Study of Fuzzy Logic to Estimate the Size of the Underground Economy in Iran

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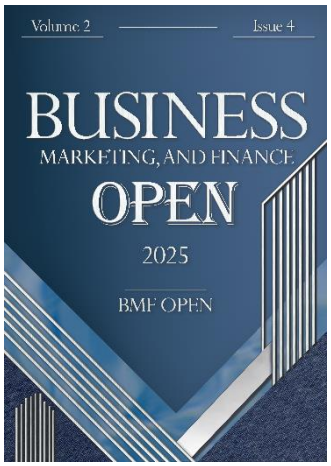

Citation: Vasheghani, J., Zandi, F., Afsharirad, M., & Khezri, M. (2025). Study of Fuzzy Logic to Estimate the Size of the Underground Economy in Iran. *Business, Marketing, and Finance Open*, 2(4), 1-11.

Received: 12 March 2025
Revised: 10 April 2025
Accepted: 26 April 2025
Published: 01 July 2025

Abstract: The presence of underground economic activities in a society constitutes a major source of social and economic dysfunction. Operating through opaque and unregulated channels, these activities undermine the effectiveness of social and economic policies, contribute to fiscal and monetary imbalances, and distort policy outcomes. Furthermore, economic sanctions imposed on Iran—beginning with the Islamic Revolution and intensifying in recent years—have posed significant challenges to the country's economy, influencing both domestic and international economic dynamics. Accordingly, this study employs a multi-stage fuzzy modeling approach to estimate the size of Iran's underground economy during the period 1991–2024. Utilizing Iranian time series data, the study also introduces a composite index of sanctions by quantifying and weighting various historical sanctions. These sanctions are incorporated into an Autoregressive Distributed Lag (ARDL) model as dummy variables to evaluate their effect on the underground economy. The findings indicate that the average size of the underground economy in Iran during the study period was approximately 37 percent of GDP. In the short-term analysis, weak sanctions were found to have no statistically significant effect on the underground economy, whereas moderate and strong sanctions exhibited positive and significant effects, with coefficients of 0.056 and 0.86, respectively. The long-term analysis revealed that weak and strong sanctions had no significant impact, while moderate sanctions were associated with a positive and statistically significant effect, with a coefficient of 0.72.

Keywords: Underground economy, economic sanctions, fuzzy logic, fuzzy inference system, autoregressive distributed lag model.

1. Introduction

Planning for economic development necessitates a comprehensive understanding of the overall performance of a country's economy. However, deficiencies in data collection methodologies and inconsistencies in implementation often compromise the accuracy and completeness of the statistical information available to researchers, analysts, planners, and policymakers. Furthermore, a portion of economic activity is deliberately concealed from formal data-collecting agencies. This concealed segment of the economy is referred to as the "underground" or "informal" economy [1, 2].

The existence of informal or underground economic activities represents a persistent challenge for governments worldwide. Over time, countries have employed various strategies and policy tools to curb such activities and

transition them into the formal economic sector. Despite these efforts, informal economic activities remain prevalent and exert observable effects on national economies [3].

In contrast to a country's formal economy, the informal economy does not adhere to official regulations and instead operates according to behavioral norms specific to this sector. The standards governing the informal economy are neither collective nor institutionalized. Across different societies, the nomenclature for such economic activities varies according to scholarly preference. In many instances, these terms capture only partial aspects of the broader informal economic phenomenon [4, 5].

Scholarly inquiry into the causes and consequences of the underground economy—and the development of corresponding policy recommendations—has been relatively limited. This is largely due to methodological challenges in measuring the scale of informal activities. Accordingly, there is a need to adopt innovative econometric approaches that offer greater flexibility in functional specification, impose fewer parametric assumptions, and exhibit robust performance across both small and large samples. In the contemporary era, technological advancement and lifestyle changes have also facilitated the evolution of criminal and corrupt practices, one of which is money laundering [6, 7].

Money laundering refers to the process of converting or transferring assets for the purpose of concealing their illicit origin or assisting individuals involved in criminal activities. The economic repercussions of money laundering are substantial. They include the distortion of macroeconomic policy, erosion of the private sector, impediments to privatization, increased inflation, deterioration of financial market integrity, heightened credit risk, disruption of both domestic and foreign investment, growth of underground activities, enhanced profitability of criminal enterprises, escalation of government expenditure, and capital flight. In Iran, the underlying drivers of money laundering include economic corruption, goods and drug smuggling, and inadequate regulatory oversight of the financial system [8, 9].

