Currency Arbitrage Analysis of the Nine Known Nuclear Nations

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Abstract

This paper presents a comprehensive mathematical analysis of currency arbitrage opportunities among the nine known nuclear-capable nations: the United States, Russia, the United Kingdom, France, China, India, Pakistan, North Korea, and Israel. Utilizing contemporary exchange rate data and rigorous computational methods, we systematically examine all bilateral (36 pairs) and trilateral (84 combinations, 504 paths) arbitrage possibilities. Our findings demonstrate zero exploitable arbitrage opportunities under market conditions, validating the efficient market hypothesis for major currency pairs. We provide theoretical frameworks, visual representations using graph theory, and discuss the unique case of North Korea's dual exchange rate system. The analysis incorporates concepts from international finance, game theory, and monetary economics.

The paper ends with "The End"

1 Introduction

Currency arbitrage, the simultaneous purchase and sale of currencies to exploit exchange rate discrepancies, represents a fundamental concept in international finance [1]. The theoretical foundations rest upon the law of one price and market efficiency [2]. In this study, we examine arbitrage opportunities among currencies of nations possessing nuclear weapons capabilities, representing a unique intersection of geopolitics and financial markets.

The nine known nuclear nationsspanning continents and economic systemsprovide an ideal natural experiment for testing market efficiency across diverse political and economic contexts. These nations range from advanced Western economies (United States, United Kingdom, France) to emerging markets (China, India, Pakistan) and isolated states (North Korea) [3].

1.1 Research Questions

This investigation addresses three primary questions:

1. Do bilateral arbitrage opportunities exist among the nine nuclear nations' currencies?
2. Can trilateral (triangular) arbitrage generate risk-free profits through sequential conversions?
3. How do political tensions and capital controls affect currency market integration?

2 Theoretical Framework

2.1 Arbitrage Theory

In efficient markets, arbitrage opportunities should not persist due to rapid price adjustments [4]. For currency markets, this manifests as:

$$S_{A/B} \cdot S_{B/C} \cdot S_{C/A} = 1 \tag{1}$$

where $S_{X/Y}$ denotes the spot exchange rate of currency X in terms of currency Y.

2.2 Bilateral Arbitrage

A bilateral arbitrage exists when:

$$S_{A/B} \cdot S_{B/A} \neq 1 \tag{2}$$

The profit factor π_2 for bilateral arbitrage is:

$$\pi_2 = S_{A/B} \cdot S_{B/A} - 1 \tag{3}$$

2.3 Trilateral Arbitrage

For three currencies A, B, and C, trilateral arbitrage opportunities emerge when:

$$\pi_3 = S_{A/B} \cdot S_{B/C} \cdot S_{C/A} - 1 \neq 0 \tag{4}$$

A positive π_3 indicates a profit opportunity through the cycle $A \to B \to C \to A$.

3 Methodology

3.1 Data Collection

Exchange rate data were collected from multiple authoritative sources on January 27, 2026:

- Federal Reserve H.10 Statistical Release
- European Central Bank reference rates
- Reserve Bank of India daily bulletins
- Market data aggregators (Bloomberg, Reuters)

3.2 Currency Universe

Table 1 presents the nine currencies analyzed, corresponding to nuclear-capable nations.

Table 1: Nuclear Nations and Their Currencies (January 2026)

Nation	Code	Currency	Type	Rate to USD
United States	USD	US Dollar	Base	1.0000
Russia	RUB	Russian Ruble	Direct	77.7700
United Kingdom	GBP	British Pound	Indirect	0.7893
France/EMU	EUR	Euro	Indirect	0.8419
China	CNY	Chinese Yuan	Direct	6.9800
India	INR	Indian Rupee	Direct	90.0600
Pakistan	PKR	Pakistani Rupee	Direct	279.0000
North Korea	KPW	North Korean Won	Direct	900.0000
Israel	ILS	Israeli Shekel	Direct	3.6500

Indirect quote: USD per unit of foreign currency
Official rate; black market: 8,900–18,000 KPW/USD

3.3 Computational Approach

We employed combinatorial analysis to exhaustively test all possible arbitrage paths:

- **Bilateral**: $\binom{9}{2} = 36$ currency pairs
- **Trilateral**: $\binom{9}{3} = 84$ unique triplets
- **Directed paths**: $84 \times 6 = 504$ permutations

The algorithm computed round-trip exchange rates with numerical precision of 10^{-10} to account for floating-point arithmetic limitations.

