineral resources using a state–space model estimated via the Kalman filter.

Methods and Materials

In the present article, following the studies of Konadu et al. (2025), Palomba and Tedeschi (2025), Ghalalebi et al. (2025), and Tesmen et al. (2024), the subject is examined in Iran using the state–space model. State–space models are among the most suitable techniques and methods used in the econometrics and time-series literature, as they enable the estimation of unobservable variables or state variables within a system of equations. These models examine structural instability in the coefficients and allow parameters to vary over time. As mentioned earlier, state–space models are used in the econometrics literature to model unobserved variables such as rational expectations, measurement errors, omitted observations, permanent income, unobservable components (cycles and trends), and the non-accelerating unemployment rate. It should be noted that the main difference between time-series models and state–space models is that in state–space models, parameters also become functions of time rather than remaining constant.

There are two major advantages to expressing dynamic models in state–space form. First, such models allow unobserved variables to be used in model estimation and make it possible to estimate them. Second, they can be analyzed using robust recursive algorithms such as the Kalman Filter. If $y_t$is the matrix of observed variables at time $t$and is of dimension $(n \times 1)$, new dynamic models of $y_t$can be specified based on the unobservable variables B_t, where this equation, when written as a vector, is known as the state vector. The state–space equation related to $y_t$is defined as the following system:

(1) $y_t = AX_t + HB_t + W_t$

(2) $B_{t+1} = FB_t + V_{t+1}$

Here, A, H, and $F$are parameter matrices with dimensions $(n \times k)$, $(n \times r)$, and $(r \times r)$, respectively. Equation (1) is known as the observation equation; in this equation, $X_t$is a $(k \times 1)$vector including exogenous or predetermined variables. Likewise, $y_t$is an $(n \times 1)$vector and serves as the dependent variable, which here represents basic metals exports. The vector $B_{t+1}$is $(r \times 1)$and contains the unobservable component, or the state variable. Equation (2), which determines the structure of the state variable, is known as the state equation. Both equations contain disturbance terms $W_t$and V_t, which are independent of each other and identically distributed:

(3) $v_t \sim N(0, Q)$

$w_t \sim N(0, R)$

Here, $Q$and Rhave dimensions $(r \times r)$and $(n \times n)$, respectively. Moreover, the disturbance terms of the observation and state equations are uncorrelated with their own lags:

(4) $E(V_t, W_t) = 0$

Whenever a time-series model is expressed in state–space form, algorithms exist that allow parameter estimation, series smoothing, or forecasting. The most important of these algorithms is the Kalman Filter, introduced by Kalman and Bucy. The Kalman Filter is a recursive method for producing optimal forecasts of unobservable variables and efficient estimates of state–space model parameters, based on mathematical expectation. One of the characteristics of the conditional expectation is that it provides the best prediction with minimum squared error. Although the Kalman Filter was invented to solve a problem in spacecraft navigation, today this technique is used to solve many problems in which incomplete observations must be combined with the underlying state of a system. As mentioned, the Kalman Filter is a recursive algorithm for computing minimum-mean-square-error linear forecasts using observed past data.

(5) $B_{t+1|t} = E(B_{t+1} \mid B_1)$

$B_t = (y'_t, y'_{t-1}, \ldots, y'_1, X'_t, X'_{t-1}, \ldots, X'_1)'$

These forecasts are computed recursively, and at each stage the mean-squared error (MSE) can also be calculated.

(6) $B_{1|0} \rightarrow B_{2|1} \rightarrow \ldots \rightarrow B_{t|t-1}$

$P_{1|0} \rightarrow P_{2|1} \rightarrow \ldots \rightarrow P_{t|t-1}$

The starting point for the forecasts in such an algorithm is $B_{1|0}$and $P_{1|0}$:

(6) $$B_{1|0} = E(B_1)$$

$$P_{1|0} = E[(B_t - E(B_t))(B_t - E(B_t))']$$

For optimal and efficient estimation of state–space models, two points must be considered; otherwise, the estimation results will be unreliable, and any inferences drawn from the results will be incorrect.