Another closely related issue in the Iranian economy is smuggling, a multifaceted phenomenon that is increasingly becoming institutionalized. A thorough understanding of smuggling requires analysis of all its dimensions. The precondition for goods smuggling is foreign exchange smuggling, which entails the conversion of national currency into foreign currency—a process known as currency substitution [10, 11].

A significant volume of foreign currency is held by actors operating in the informal sector and remains outside the formal banking system. Considering Iran's historical experience and the consistent increase in the circulation of U.S. dollars since 1974, as well as the enduring presence of economic sanctions, the likelihood of an expanding underground economy is high. Neglecting this reality obscures the data available to academic and policy communities, impeding accurate analysis, effective policymaking, and sound implementation. Thus, the benefits of accurately measuring the size, trends, causes, and consequences of the underground economy far outweigh the associated costs. Measurement plays a crucial role in this endeavor [12-14].

The present study focuses specifically on assessing the impact of economic sanctions on the size of the underground economy in Iran, utilizing fuzzy logic and its associated inferential methodologies. The measurement approach is designed to allow comparability with prior studies conducted in this domain [15, 16].

To develop a clear understanding of Iran's underground economy, it is essential to examine its legal standing and analyze the characteristics of individuals engaged in such activities. Broadly, the informal sector can be divided into legal and illegal components. The legal component encompasses unmeasured and unregistered economic activities, which are prevalent in many developing—and to a lesser extent, developed—countries. These include home-based production, informal small-scale labor, unreported cash transactions, and barter exchanges. Additional

legal components include government-controlled monopolies in foreign trade, preferential domestic distribution networks, and unofficial credit systems outside the formal banking sector (Pourfathi & Kafai, 2019: 97).

Moreover, certain public officials and senior managers benefit from non-monetized perks, such as government-provided housing and vehicles, which are not recorded in national accounts but contribute to the underground economy. The illegal component encompasses a wide array of illicit activities, typically carried out covertly by individuals or organized criminal networks [17]. These activities include the smuggling of goods and narcotics, document forgery, property rights violations, money laundering, illicit trade in antiquities, and bribery. Many economic actors involved in these activities evade taxes, perceiving taxation as unjust, despite the fact that tax revenues fund essential public services.

Some governmental institutions operate private firms with profit-making objectives, and these firms' financial activities are rarely disclosed. Their balance sheets are seldom published, if at all. Additionally, the Central Bank's practice of selling petrodollars on the black market facilitates capital flight, bypassing official reporting mechanisms. These conditions suggest that the underground economy in Iran is extensive and deeply embedded within the country's socio-economic structures [18].

The phenomenon examined and quantified in this study contributes to a host of socio-economic disruptions. It manifests through hidden channels that undermine social planning, monetary stability, financial integrity, and policy effectiveness. Known as the underground economy, this phenomenon demands rigorous analysis due to its substantial influence on macroeconomic regulation and fiscal policy. However, its covert nature presents significant challenges to direct measurement and empirical research [19].

This research seeks to analyze the effect of economic sanctions on the size of the underground economy in Iran using fuzzy logic methodologies. Specifically, it aims to estimate the determinants of the underground economy's magnitude and address key questions regarding the structural challenges it presents and how best to estimate its scale within the Iranian context.

2. Methodology

The methodology employed in this study is of a descriptive-survey nature, while the research type is classified as causal and applied, given that the anticipated results can be utilized to examine the dimensions of the underground economy. The findings are intended for practical use in academic institutions and economic research centers. To establish the theoretical foundations presented in the theoretical chapters, data were collected from existing documents, including books, scholarly articles, research reports, and dissertations relevant to the subject matter. In estimating the underground economy index using fuzzy logic, numerous variables are involved, which are grouped into three sub-indices: the financial sector, the monetary sector, and the real sector. Since the initial step in fuzzy logic modeling involves identifying the relevant indicators, the precise definition and clear explanation of each variable are of critical importance. Given that different interpretations of the indicators and their membership functions can yield varying outcomes, the careful selection and definition of these indicators is essential. Consistent with the conceptualization of the underground economy and its operational mechanisms, the variables employed in estimating the underground economy index in this study are categorized as follows: (1) monetary sector variables, including the relative price index of non-tradable to tradable goods and the liquidity growth rate; (2) real sector variables, including the non-oil trade balance, the ratio of value added in the construction sector to non-oil GDP, and the ratio of value added in the agricultural sector to non-oil GDP; (3) financial sector

variables, including the ratio of oil revenues to GDP and the ratio of oil revenues to total government budget revenues.