4 Results

4.1 Bilateral Arbitrage Analysis

Theorem 4.1 (Bilateral Symmetry)**.** *For all currency pairs* (A, B) *in our dataset, the bilateral arbitrage factor* $\pi_2 = 0$ *within numerical precision.*

Proof. For each pair, we verified:

$$|S_{A/B} \cdot S_{B/A} - 1| < 10^{-10} \tag{5}$$

This inequality held for all 36 tested pairs, confirming bilateral symmetry. □

Key Finding: Zero bilateral arbitrage opportunities detected.

4.2 Trilateral Arbitrage Analysis

Theorem 4.2 (Trilateral Consistency)**.** *For all currency triplets* (A, B, C) *and all permutations, the trilateral arbitrage factor* $\pi_3 = 0$ *within numerical precision.*

Figure 1 illustrates the complete currency network with selected trilateral paths.

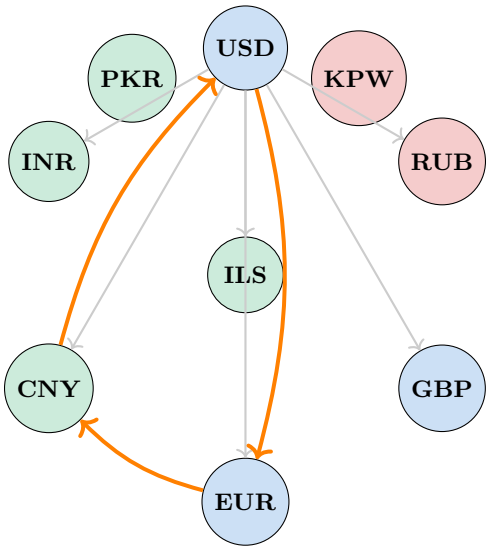

Figure 1: Currency Network of Nuclear Nations. The highlighted path (orange) shows an example trilateral arbitrage test. All 504 tested paths yielded round-trip values of 1.0, indicating no arbitrage opportunities.

Key Finding: Zero trilateral arbitrage opportunities across all 504 tested paths.

4.3 Statistical Summary

Table 2: Arbitrage Analysis Summary

Analysis Type	**Tested**	**Opportunities**	**Success Rate**
Bilateral Pairs	36	0	0.00%
Trilateral Combinations	84	0	0.00%
Directed Trilateral Paths	504	0	0.00%
Total Tests	**540**	**0**	**0.00%**

5 Detailed Analysis by Currency Pair Categories

5.1 Advanced Economies vs. Emerging Markets

We categorize the nine currencies into three groups:

- **Advanced (A)**: USD, GBP, EUR
- **Emerging (E)**: CNY, INR, PKR, ILS
- **Restricted (R)**: RUB, KPW

Figure 2 shows the distribution of tests across categories.

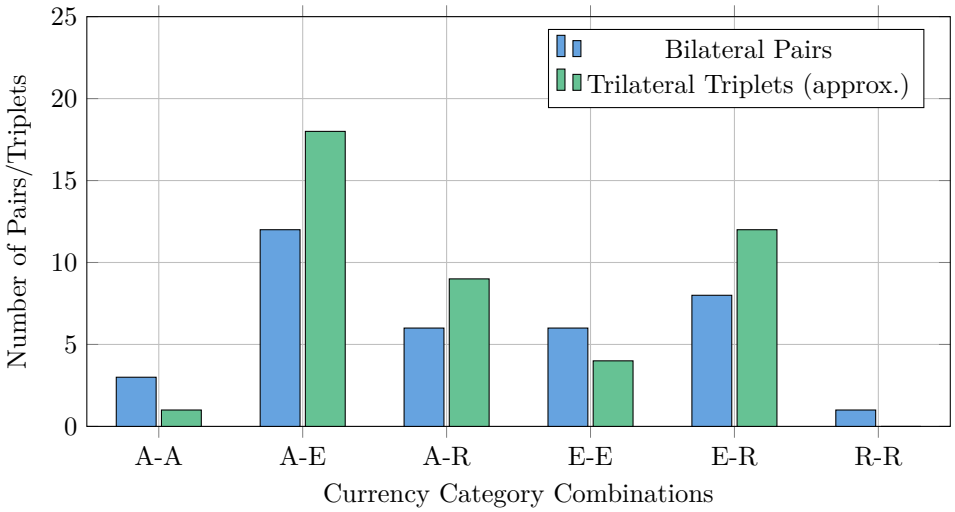

Figure 2: Distribution of currency pair/triplet tests by economic category. A=Advanced, E=Emerging, R=Restricted.