1. In the state–space equation system, the ratio of the variance of the disturbance term in the state equation to the variance of the disturbance term in the observation equation is called the signal-to-noise ratio. If the signal-to-noise ratio is non-zero, it can be said that the estimated state–space equations are valid and the resulting variable outputs are acceptable. However, if this ratio equals zero, the estimated state–space model encounters the problem of accumulation (pile-up).
2. When using the Kalman Filter for parameter estimation, it is necessary that the disturbance terms in both the observation and state equations follow a Gaussian (normal) distribution. Therefore, diagnostic tests must be conducted to verify the assumptions of the Kalman Filter. The main model used in this research is considered as follows:

(7)

$$EXMET_{it} = \alpha_0 + \beta_1 OILSH_{it} + \beta_2 ENRGY_{it} + \beta_3 IQ_{it} + \beta_4 K_{it} + \beta_5 L_{it} + \beta_6 GE_{it} + \beta_7 COMP_{it} + \beta_8 EPU_{it} + \beta' Z_t + \varepsilon_t$$

where:

EXMET: exports of mineral ores and basic metals (percent of merchandise exports);

OILSH: crude oil price volatility calculated using ARCH and GARCH models;

GE: geopolitical risk, derived from indicators of political stability and absence of violence in the region. This index ranges from 0 to 100, where higher values indicate improved political stability and reduced violence;

COMP: economic complexity index.

The Economic Complexity Index (ECI) is a concept used to measure the level of knowledge, skills, and productive capabilities embedded within a country’s economic structure. This index indicates the extent to which a country’s economy is diversified, advanced, and knowledge-based. In other words, economic complexity reflects the kinds of products a country produces and exports, and the degree to which these products can be produced in other countries. If a country exports a large number of goods, and these goods are produced in only a few other countries, its economy is considered more complex. Therefore, economic complexity essentially reflects the number and diversity of productive capabilities present within a country—meaning the set of knowledge, skills, technologies, and institutions that enable the production of various goods. The more diverse and advanced these capabilities are, the more complex the country’s economy will be.

From a conceptual standpoint, the Economic Complexity Index is a combination of two main characteristics:

Diversity: the number and range of goods that a country is able to produce and export.

Ubiquity: the degree to which these goods are common or rare globally—that is, the number of countries capable of producing the same goods.

A complex economy is one that produces a wide variety of goods (high diversity) and, at the same time, goods that can be produced in only a few other countries (low ubiquity). Operationally, the Economic Complexity Index is calculated based on countries’ export data. First, a country–product matrix is constructed, indicating which goods each country exports with a revealed comparative advantage (RCA). Then, based on this matrix, two indices—“country diversity” and “product ubiquity”—are calculated, and through the network-based interaction between countries and products, the complexity of each country is derived. In the computation process, using mathematical methods and network analysis (including eigenvector decomposition), the ECI is extracted as the second eigenvector of the country–product co-dependence matrix. The resulting values are standardized and expressed numerically, such that countries with higher index values possess more diversified and knowledge-intensive economies. Interpretatively, a higher ECI value indicates an advanced, industrial economy with robust innovation capacity, while lower values typically belong to countries whose economies rely on exports of raw materials or simple goods. For instance, countries such as Japan, Germany, and South Korea have high economic complexity, whereas Saudi Arabia and Nigeria—due to their dependence on crude oil exports—have low complexity levels. In summary, the Economic Complexity Index is an analytical tool for understanding the "depth of knowledge and productive capabilities" within economies and is regarded as one of the most important indicators for predicting long-term economic growth and future industrial trajectories.

EPU = Economic Policy Uncertainty:

Given the prevailing economic conditions in Iran—marked by recurring fluctuations in exchange rates, growth in the money supply, suboptimal economic growth, and heavy dependence on oil revenues that has reduced attention to tax revenues—it is necessary to introduce an index tailored to Iran's economy that captures policy uncertainty. Following the study by Looney et al. (2021), for Iran's economy, fluctuations in three policy indicators—fiscal, monetary, and exchange rate policies—are first calculated using the Hodrick–Prescott filter. Then, a composite index of the volatility of these variables is estimated and introduced as the economic uncertainty index.