The objective of this research is to develop a method for annually measuring the size of the underground economy in Iran. The required data are computed and used to construct moving averages specific to our analysis. The selection of these institutional variables is partially subjective; nevertheless, a positive and direct relationship between these causal variables and the size of the underground economy is assumed. It is acknowledged that fuzzy modeling imposes a structural limitation in that each inference requires exactly two input variables. However, two variables alone may not fully capture the complexity of the output variable. To address this, a multi-stage fuzzy inference system is employed in the present study. It is important to note that, although per capita consumption in the illegal sector is not directly included in the model, its effects are indirectly incorporated in the subsequent stages of fuzzy inference. As is standard in fuzzy logic modeling, the process consists of three main stages: fuzzification, fuzzy inference, and defuzzification, each of which is explained below.

First Stage: Membership Functions (Fuzzification)

In this stage, based on the statistical values of the input variables, membership functions are defined. For each inference block—comprising two specific input variables—a fuzzy set with five linguistic labels is constructed. The input variables are categorized as: very low, low, normal, high, and very high. The output variables are labeled as: very small, small, medium, large, and very large. To define the criteria associated with these labels, a baseline value is established using a moving average for each input variable. A six-year moving average is applied to mitigate the effects of business cycles and establish a normalized benchmark for each variable, starting from 1973.

To graphically represent these membership functions, linear transitions are plotted from $\alpha(x) = 1$ at the peak value of a linguistic variable to $\alpha(x) = 0$ at the boundary of the adjacent linguistic category. For instance, to represent the variable "Low," a line is drawn from Mean − SD with $\alpha(x) = 1$ to Mean − 2SD with $\alpha(x) = 0$. Similarly, another line is drawn from Mean − SD to Mean with corresponding membership values. This process yields membership functions for each linguistic variable, as illustrated in Figure 3-7. As a result, for each input variable and period, two sets of five values (called breakpoints) are defined. After these breakpoints are determined, actual data values are mapped to the relevant membership functions. In fuzzy logic, a specific data point can simultaneously belong to multiple fuzzy sets.

Second Stage: Levels of Association and Decision Rules

In this stage, the inputs consist of the membership degrees obtained in the previous step. Each inference block receives two input data sets, and decision rules are constructed to determine how their membership functions are combined to yield output associations. If only two input variables are considered for evaluating the underground economy, the system can be described using 25 decision rules. The total number of rules in the fuzzy rule base is calculated using the expression n^t, where n represents the number of linguistic categories, and t represents the number of independent (causal) variables. These rules are developed based on expert knowledge in the domain.

Each fuzzy inference comprises 25 "if-then" rules, customized to the specific variable pair under consideration. An example rule may state: "If both tax burden and energy consumption are very high, then the underground economy is very large." The full set of rules is provided in Table 1. These rules use straightforward linguistic constructs for interpretation.

Table 1. Fuzzy Rules

Degree	Irregular Sector	ENERGY	BURDIMP	Rule No.
1	VB	VH	VH	1
0.8	VB	H	VH	2
1	S	N	VH	3
0.8	S	L	VH	4
0.8	A	VL	VH	5
1	VB	VH	H	6
1	B	H	H	7
0.8	B	N	H	8
1	A	L	H	9
1	S	VL	H	10
1	B	VH	N	11
0.8	B	H	N	12
1	A	N	N	13
0.8	S	L	N	14
1	S	VL	N	15
1	B	VH	L	16
1	A	H	L	17
0.8	S	N	L	18
1	S	L	L	19
1	VS	VL	L	20
0.8	A	VH	VL	21
0.8	S	H	VL	22
1	S	N	VL	23
0.8	VS	L	VL	24
1	VS	VL	VL	25

VH = Very High, H = High, N = Normal, L = Low, VL = Very Low

VB = Very Large, B = Large, A = Average, S = Small, VS = Very Small

Stage Three: Determinization (Extraction of Underground Economy Trends)

In the final stage, fuzzy linguistic values are transformed into precise numerical values for decision-making. This is achieved by assigning scalar values of 0, 0.25, 0.5, 0.75, and 1.0 to the linguistic categories "very small," "small," "medium," "large," and "very large," respectively, representing the estimated size of the underground economy. MATLAB software is used for the computational implementation of this process. Based on the input data and the predefined fuzzy rules, the software generates annual output values—ranging between 0 and 1—which represent a normalized index of the underground economy for each year.