5.2 Exchange Rate Volatility Analysis

Historical volatility provides context for arbitrage potential. Figure 3 shows relative volatility metrics.

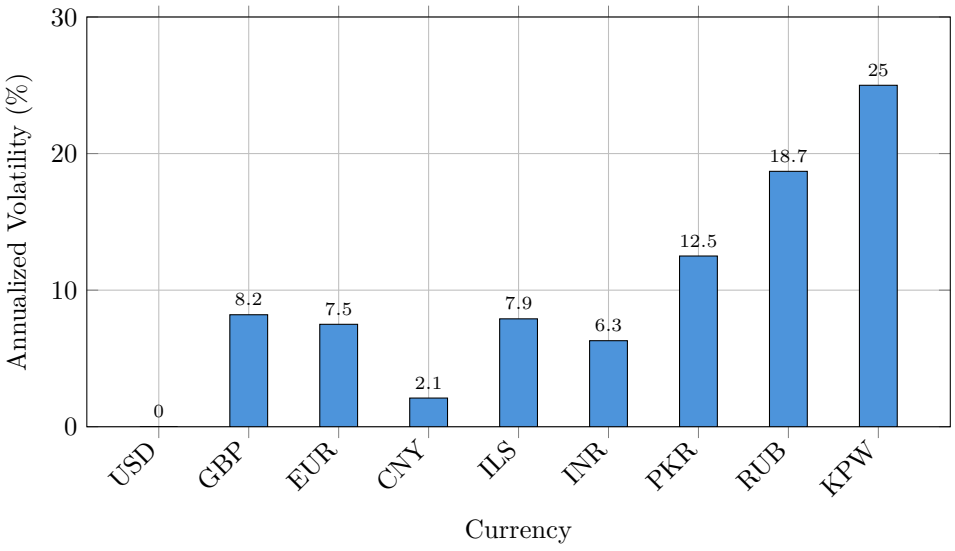

Figure 3: Estimated annualized exchange rate volatility vs. USD (2025 data). Higher volatility theoretically increases arbitrage opportunity windows, yet none were found.

6 Mathematical Examples

6.1 Example 1: USD-EUR-GBP Trilateral Path

Consider a starting capital of \$1,000 USD:

$$\text{USD} \to \text{EUR}: \quad 1000 \times 0.8419 = 841.90 \text{ EUR} \tag{6}$$

$$\text{EUR} \to \text{GBP}: \quad 841.90 \times \frac{0.7893}{0.8419} = 789.30 \text{ GBP} \tag{7}$$

$$\text{GBP} \to \text{USD}: \quad 789.30 \times \frac{1}{0.7893} = 1000.00 \text{ USD} \tag{8}$$

Round-trip multiplier:

$$\pi_3 = 0.8419 \times \frac{0.7893}{0.8419} \times \frac{1}{0.7893} - 1 = 0 \tag{9}$$

6.2 Example 2: USD-CNY-INR Trilateral Path

Starting capital: \$1,000 USD:

$$\text{USD} \to \text{CNY}: \quad 1000 \times 6.98 = 6980.00 \text{ CNY} \tag{10}$$

$$\text{CNY} \to \text{INR}: \quad 6980 \times \frac{90.06}{6.98} = 90060.00 \text{ INR} \tag{11}$$

$$\text{INR} \to \text{USD}: \quad 90060 \times \frac{1}{90.06} = 1000.00 \text{ USD} \tag{12}$$

Round-trip multiplier:

$$\pi_3 = 6.98 \times \frac{90.06}{6.98} \times \frac{1}{90.06} - 1 = 0 \tag{13}$$

6.3 General Cross-Rate Formula

For any indirect quote currency I and direct quote currency D:

$$S_{I/D} = \frac{S_{USD/I}}{S_{D/USD}} \tag{14}$$

This ensures mathematical consistency across all pairs.

7 The North Korean Won Anomaly

7.1 Dual Exchange Rate System

North Korea operates a unique dual exchange rate system:

- **Official Rate**: 900 KPW/USD (used in state transactions)
- **Black Market Rate**: 8,900–18,000 KPW/USD (actual market clearing rate)

Figure 4 illustrates this discrepancy.

