

ECONOMIC CONSEQUENCES OF THE SHADOW CIRCULATION OF SURROGATE ALCOHOL UNDER MARTIAL LAW: FORENSIC AUDIT TOOLS AND THE RETURN ON INVESTMENT IN INNOVATION

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Abstract. This study examines the financial and economic consequences of the shadow market for surrogate alcohol in Ukraine under martial law. It also considers the macroeconomic feasibility of investing in innovative forensic audit tools to prevent this phenomenon. Martial law has exacerbated the shadow trade in excise goods significantly. Temporary bans on the sale of legal alcohol have led to a consistent demand for illicit products. This results in multimillion losses to the state budget due to lost excise and value-added tax revenue. Meanwhile, the consumption of surrogates, particularly among military personnel, leads to significant human capital losses and places a substantial financial burden on the healthcare system in terms of the costs of intensive care, antidotes and long-term medical rehabilitation. In this context, the study examines the economic feasibility of using high-tech equipment for isotopic analysis to identify the sources of counterfeit products at an early stage. The study takes a comprehensive approach, combining methods of macroeconomic analysis, health economics and criminalistic modelling. The cost-benefit analysis methodology was used to evaluate the financial viability of purchasing innovative analytical equipment (GC-IRMS), contrasting it with the state's current expenditure on treating intoxications and losses from the shadow economy. The empirical basis consisted of an analysis of current Ukrainian legislation and materials from criminal proceedings under Article 204 of the Ukrainian Criminal Code, as well as European scientific studies in toxicology and economic security. The main objective of this article is twofold: firstly, to assess the economic losses incurred by the state due to the illegal alcohol market (in terms of budget losses and medical expenses for military personnel); and secondly, to provide a scientific and economic justification for implementing chemical profiling methods (such as isotope mass spectrometry) as a cost-effective forensic audit tool. This demonstrates that proactively identifying the source of counterfeit alcohol is more cost-effective than addressing the medical and demographic consequences of mass poisonings. The study demonstrated that temporary administrative bans on the legal alcohol market (the 'zero tolerance' paradox), without adequate enforcement mechanisms, stimulate a highly profitable shadow economy. It has been established that the state's financial expenditure on emergency medical care, intensive care unit stays and subsequent social support for military personnel poisoned by surrogates or new psychoactive substances (NPS) exceeds the cost of preventive measures by a factor of ten. The existing forensic and expert control system in Ukraine has a critical methodological gap in that it is purely reactive and does not allow the source of supply (the manufacturing plant) to be traced. The purchase of gas chromatography–isotope ratio mass spectrometry (GC-IRMS) equipment is economically justified, offering an extremely high return on investment (ROI). Implementing this innovative forensic investigation tool will enable the identification of the geographic and botanical origin of raw materials at an early stage, eliminating industrial supply sources for the black market

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and recovering lost tax revenue for the budget. Furthermore, it will prevent large-scale losses of human capital in Ukraine's security and defence sector.

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JEL Classification: I18, K42, H26, O38

1. Introduction

The illicit trade in surrogate alcohol (SA) poses a significant threat to global macroeconomics, undermining a country's economic security and straining healthcare budgets. It is not only a social and medical challenge, but also a major issue. According to international estimates, 25–40% of all alcohol consumed worldwide is produced and traded outside the legal economic sphere (Lachenmeier et al., 2011). This results in colossal financial losses for governments due to the evasion of excise duties and taxes. It also generates additional economic costs due to the premature loss of working capacity and disability in thousands of cases each year (Lachenmeier et al., 2007).

Amid the imposition of full-scale martial law in Ukraine, the severity of this economic problem has reached unprecedented levels. A 'perfect storm' of macroeconomic and regulatory factors has emerged, fuelling the growth of the black market. Disruptions to the supply chains for legal products, as well as temporary administrative bans ('prohibitions'), imposed by military administrations on the sale of alcoholic beverages, have created a steady demand for surrogates (Osintseva & Shapovalov, 2024). Although the prohibition policy was intended to improve discipline and law and order, it paradoxically created a highly profitable niche in the shadow economy. The market was quickly flooded with counterfeit products made from the cheapest raw materials, which led to an increase in toxicological threats.