3. Findings and Results

Estimating the size of the underground economy involves quantifying the volume and monetary value of informal economic activities in order to more accurately identify and understand the structure of economic transactions within a country. While directly measuring activities that are inherently concealed may seem implausible, empirical research enables the approximation of their magnitude by observing the indirect effects they leave across various economic indicators. A key feature of underground economy estimation is its comparison with the formal economy, thereby highlighting its relative scale and significance. If the estimated size of the

underground economy is found to be marginal in relation to the formal economy, it may not be a cause for serious concern. However, if the unrecorded economic activity is substantial enough to distort macroeconomic assessments, its exclusion becomes unjustifiable.

Using MATLAB software, the fuzzy inference system was simulated for the period 1991 to 2024, generating a fuzzy time series for the financial sector of the underground economy.

In the first stage, the estimated data and related time series were employed in an Autoregressive Distributed Lag (ARDL) model to evaluate the impact of economic sanctions—introduced as dummy variables—on the size of the underground economy between 1991 and 2024. The results of these estimations are analyzed and interpreted below.

Data Introduction

The time series data used in this study span the period from 1991 to 2024. The dependent variable is the underground economy index (UE), and the independent variables include corporate tax (TAXCO), income tax (TAXINC), import tax (TAXIMP), the economic openness index (OPEN1), GDP per capita as a proxy for economic growth (Y), and several dummy variables: the imposed war period (D1) and economic sanctions categorized as weak (SW), moderate (SM), and strong (SS). These data were extracted from the annual reports and time series publications of the Central Bank of Iran.

The ARDL approach comprises two stages to determine the existence of long-run relationships among variables. The first step involves testing for the presence of cointegration among all variables in the model. The ARDL framework estimates (P+1) regressions to determine the optimal lag structure for each variable, where *P* is the maximum number of lags and *K* is the number of regressors. The second step, conducted only if a long-run relationship is established, involves estimating both the long-run and short-run coefficients.

Results of the Stationarity Test of Variables

Before proceeding with the ARDL estimation, the stationarity properties of all variables were examined to ensure that none were integrated of order two, I(2), which would invalidate the use of the ARDL bounds testing approach. As noted by Uttara, the presence of I(2) variables renders the F-statistics unreliable, as the ARDL methodology assumes that variables are either I(0) or I(1). Accordingly, unit root testing was performed using the Augmented Dickey-Fuller (ADF) test. This involved testing the logarithmic levels with both constant and trend terms, and testing the first differences with only a constant term. The results show that all variables are either I(0) or I(1), confirming the validity of the ARDL application.

Table 2. Unit Root Test Results for Model Variables

Variable	Test Critical Values	ADF Test Statistic	Prob.	Integration Order
LNUE	-3.632900	-3.661206	0.0153	I(0)
LNTAXCO	-3.639407	-7.941246	0.0000	I(1)
LNTAXINC	-3.639407	-4.047132	0.0035	I(1)
LNTAXIMP	-3.661661	-3.921010	0.0053	I(1)
LNOPEN1	-3.639407	-5.679796	0.0000	I(1)
LNY	-3.646342	-6.466100	0.0000	I(1)

Null hypothesis: each variable has a unit root. Exogenous: constant; Lag selection based on Schwarz Information Criterion (SIC), MAXLAG=9. MacKinnon (1996) one-sided p-values reported at 1% significance level.

Results of ARDL Dynamic Model Estimation

The estimation procedure follows a stepwise specification approach, evaluating three key equations: the short-run dynamics, long-run relationship, and error correction model (ECM). The optimal lag structure was selected

using the Schwarz-Bayesian Criterion (SBC) to minimize degrees-of-freedom loss. The short-run estimation results are summarized in Table 3.