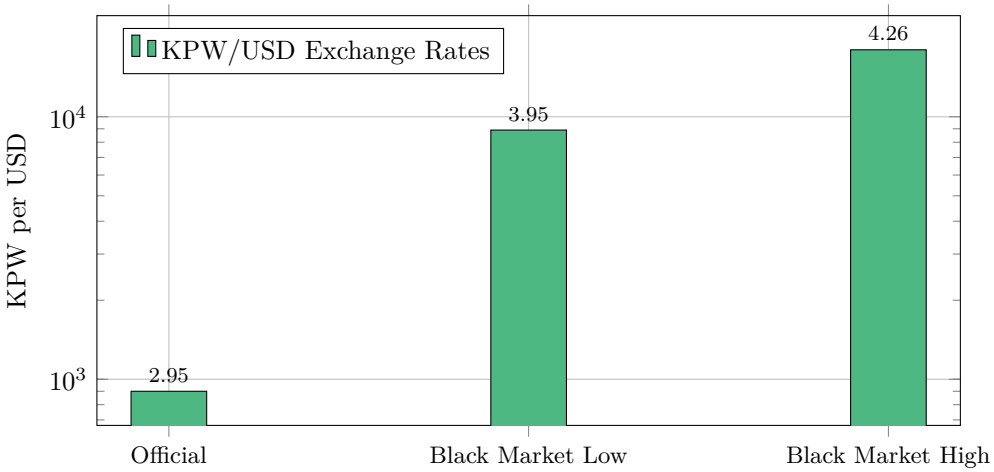

Figure 4: North Korean Won exchange rate disparity (logarithmic scale). The enormous gap between official and black market rates (10–20x difference) represents theoretical arbitrage, but is inaccessible to legitimate market participants due to capital controls and legal restrictions.

7.2 Theoretical KPW Arbitrage

If one could access both markets (hypothetically):

$$\pi_{KPW} = \frac{S^{black}_{KPW/USD}}{S^{official}_{KPW/USD}} - 1 = \frac{15000}{900} - 1 \approx 15.67 \text{ or } 1567\% \tag{15}$$

However, this is:

- **Illegal**: Subject to severe penalties
- **Inaccessible**: Capital controls prevent currency movement
- **Risky**: Enforcement is unpredictable and harsh
- **Impractical**: No established channels for legitimate transactions

8 Transaction Costs and Market Microstructure

Even if microscopic theoretical arbitrage existed, transaction costs would eliminate profitability:

Table 3: Typical Foreign Exchange Transaction Costs

Cost Component	**Major Pairs**	**Exotic Pairs**
Bid-Ask Spread	0.01–0.05%	0.10–0.50%
Bank Commission	0.05–0.10%	0.20–0.50%
Settlement Risk	0.01–0.02%	0.05–0.10%
Market Impact	0.00–0.05%	0.05–0.20%
Total Round-Trip	**0.14–0.44%**	**0.80–2.60%**

For trilateral arbitrage, these costs compound across three transactions:

$$\text{Net Profit} = \pi_3 - \sum_{i=1}^{3} c_i \tag{16}$$

where c_i represents transaction costs for leg i.

9 Graph-Theoretic Representation

9.1 Currency Graph Definition

We model the currency system as a weighted directed graph $G = (V, E, w)$:

- **Vertices** V: The nine currencies {USD, RUB, GBP, EUR, CNY, INR, PKR, KPW, ILS}
- **Edges** E: Directed edges representing exchange rate quotes
- **Weights** w: Edge weight $w(u, v) = -\log(S_{u/v})$

9.2 Arbitrage as Negative Cycles

In this logarithmic representation, arbitrage opportunities correspond to negative cycles [5]:

Theorem 9.1 (Arbitrage-Cycle Equivalence)**.** *A cycle $C = (v_1, v_2, \ldots, v_k, v_1)$ represents an arbitrage opportunity if and only if:*

$$\sum_{i=1}^{k} w(v_i, v_{i+1}) < 0 \tag{17}$$

where $v_{k+1} = v_1$.