The method for measuring the uncertainty index is as follows: first, fluctuations in monetary policy variables (monetary base), fiscal policy variables (budget deficit and taxes), and exchange rate policy (exchange rate), as well as fluctuations in inflation and economic growth, are calculated using the Hodrick–Prescott filter. Then, using Principal Component Analysis (PCA), the economic uncertainty index is constructed. PCA reduces the dimensionality of all observations based on a composite index and clusters similar observations. In this method, the variables present in a multivariate space are compressed into a set of uncorrelated components, each of which is a linear combination of the original variables. These uncorrelated components are the principal components (PCs), derived from the eigenvectors of the covariance or correlation matrix of the original variables. Reducing the number of variables and identifying the relational structure among them are major applications of PCA. The main advantage of this method in econometrics is its ability to eliminate multicollinearity in models caused by the large number of variables.

Table 1. Economic Policy Uncertainty Index

Policy Area	Acronym	Operational Definition
Monetary Policy	IR	Interest rate: The cost of borrowing money that the borrower must pay; alternatively, the opportunity cost borne by the lender for foregoing alternative uses of funds.
	M	Monetary base: Total amount of money created by the central bank with high liquidity, including all cash in circulation plus bank reserves held at the central bank.
Fiscal Policy	BD	Budget deficit: The excess of government expenditures over its revenues; commonly used during economic recessions.
	TAX	Taxation: Transfer of part of society's income to the government or the share of profits from economic activity that accrues to the state; revenue derived from tax-rate changes or expansion of the tax base.
Exchange Rate Policy	ER	Exchange rate: The value at which domestic currency is traded for foreign currency; the amount of national currency required to obtain one unit of foreign currency.
Inflation	INF	Inflation rate: The average sustained increase in the general price level, calculated using the price index of 386 goods in Iran.
Economic Growth	GDP	Gross Domestic Product: Total monetary value of final goods and services produced by resident economic units within a specific period (annual or quarterly).

L: represents conventional production inputs such as labor.

K: per capita gross fixed capital formation in U.S. dollars (percentage of growth rate).

ENRGY: per capita energy consumption measured in kilograms of oil equivalent.

Institutional Quality (IQ): the average institutional quality index. To measure institutional quality, five main categories are combined: (1) size of government, (2) legal system and property rights, (3) accountability and transparency, (4) freedom of international trade, and (5) credit, labor, and business regulations. Each category consists of several subcomponents, and the Fraser Institute calculates the average of these five indices to form a complete institutional quality index for each country. In this index, 0 represents the lowest institutional quality, and 5 represents the highest.

$\beta' Z$= vector containing control variables.

The study period consists of annual data from 1996 to 2024, and all data used in this research are extracted from the World Bank and Transparency International.

Findings and Results

Before applying the Kalman Filter technique, it is necessary to ensure the instability of the estimated model parameters; for this purpose, the Hansen test is used.

Table 2. Hansen Test of Parameter Instability

	Stochastic	Deterministic	Excluded
Lc statistic	Trends (m)	Trends (k)	Trends (p2)
18.254	5	0	0

In the Hansen test, the null hypothesis H_0indicates parameter stability. The Hansen test results in Table (1) for the model show a test statistic of 18.254 with a p-value of 0.01. Since the significance level is less than the 0.05 threshold, the Hansen test rejects the null hypothesis $H_0$of parameter constancy. In light of these results, this study applies the Kalman Filter technique.