This study is relevant because it reexamines the issue of counterfeit alcohol from the perspectives of health economics and national security. While the current law enforcement system reacts to consequences by spending resources on investigating fatalities, the healthcare system bears the financial burden of treatment. There is a critical shortage of Ukrainian academic studies demonstrating the economic viability of preventive forensic technologies for the early detection and disruption of industrial sources of counterfeit alcohol. This study aims to provide a comprehensive assessment of the economic and demographic losses resulting from the illegal SA market, particularly the costs of treating military personnel, and to demonstrate the financial feasibility of implementing high-precision isotopic chemical profiling methods as a cost-effective forensic audit tool.

This objective was achieved through the use of a comprehensive, interdisciplinary approach.

The economic justification is based on cost-benefit analysis methodology, shadow economy theory, and human capital preservation concepts. The study examined materials from criminal proceedings under Article 204 of the Criminal Code of Ukraine, as well as the regulatory framework and leading international practices for identifying liquids.

2. The Shadow Market for Excise Goods and Macroeconomic Losses of Human Capital in the Security Sector

The existence of a black market in counterfeit alcohol deals the state a double economic blow. Firstly, it is a classic case of tax evasion (a violation of Article 204 of the Criminal Code of Ukraine), which deprives the state budget of billions of dollars in excise and VAT revenues – funds that are urgently needed to finance the defence sector. The funds lost by the state can be calculated using the following formula:

$$T_{\text{loss}} = V_{\text{shadow}} \times (R_{\text{excise}} + R_{\text{vat}})$$

Where V_{shadow} – the volume of the shadow market of the surrogate in liters of 100% alcohol, R_{excise} – the excise tax rate per 1 liter of 100% alcohol (according to the Tax Code of Ukraine), R_{vat} – the VAT rate.

This formula is a standard arithmetic algorithm used by auditors from the Economic Security Bureau (ESB) and the State Tax Service to calculate the economic losses incurred by the state in criminal proceedings under Articles 204 and 212 of the Criminal Code of Ukraine. It simply converts the volume of counterfeit goods into a financial equivalent using excise tax and VAT rates, in accordance with the Tax Code of Ukraine.

Accurate official data on the size of the black market for counterfeit alcohol – expressed exclusively in physical liters of 100% alcohol – for the years 2024–2025 are not published as a separate statistical indicator. Traditionally, think tanks and government agencies (including CASE Ukraine, the Economic Expert Platform and the Verkhovna Rada Committee on Finance) estimate this market in terms of percentages (i.e., the share of the shadow market) and financial losses to the budget. However, it is possible to estimate the physical volume of this market based on data on legal production and the percentage of the shadow market.

According to estimates by the Economic Expert Platform, the proportion of illicit alcohol is expected to decrease significantly, from 47% in

2022 to approximately 15% by the end of 2025. However, some experts, citing CASE Ukraine's methodologies, suggest that the level of illicit alcohol consumption could still reach 34–36%.

In the first 11 months of 2025, 32.56 million decalitres (dals) of pure (100%) alcohol were legally produced in Ukraine. Since 1 dal equals 10 litres, the total legal volume amounts to 325.6 million litres of pure alcohol. This figure is 26.6% higher than in the same period in 2024. During the first 10 months of 2024, legal production totalled 23.7 million dal (237 million litres).

If 325.6 million litres (based on data for the first 11 months of 2025) represent 85% of the legal market, then the most optimistic estimate of the size of the black market is 15%. This suggests that the volume of illegal 100% alcohol is approximately 57 million litres. However, if pessimistic estimates are used (a shadow market of 34–36%), the volume of illegal alcohol exceeds 150 million litres per year.

Based on these figures, one can conclude that the state incurs significant losses each year as a result of the substantial shadow economy. The black market for alcohol and tobacco collectively costs the Ukrainian budget around 30 billion UAH in lost tax revenue. Total losses from all excise goods are estimated at 36–40 billion UAH annually.

On the other hand, the most serious hidden economic consequence is the enormous loss of human capital, particularly among the Armed Forces of Ukraine's service members, which directly impacts overall defence capability.

Management approaches based on strict administrative prohibitions are often economically inefficient. Article 172-20 of the Code of Ukraine on Administrative Offences imposes severe penalties on military personnel for consuming alcohol, ranging from substantial fines to confinement in a guardroom. Commanding officers are strictly responsible for concealing such incidents. Although this 'zero-tolerance' system is intended to maintain discipline, it creates a profound management paradox. Harsh sanctions encourage service members under chronic combat stress to seek out unregulated sources of alcohol from local black-market dealers. Furthermore, the fear of punishment for both subordinates and commanders leads to cases of non-fatal poisoning from homemade alcohol being systematically concealed. Symptoms of intoxication are often attributed to 'food poisoning' to avoid administrative detentions that could disrupt the unit's cohesion.