Short-run results show that the economic openness index (with a two-period lag), corporate tax, and import tax have a positive and statistically significant effect on the underground economy index, with coefficients of 0.19, 0.073, and 0.127, respectively. However, income tax and economic growth rate did not exert significant short-run effects. The dummy variable for the imposed war period exerted a negative effect (−0.025). Weak sanctions were not statistically significant, while moderate and strong sanctions had positive and significant short-term effects with coefficients of 0.056 and 0.86, respectively.

Table 3. Results of ARDL Model Estimation (ARDL(1,1,0,2,2,0), Dependent Variable: LNUE, 36 observations (1991–2024))

Regressor	Coefficient	Std. Error	T-Ratio [Prob.]
LNUE(-1)	0.33325	0.09560	3.4858 [0.003]
LNTAXCO	0.07306	0.03142	2.3253 [0.032]
LNTAXINC	−0.04097	0.05292	−0.7742 [0.449]
LNTAXIMP	0.12737	0.03780	3.3699 [0.003]
LNOPEN1(-2)	0.19114	0.05467	3.4962 [0.003]
LNY	0.04166	0.04043	1.0306 [0.316]
T	0.02083	0.00782	2.6627 [0.016]
SW	0.1810	0.8525	0.6555 [0.520]
SM	0.0568	0.1439	2.5484 [0.089]
SS	0.8635	0.9839	1.5745 [0.072]
D1	−0.02519	0.1917	−0.1315 [0.897]

$R^2 = 0.98078$ F-statistic Prob. = 0.004 Durbin-Watson = 1.7249

Serial Correlation (χ^2, 1 lag) = 0.9465 [0.331] LM Statistic (χ^2, 2 lags) = 3.7671 [0.013]

Table 4. Long-Run Coefficient Estimates of ARDL Model (ARDL(1,1,0,2,2,0), Dependent Variable: LNUE, 36 observations (1991–2024))

Regressor	Coefficient	Std. Error	T-Ratio [Prob.]
LNTAXCO	0.20202	0.06515	3.1007 [0.006]
LNTAXINC	−0.06145	0.08153	−0.7538 [0.461]
LNTAXIMP	0.07074	0.04977	1.4216 [0.172]
LNOPEN1	0.27221	0.09507	2.8631 [0.010]
LNY	0.06248	0.06231	1.0028 [0.329]
T	0.03125	0.01034	3.0218 [0.007]
SW	2.0678	3.1348	0.6596 [0.517]
SM	0.7271	0.1324	2.5513 [0.067]
SS	1.8614	3.2204	0.5780 [0.570]
D1	−0.01638	0.1246	−0.1314 [0.897]

The long-run results indicate that corporate tax and the economic openness index have a positive and significant effect on the underground economy, with coefficients of 0.20 and 0.27, respectively. Weak and strong sanctions were not significant in the long run; however, moderate sanctions demonstrated a positive and significant effect with a coefficient of 0.72.

To analyze how short-run disequilibria are corrected over time, the Error Correction Model (ECM) was employed. The ECM coefficient reflects the percentage of disequilibrium corrected each period to restore long-run equilibrium. As shown in Table 5, the ECM coefficient is −0.667, indicating that 66.7% of short-run imbalances are corrected in each period.

Table 5. Error Correction Model (ECM) Results

Regressor	Coefficient	Std. Error	T-Ratio [Prob.]
dLNTAXCO	0.07306	0.03142	2.3253 [0.030]
dLNTAXINC	−0.04097	0.05292	−0.7742 [0.447]
dLNTAXIMP	0.12737	0.03780	3.3699 [0.003]
dLNTAXIMP1	0.06523	0.03228	2.0211 [0.056]
dLNOPEN1	0.01362	0.05854	0.2328 [0.818]
dLNOPEN11	−0.19114	0.05467	−3.4962 [0.002]
dLNY	0.04166	0.04043	1.0306 [0.314]
dT	0.02083	0.00782	2.6627 [0.015]
dSW	0.1810	0.8525	0.6555 [0.519]
dSM	0.0568	0.1439	2.5484 [0.089]
dSS	0.8635	0.9839	1.5745 [0.071]
dD1	−0.02519	0.1917	−0.1315 [0.897]
ecm(−1)	−0.66675	0.09560	−6.9741 [0.000]

ECM Equation:

LNUE − 0.20202×LNTAXCO + 0.06145×LNTAXINC − 0.07074×LNTAXIMP − 0.27221×LNOPEN1 − 0.06248×LNY − 0.03125×T − 2.0678×SW − 0.7271×SM − 1.8614×SS + 0.01638×D1

4. Discussion and Conclusion

Based on the statistical trends derived from both the household and informal sectors, it can be concluded that the Iranian economy is transitioning from a traditional structure to a more modern configuration. However, the primary driver of the underground economy's expansion appears to be economic in nature. While the household sector—particularly in the earlier years—has declined, the informal sector has remained relatively stable. In contrast, the irregular and illegal sectors, especially in the later years of the study period, have expanded, contributing to the overall growth in the size of Iran's underground economy. Contributing factors include rising unemployment, increased money supply, general inflation, trade restrictions, and inefficiencies within the tax system. The results are consistent with prior studies [13, 14, 17, 19-26].

In the household sector, the reduction in rural and nomadic populations due to internal migration toward urban areas and the rise in urbanization and modern lifestyles has diminished the practice of subsistence production. This shift has reduced the household sector's share in the underground economy, particularly before 2001. Moreover, the per capita consumption index has been employed as an indicator of shifts in product markets and informal production. It is expected that variations in this index directly affect the relative size of the underground economy. Therefore, with the intensification of sanctions and their impact on society, economic activity within this segment has grown in recent years.

An analysis of Iran's unemployment rate indicates that it fluctuates cyclically, with notable patterns recurring over approximately nine-year intervals. Elevated unemployment rates increase the likelihood of individuals participating in informal employment, including part-time and temporary jobs, thereby expanding the informal economy.

Since the 1980s, beginning with the Iran–Iraq War, the import tax burden has consistently increased, accompanied by a rise in money demand to peak levels. Furthermore, in the 1990s, financial and trade sanctions—

along with the confiscation of property and assets belonging to individuals and institutions—significantly bolstered the irregular and especially illegal sectors. These developments notably inflated the size of the underground economy, with its share reaching approximately 50 percent of Iran's GDP by 1991.

Short-term estimation results indicate that the imposition of weak sanctions had no statistically significant impact on the volume of the underground economy, whereas medium and strong sanctions exerted a positive and significant influence. This finding aligns with theoretical expectations, as weak sanctions are typically circumvented with relative ease, while medium and strong sanctions generate more pronounced economic distortions, which in turn fuel underground economic activity.

In contrast, long-term estimation results reveal that neither weak nor strong sanctions had a statistically significant effect on the underground economy, but medium sanctions maintained a positive and significant influence. This divergence between short-term and long-term effects underscores an important dynamic. In the long run, the impact of weak sanctions is nullified in the same manner as in the short term. Moreover, consistent with theoretical frameworks, the effectiveness of sanctions tends to diminish over time. Strong sanctions, in particular, often prompt the targeted country to undertake structural reforms and resilience-building efforts, thereby neutralizing their long-term effect. This strategic adaptation has been conceptualized as a process through which sanctions, initially perceived as a threat, are transformed into an opportunity for strengthening domestic economic structures—a viewpoint endorsed by numerous scholars and policy analysts.

Nevertheless, while sanctions impose tangible costs, they are not devoid of consequences and must be accounted for in pursuit of national objectives. Although moderate and strong sanctions significantly affect the underground economy in the short term, policymakers can mitigate these impacts by identifying points of vulnerability and implementing targeted interventions. In some cases, reciprocal and strategic countermeasures may also be warranted.

To this end, several strategies may enhance national economic resilience and reduce the size of the underground economy. These include: diversifying trade partnerships and regulating international economic relations; promoting domestic production to reduce reliance on imports; supporting vulnerable populations; addressing the balance of payments deficit; broadening the country's value system; and strategically managing public opinion and societal perceptions. Collectively, such measures can increase economic resistance to sanctions and contribute to a reduction in underground economic activity, ultimately fostering long-term economic growth.

Authors' Contributions

Authors equally contributed to this article.

Ethical Considerations

All procedures performed in this study were under the ethical standards.

Acknowledgments

Authors thank all participants who participate in this study.

Conflict of Interest

The authors report no conflict of interest.

Funding/Financial Support

According to the authors, this article has no financial support.

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