Table 3. Estimated Function with State–Space Model (Kalman Filter)

Variable	Final State	Standard Deviation	Z-statistic	p-value
Cyclical component of oil price volatility (SV1)	-0.143018	0.035591	-4.018401	0.0001
Cyclical component of economic complexity (SV2)	-0.054376	0.005852	-9.292337	0.0000
Cyclical component of economic policy uncertainty (SV3)	-0.063358	0.004479	-14.14551	0.0000
Cyclical component of geopolitical risk (SV4)	-0.059112	0.021210	-2.786992	0.0055
Cyclical component of institutional quality (SV5)	-0.085252	0.028687	-2.971779	0.0031
Cyclical component of labor (SV6)	0.209126	0.078989	2.647525	0.0081
Cyclical component of capital (SV7)	0.117919	0.027292	4.320632	0.0000
Cyclical component of per capita energy consumption (SV8)	-0.007533	0.004508	-1.671211	0.0950

Based on the Kalman Filter model results, crude oil price volatility, geopolitical risk, economic policy uncertainty, and energy consumption have negative effects on the exports of mineral resources and basic metals in Iran, whereas investment and labor have positive effects. Institutional quality, due to structural challenges and weak transparency, has had a limited and sometimes negative short-term impact on this dependent variable. The economic complexity index in Iran's economy, owing to limited production diversity and dependence on oil, has not exerted a significant positive effect on basic metals exports; in the model its impact is limited and short-lived. All analyses are conducted over the period from 1996 to 2024, and the historical trends of changes in the variables are taken into account.

The Kalman Filter model results show that global crude oil price volatility has a significant negative effect on Iran's mineral and basic metals exports. During the period from 1996 to 2024, increased oil price volatility has raised production costs and the cost of securing energy-intensive inputs for metal industries, which in turn has reduced exports. Pressure on corporate profit margins and disruptions in production planning are the main channels for this negative effect. Historical trend analysis of the data for 1996 to 2024 indicates that during episodes of sharp oil price increases, export competitiveness and the ability to fulfill international contracts have weakened more severely. Oil market volatility has also increased financial risk and constrained firms' access to working capital.

Improved political stability and reduced regional threats have a positive effect on basic metals exports. Over the period from 1996 to 2024, rising geopolitical risk has reduced investor and exporter confidence and increased operational and commercial risk. Model analysis indicates that in periods of heightened risk, export capacity in metal industries has declined and market volatility has intensified. Historical data for this period show that higher geopolitical risk has led to weaker trade interactions and higher export insurance costs, thereby undermining conditions for sustainable growth in basic metals exports.

In Iran, the economic complexity index has a limited positive role for basic metals exports due to heavy dependence on oil and constrained production diversification. Data for the period from 1996 to 2024 show that limited expansion of production diversity and concentration of the economy on mineral resources have made the effect of this index short-term and small. Therefore, in the model analysis, COMP has had a limited impact on basic metals exports.

Rising volatility in monetary, fiscal, and exchange rate policies has a negative effect on basic metals exports. Data for 1996 to 2024 show that policy uncertainty has reduced investment and constrained production for export. Historical trend analysis for this period indicates that in times of high uncertainty, exports have declined and foreign markets have experienced disruptions. The negative effect has been amplified through higher financing costs and exchange rate volatility.

Access to production inputs has a positive effect on basic metals exports. In the period from 1996 to 2024, increased investment in equipment and skilled labor has expanded production capacity and export potential in metal industries. Analysis of the data for this period shows that strengthened production and improved product quality have supported more sustainable exports of basic metals, and this positive effect has persisted over the historical horizon.

Energy consumption has a dual effect on basic metals exports. During 1996 to 2024, high energy consumption has been a sign of robust production, but rising energy costs have reduced export competitiveness. Data analysis for this period shows that optimal energy management and improved efficiency mitigate the negative cost impact of energy prices on exports and contribute to export sustainability.

Institutional quality in Iran faces constraints, and its effect on basic metals exports is short-term, limited, and sometimes negative. Over the period from 1996 to 2024, weak transparency, inadequate accountability, and inefficient regulations have increased operational risk and reduced exporters' confidence. Historical data for this period demonstrate that institutional reforms and improved transparency can raise exports in the long run, but no significant short-term effect on export growth has been observed.

Sensitivity of the basic metals market to oil market volatility; sensitivity of the basic metals market to energy consumption; sensitivity of the basic metals market to geopolitical risk; sensitivity of the basic metals market to economic complexity; sensitivity of the basic metals market to institutional quality; sensitivity of the basic metals market to economic uncertainty.