From a macroeconomic perspective, such concealment has catastrophic consequences for the healthcare economy. Every case of surrogate alcohol poisoning requires immediate medical intervention, even if it is not fatal. Treating patients in the intensive care unit (ICU) using haemodialysis systems to remove

methanol metabolites from the blood, administering expensive antidotes such as fomepizole and providing long-term inpatient rehabilitation places a heavy financial burden on the Ministry of Defence's medical budget and the public health system. In addition to direct medical costs, the state incurs significant indirect costs. A highly qualified military specialist, in whose training, equipment and education the state has invested significant funds, is sidelined for an extended period (and sometimes permanently, due to acquired disability or blindness). Declines in cognitive function and combat effectiveness on the front line due to the consumption of low-quality surrogates containing high levels of fusel oils directly impact defence capabilities, effectively turning the black market for counterfeit products into a hybrid weapon with prolonged effects.

Using classical methodology, the following formula has been proposed to calculate the total economic losses to the state resulting from a single case of severe poisoning of a service member:

$$L_{total} = (C_{icu} + C_{antidote} + C_{rehab}) + (V_{training} + V_{lost_gdp} + P_{disability})$$

where:

C_{icu} – the cost of staying in an intensive care unit or the average cost of a bed-day in Ukraine;

$C_{antidote}$ – the cost of specific antidotes and blood purification procedures;

C_{rehab} – costs for long-term inpatient rehabilitation;

$V_{training}$ – state investments in the basic and professional training of a military serviceman, which are lost in the event of his retirement from service;

V_{lost_gdp} – GDP lost due to premature loss of working capacity;

$P_{disability}$ – social disability benefits.

A striking example of economic and demographic loss is the tragic incident in Yuzhnoukrainsk in March 2022, when a local resident organised the sale of an alcohol concentrate of unknown origin during a strict ban on the sale of alcohol. Three people died and five suffered severe methanol poisoning as a result of consuming this counterfeit product, requiring significant resources to save their lives (Osintseva & Shapovalov, 2024). This case demonstrates the high degree of flexibility of 'dark logistics' and suggests that law enforcement only responds to the final consequences, disregarding the economic feasibility of eliminating the sources of counterfeit production.

3. Toxicological Risks and the Financial Burden on the Healthcare System

The economic damage caused by counterfeit alcohol is directly proportional to the complexity of its chemical composition. Risks can be categorised as either unintentional contaminants resulting from

cheap, artisanal production, or intentional adulterants added to enhance the effect. Methanol is the most dangerous and classic contaminant. Once it enters the body, it causes severe metabolic acidosis and optic nerve damage. Providing medical care for such patients requires highly specialised professionals and expensive equipment, both of which are extremely scarce resources in wartime conditions. The presence of heavy metals, such as lead, in artisanal distillation devices causes chronic intoxication. The treatment of this condition requires significant financial investment and results in prolonged disability for patients (The AMPHORA Project, 2013).

The problem of new psychoactive substances (NPS) being used as adulterants is an even more complex and financially draining issue for the healthcare system. Underground producers use homemade alcohol as a liquid carrier for delivering synthetic cathinones or 'designer' benzodiazepines. According to European agencies (European Union Drugs Agency, 2025; Shafi et al., 2020), the NPS market is growing exponentially and generating substantial unregulated profits. The toxicological synergy between ethanol and depressants (such as benzodiazepines) produces a multiplicative rather than an additive effect on central nervous system depression, which can lead to respiratory arrest.

Modern Ukrainian medical and expert institutions are not equipped to detect such combinations on a large scale. Standard forensic medical examinations only detect ethanol, and targeted screening for NPS is not conducted due to a lack of expensive testing systems and protocols. Consequently, the true cause of a patient's death or critical condition remains undetermined. This hinders the development of effective clinical treatment protocols and results in the healthcare system wasting resources on ineffective therapeutic measures. This is precisely why European

researchers are insisting on the implementation of risk-based methodologies, such as the AMPHORA project, which can optimise healthcare costs through accurate toxicological screening.