Table 4. Estimated State–Space Model Parameters Using the Kalman Filter

Year	Oil Volatility Sensitivity	Energy Consumption Sensitivity	Geopolitical Risk Sensitivity	Economic Complexity Sensitivity	Institutional Quality Sensitivity	Economic Uncertainty Sensitivity
1996	-0.063253	0.089565	-0.069863	0.089653	0.023632	-0.01936
1997	-0.089888	0.075966	-0.081702	0.109742	0.0630096	-0.01825
1998	-0.203642	0.063263	-0.239396	0.258967	0.240491	-0.01825
1999	-0.469586	0.056356	-0.139261	0.151833	0.295646	-0.01891
2000	-0.664503	0.045263	-0.116344	0.180859	0.002204	-0.0196
2001	-0.668564	0.013325	-0.166384	0.203483	0.0274091	-0.01988
2002	-0.663272	0.004504	-0.065944	0.313947	0.023985	-0.02185
2003	-0.615036	0.004447	-0.083160	0.339443	0.0158857	-0.02129
2004	-0.586836	0.004223	-0.180423	0.223631	0.0264694	-0.02199
2005	-0.591769	0.003873	-0.139489	0.249958	0.0204397	-0.02259
2006	-0.607520	0.002893	-0.178168	0.233006	0.0259352	-0.02342
2007	-0.627595	0.001759	-0.166921	0.208085	0.0234393	-0.02342
2008	-0.629413	0.001437	-0.147174	0.159790	0.0223404	-0.02382
2009	-0.654091	-0.001435	0.1605758	0.0780541	-0.028843	-0.02382
2010	-0.650427	-0.001387	0.1754937	-0.0985058	-0.033835	-0.02382
2011	-0.676781	-0.001155	0.0164146	-0.0839918	-0.018244	-0.02382
2012	-0.661616	-0.001091	0.0291890	-0.0783087	-0.004741	-0.02382
2013	-0.608594	-0.001067	0.0024875	-0.0936885	-0.013896	-0.02382
2014	-0.565363	-0.001067	0.0307732	-0.0829554	-0.012411	-0.02382
2015	-0.578772	-0.001063	0.0229105	-0.0831049	-0.010228	-0.02382
2016	-0.577522	-0.001052	0.0202139	-0.0829490	-0.010003	-0.02523
2017	-0.587550	-0.001006	0.0035947	-0.0934003	-0.011301	-0.0328
2018	-0.589381	-0.000941	0.0093492	-0.0913232	-0.012326	-0.03533
2019	-0.592498	-0.000925	0.0190761	-0.0873696	-0.015257	-0.0368
2020	-0.590767	-0.000887	0.0222602	-0.0845215	-0.015833	-0.04145
2021	-0.590591	-0.000885	0.0168875	-0.0856774	-0.015164	-0.04735
2022	-0.591251	-0.000985	0.0156523	-0.0865952	-0.015012	-0.04952
2023	-0.591598	-0.000984	0.0156452	-0.0866230	-0.015084	-0.04964
2024	-0.591685	-0.000995	0.0156321	-0.0866580	-0.015095	-0.04975

As shown by the diagnostic test results in Table (5), the estimated model does not suffer from heteroskedasticity or serial autocorrelation, which supports the validity of the estimated model results.

Table 5. Diagnostic Test Results for the Model

Test Statistic	Diagnostic Tests
F Version	LM Version
1.3254 (0.3652)	1.5241 (0.2965) – Serial correlation test – Model 1
1.3274 (0.4125)	1.2745 (0.4528) – Heteroskedasticity test

Numbers in parentheses indicate p-values.

Discussion and Conclusion

The purpose of this study was to examine the dynamic and time-varying spillover effects of global crude oil price volatility, economic policy uncertainty, geopolitical risk, institutional quality, economic complexity, capital, labor, and per-capita energy consumption on Iran's exports of basic metals and mineral resources using a state–space model estimated through the Kalman filter. The findings reveal that oil price volatility exerts a significant and persistent negative influence on the performance of Iran's basic metals sector. This result is aligned with a growing body of international evidence demonstrating that oil markets act as dominant transmitters of shocks across commodity systems, often increasing volatility in non-energy markets such as metals (2, 3, 5). As global oil prices fluctuate, cost structures within energy-intensive metal industries shift rapidly, affecting competitiveness, production planning, and export capacity. Such patterns have also been observed in high-frequency spillover studies where oil shocks intensify volatility transmission to non-energy commodities, especially during global stress periods (7, 15). The negative effect found in this study complements these findings and underscores the structural importance of oil-linked production costs in shaping export dynamics in oil-dependent economies.

The results also show that geopolitical risk has a strong negative effect on exports, consistent with evidence that geopolitical shocks and regional instability heighten systemic risk across commodity markets, disrupt trade networks, and increase insurance premiums and transaction costs (10). Studies focusing on emerging markets and crisis dynamics show that geopolitical disruptions can amplify volatility spillovers and increase financial fragility, with adverse consequences for commodity-exporting economies (11, 14). Given Iran's exposure to sanctions, geopolitical tensions, and regional conflicts, these findings reflect broader global patterns while highlighting Iran's heightened vulnerability due to structural and systemic factors.

The negative and significant impact of economic policy uncertainty (EPU) identified in the model is also consistent with previous research across commodity markets and emerging economies. Studies on uncertainty reveal that policy instability exacerbates volatility, reduces investor confidence, and weakens production stability, particularly in sectors relying on long-term investment and foreign trade (13). Empirical findings on tail-risk connectedness further show that uncertainty magnifies the propagation of extreme shocks, leading to more severe downturns in commodity exports (11). In Iran, this effect is intensified by structural characteristics such as fiscal dependence on oil revenues, fluctuating monetary policy, and exchange-rate instability—factors that earlier studies on Iranian macro-economy have emphasized as central sources of cyclical vulnerability (25). In this context, the negative relationship between EPU and the export performance of basic metals is both expected and consistent with theoretical and empirical literature.

Institutional quality, although statistically significant in certain periods, shows a limited and occasionally negative effect on metal exports. This mirrors findings from resource-rich economies where weak institutions constrain diversification and reduce the capacity to manage volatility (19, 22). Research on institutional quality in Iran, Eurasian economies, and OPEC states demonstrates that governance weaknesses—such as insufficient transparency, weak regulatory quality, and limited accountability—depress economic performance and amplify the negative effects of resource dependence (20, 23). Similarly, studies investigating the resource–governance–growth nexus show that institutional factors shape how natural resource revenues are used, whether they foster diversification, and whether non-oil tradable sectors such as basic metals can grow sustainably (21, 24). Therefore, the limited and sometimes negative contribution of institutional quality in the current study aligns with broader evidence that institutional weaknesses in Iran reduce resilience to external shocks and suppress export competitiveness.

The findings further indicate that economic complexity (ECI) has a small and short-lived effect on Iran's basic metals exports. This is consistent with macro-structural analyses highlighting Iran's limited diversification and the dominance of oil-related exports, which restrict the growth of complex industries and knowledge-intensive production capabilities (22). Research on commodity markets shows that complexity is an important buffer against volatility, enabling countries to upgrade production and develop competitive export baskets; however, such advantages accrue primarily to economies that have already diversified into technologically advanced sectors (1, 6). For Iran, where production structures remain heavily concentrated in oil, gas, and raw mineral extraction, the ability of economic complexity to influence short-run export dynamics remains limited. This reinforces earlier evidence from Iranian studies noting that resource dependence and Dutch disease effects have hindered industrial deepening and constrained the expansion of higher-value manufacturing sectors (16, 17).