The results of the analysis demonstrate the economic unsustainability of reactive medical and law enforcement systems. The financial burden caused by treatment and loss of productive capacity makes the transition to forensic audit tools, particularly GC-IRMS, unavoidable. These tools will enable industrial sources of surrogate supply to be identified and eliminated at an early stage, before catastrophic medical and demographic consequences set in.

4. The Economic Payback of Innovative Equipment as a Measure of Early Forensic Prevention

In order to prevent economic and demographic losses, there needs to be a shift from reactive law enforcement to proactive forensic intelligence. However, Ukraine's current system of forensic expert oversight has critical institutional and technological gaps. According to the current methodological guidelines, chemical experts at the National Forensic Expertise Centre of the Ministry of Internal Affairs of Ukraine are not authorised to conclude whether alcohol-containing liquids are harmful to human health. They merely note non-compliance with DSTU standards with regard to the presence of impurities. Conversely, medical toxicologists from the Ministry of Health determine the cause of death, yet they do not investigate the origin of the liquid. The Economic Security Bureau (ESB) investigator receives two separate reports, neither of which indicates the origin of the illegal raw materials.

Traditional analytical methods are based on gas chromatography (GC-MS), which analyses fermentation by-products (congeners) (Hegde & Pathak, 2023;

Table 1

Comparative Analysis of the Economic Efficiency of Traditional (GC-MS) and Innovative (GC-IRMS) Models of Forensic Examination

Economic evaluation parameter	Traditional model (GC-MS)	Innovative model (GC-IRMS)	Economic effect of implementation
Expenditure Targeting	Reactive (investigating consequences, post-incident medical expenses)	Proactive (forensic investigation, loss prevention)	Reduction of the government's total costs in the long term
Level of Detection of Economic Crimes	Low (identification of only small-scale dealers and distributors)	High (identification of industrial manufacturing plants based on isotopic profiles)	Millions in excise taxes and VAT returning to the shadow economy
Medical costs (use of antidotes, hemodialysis)	Maximum (in cases of mass poisoning)	Minimum (blocking the distribution channel before the counterfeit product reaches the consumer)	Direct savings for the health care budget and the Ministry of Defence
Return on Investment (ROI)	Low (the equipment is cheaper, but does not generate a macroeconomic effect)	Extremely high (high CapEx pays for itself quickly by shutting down 1–2 shadow factories)	Rapid return on investment due to the de-shadowing of the economy

Rodda et al., 2013). While this enables investigators to determine the 'common origin' of the seized bottles, it cannot trace the source back to an industrial source, such as an underground distillery or smuggling channel. Modern science offers a revolutionary method: isotope ratio mass spectrometry (IRMS), combined with gas chromatography (GC-IRMS). This method analyses the stable isotopes of the target ethanol molecule itself, rather than impurities (Perini et al., 2024).

Isotope analysis can identify the botanical origin of raw materials (such as beets, corn, wheat or petroleum products) with 100% accuracy, thanks to the different photosynthetic pathways (Gürbüz & Gürbüz, 2021). Furthermore, the isotopic composition of the water absorbed by a plant carries a distinctive regional signature, enabling the geographic origin of the alcohol to be determined.

From an economic analysis perspective, the implementation of GC-IRMS is an extremely cost-effective solution. However, capital expenditure (CapEx) for purchasing the necessary equipment and training personnel is relatively high. However, the return on investment (ROI) is exceptional.

Using the classical cost-benefit analysis methodology as a basis, this formula has been developed to calculate the economic payback period resulting from the implementation of a single GC-IRMS laboratory:

$$ROI = \frac{(E_{tax} + E_{med}) - (C_{capex} + C_{opex})}{C_{capex} + C_{opex}} \times 100\%$$

where:

E_{tax} – the amount of saved/returned taxes (excise duty, VAT) due to the elimination of underground production (result of forensic intelligence);

E_{med} – the healthcare system saved money on the treatment of intoxications (ICU, hemodialysis, antidotes);

C_{capex} – capital costs for the purchase of GC-IRMS equipment and training of experts;

C_{opex} – operating costs (reagents, carrier gases, depreciation).

In order to furnish practical evidence of the macroeconomic feasibility of transitioning to a proactive forensic audit model, a model of the return on investment (ROI) will be constructed using the example of purchasing a single gas chromatography–isotope ratio mass spectrometry (GC-IRMS) system.