The positive and significant effects of capital and labor on exports are consistent with classical and contemporary theories of export performance. Productive capacity, technological upgrading, and availability of skilled labor are key determinants of export competitiveness, particularly in resource-based industries where scale, efficiency, and operational capabilities shape international performance. Empirical research demonstrates that investment in production systems enhances capacity utilization, reduces marginal costs, and strengthens firms' ability to absorb external shocks (24). In emerging markets, capital deepening and expansion of manufacturing infrastructure contribute to improved export performance by enabling firms to increase output, diversify product portfolios, and comply with international standards (23). The positive impact of labor mirrors findings showing that skilled human capital supports technological adaptation and operational flexibility, allowing firms to adjust production in response to market fluctuations (13). Together, these results highlight that domestic production factors remain critical for strengthening the competitiveness of Iran's metals sector despite external constraints.

Per-capita energy consumption exhibits a dual effect, with its cyclical component showing a negative relationship with exports. This result complements international findings that energy-intensive industries are highly sensitive to fuel price volatility and energy availability, especially under conditions of global uncertainty (4, 9). While higher energy use may signal increased production, rising energy costs—amplified by oil price fluctuations—reduce competitiveness, particularly in global markets where cost efficiency is crucial. This is consistent with evidence that oil shocks raise production costs across commodity sectors, weakening the export performance of metal industries during periods of instability (3). For Iran, where energy subsidies, pricing reforms, and policy fluctuations have remained persistent issues, the dual nature of the energy–export relationship is both theoretically coherent and empirically intuitive.

Overall, the study's findings reinforce the centrality of global oil market volatility in shaping the performance of Iran's metals sector, while highlighting the moderating roles of policy uncertainty, geopolitical risk, institutional structures, and production inputs. The use of a Kalman filter approach reveals the time-varying nature of these relationships, offering nuanced insights into how structural dependence on oil influences the evolution of non-oil export sectors. Such results converge with studies applying time-varying connectedness and systemic risk frameworks in global commodity markets, emphasizing that spillovers are dynamic and highly sensitive to macroeconomic, geopolitical, and institutional factors (8, 10, 12). For Iran, the findings underscore the challenges of navigating a volatile global environment while pursuing diversification, structural transformation, and export expansion.

This study, despite its contributions, has several limitations. First, the analysis relies on annual data, which may smooth out short-term fluctuations and limit the ability to capture high-frequency spillover dynamics that are particularly relevant in energy and metal markets. Second, the construction of the economic policy uncertainty index and institutional quality variables may be sensitive to measurement choices, filtering techniques, or the availability of consistent long-term data. Third, although the Kalman filter enables time-varying parameter estimation, it does not fully account for potential non-linearities, threshold effects, or structural breaks driven by major geopolitical or economic events. Finally, the study focuses on Iran as a single-country case, limiting generalizability to other resource-dependent economies with different institutional or structural contexts.

Future research could extend the current analysis by integrating higher-frequency data to capture short-term spillover patterns more precisely. Incorporating non-linear or regime-switching models would allow researchers to examine how spillover intensities change during crisis periods versus stable periods. Comparative studies across multiple oil-dependent economies could offer broader insights into the role of institutions, economic complexity, and policy frameworks in moderating volatility transmission. Additionally, future work may examine micro-level firm data to better understand how individual companies within the metals sector respond to oil shocks, policy uncertainty, and geopolitical risk. Exploring the role of technological upgrading and energy efficiency improvements could also provide a deeper understanding of long-run competitiveness in the metals industry.

Policymakers should prioritize stabilizing the macroeconomic environment, improving transparency, and strengthening institutional frameworks to reduce vulnerability to external shocks. Expanding investment in technology, energy efficiency, and human capital can enhance production capacity and international competitiveness in the basic metals sector. Diversifying export markets and fostering long-term commercial partnerships would also help mitigate the adverse effects of global volatility. Furthermore, designing consistent monetary, fiscal, and exchange-rate policies can reduce uncertainty, strengthen investor confidence, and support the long-term development of non-oil export sectors.

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Authors’ Contributions

All authors equally contributed to this study.

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The authors of this article declared no conflict of interest.

Ethical Considerations

All ethical principles were adheried in conducting and writing this article.

Transparency of Data

In accordance with the principles of transparency and open research, we declare that all data and materials used in this study are available upon request.

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