The approximate market value (CapEx) of a modern GC-IRMS analytical system is around 400,000 USD (approximately 16 million UAH at the current exchange rate). At first glance, this represents a significant financial burden for the expert budget. However, the macroeconomic impact of its implementation demonstrates an unprecedented rate of return on investment.

Next, consider a conservative scenario. A forensic investigation using GC-IRMS identified an isotopic signature, resulting in the closure of a clandestine facility

producing 10 metric tons (10,000 litres) of counterfeit alcohol per month, calculated as 100% alcohol.

According to the Tax Code of Ukraine, the excise tax rate is 133.31 UAH per litre of 100% alcohol. Direct monthly budget losses from unpaid excise tax alone amount to: 10,000 litres $\times$ 133.31 UAH = 1,333,100 UAH. Taking unpaid VAT (20%) into account, the monthly fiscal loss amounts to approximately 1.6 million UAH (or 40,000 USD). In other words, the equipment would pay for itself in 10 months simply by bringing tax revenue out of the shadows.

The sale of counterfeit alcohol of such poor quality inevitably leads to mass poisonings. Assuming that only 1% of 10 metric tons of counterfeit alcohol causes severe poisoning, this would result in the hospitalisation of around 100 patients (including military personnel) each month. The state's economic costs per patient include an estimated 20,000–30,000 UAH for an intensive care unit (ICU) stay and haemodialysis, and about 40,000 UAH for specific antidotes (e.g., fomepizole). There are also indirect losses due to the temporary loss of a specialist's combat readiness. The state spent over 300,000 UAH training this specialist. The total medical and demographic costs of 100 cases of poisoning amount to at least 6–8 million UAH (equivalent to 150,000–200,000 USD) per month.

The state's total monthly losses resulting from operating just one production line with a capacity of 10 metric tons per month (including fiscal, medical, and demographic factors) amount to approximately 190,000–240,000 USD. Thus, an investment of 400,000 USD in innovative GC-IRMS equipment pays for itself in less than 2 months (400,000 USD / 200,000 USD = 2 months) by eliminating just one source of surrogate supply. After this period, the innovative equipment begins to generate a 'net profit' for the country's economic security, proactively preserving human capital.

The identification of a unique isotopic signature in a seized batch of surrogate alcohol enables law enforcement agencies to not only punish a minor offender but also to track down and completely dismantle the industrial production chain. Shutting down just one large-scale underground factory ensures:

a) The immediate cessation of the supply of thousands of litres of poison was of paramount importance. This measure saved the healthcare budget millions of hryvnias in potential patient treatment costs and preserved the human capital of the Armed Forces of Ukraine.

b) The elimination of tax evasion schemes is of paramount importance in the return of legal excise tax revenues to the economy. These revenues are instrumental in covering the cost of the specialised equipment purchased.

It is therefore important to note that the transition to early prevention technologies is economically and humanitarily beneficial.

5. Conclusions

The black-market trade in counterfeit alcohol has become a systemic threat to Ukraine's economic security and defence capabilities under martial law, going beyond being merely a public health offence. The analysis convincingly demonstrates the economic ineffectiveness of total administrative bans ('the zero-tolerance paradox') without parallel implementation of innovative tools for detecting black markets. The shadow economy responds flexibly to shortages by establishing highly lucrative supply networks for toxic counterfeit goods. This results in the state suffering double financial losses: significant shortfalls in excise tax revenue and substantial increases in emergency medical care expenditure.

The healthcare economy is dealt a critical blow by the need to treat patients (particularly military personnel) who have been poisoned by methanol or new psychoactive substances. The loss of a combat-ready soldier to intoxication represents not only a demographic tragedy, but also a substantial macroeconomic loss

of human capital, in which the state has invested considerable financial resources. The current reactive model of forensic expertise is economically unprofitable because it only establishes toxicity after the event and does not allow law enforcement agencies to eliminate the source of the problem.

It has been demonstrated that investing in the modernisation of forensic centres' analytical infrastructure – specifically, by procuring isotope mass spectrometry (GC-IRMS) systems – is an economically sound management decision with an exceptionally high return on investment (ROI). Accurately identifying the geographic and botanical origin of ethanol enables law enforcement agencies, particularly the BEB, to proactively eliminate clandestine production facilities using forensic intelligence methodologies. This prevents mass poisonings at an early stage, preserves the working capacity of citizens and returns tax revenues to the legal sector of the economy, more than offsetting the initial costs of purchasing the equipment and providing a solid foundation for the state's financial and national security.

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