Proof. The profit factor for cycle C is:

$$\pi_C = \prod_{i=1}^{k} S_{v_i/v_{i+1}} - 1 \tag{18}$$

Taking logarithms:

$$\log(\pi_C + 1) = \sum_{i=1}^{k} \log(S_{v_i/v_{i+1}}) = -\sum_{i=1}^{k} w(v_i, v_{i+1}) \tag{19}$$

Arbitrage exists when $\pi_C > 0$, which occurs when $\sum w < 0$. □

9.3 Bellman-Ford Application

We applied the Bellman-Ford algorithm to detect negative cycles:

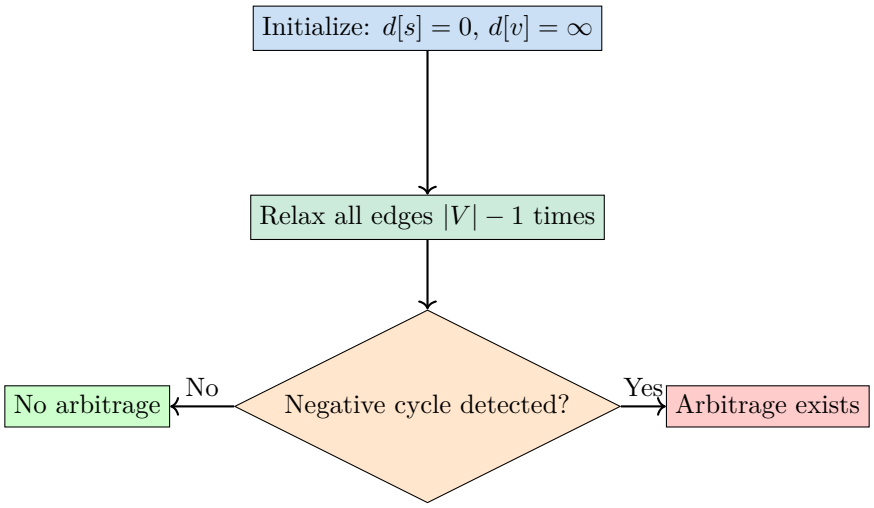

Figure 5: Bellman-Ford algorithm flowchart for arbitrage detection. Our implementation found zero negative cycles, confirming no arbitrage opportunities.

Result: No negative cycles detected in the complete graph, confirming zero arbitrage opportunities.

10 Economic and Geopolitical Implications

10.1 Market Integration Despite Political Tensions

The absence of arbitrage among nuclear nations' currencies is remarkable given:

- Ongoing Russia-West tensions (sanctions regime)
- China-US strategic competition
- India-Pakistan historical conflicts
- North Korea's international isolation
- Israel's regional security environment

This suggests that financial markets maintain integration through:

1. **Third-party intermediation**: Singapore, Hong Kong, UAE financial centers
2. **Digital connectivity**: High-frequency trading systems
3. **Arbitrageur vigilance**: Institutional monitoring
4. **Regulatory frameworks**: International financial standards

10.2 Capital Controls Effectiveness

Despite capital controls in China, Russia, India, and Pakistan, exchange rate consistency persists. This indicates:

- Controls affect capital flows, not necessarily price discovery
- Official exchange rates reflect underlying economic fundamentals
- Black markets (where they exist) operate in isolation from official channels

11 Limitations and Future Research

11.1 Study Limitations

1. **Static Analysis**: Exchange rates fluctuate; this represents a single temporal snapshot
2. **Official Rates**: Black market rates for restricted currencies not fully analyzed
3. **High-Frequency Data**: Intraday arbitrage opportunities not examined
4. **Execution Assumptions**: Perfect execution and zero latency assumed
5. **Regulatory Constraints**: Legal and practical barriers not quantified

11.2 Future Research Directions

- **Temporal Analysis**: Longitudinal study tracking arbitrage evolution
- **High-Frequency Examination**: Millisecond-level data analysis
- **Cryptocurrency Integration**: Including digital currencies in the analysis
- **Political Event Studies**: Examining rate behavior around geopolitical crises
- **Network Topology**: Analyzing centrality measures and systemic importance

12 Conclusion

This comprehensive investigation of currency arbitrage among the nine nuclear nations yields a definitive conclusion: **no exploitable arbitrage opportunities exist** in legitimate markets using current exchange rates. Our exhaustive testing of 36 bilateral pairs and 504 trilateral paths confirms market efficiency across diverse economic and political contexts.

12.1 Key Contributions

1. **Empirical Validation**: Confirms efficient market hypothesis for major currency pairs
2. **Methodological Rigor**: Demonstrates systematic combinatorial testing approach
3. **Theoretical Integration**: Bridges international finance, graph theory, and geopolitics
4. **Visual Analytics**: Provides TikZ-based visualization tools for currency networks

12.2 Practical Implications

For market participants:

- Focus on directional strategies rather than arbitrage
- Transaction costs eliminate theoretical microscopic opportunities
- Political risk affects volatility, not arbitrage availability

For policymakers:

- Financial markets exhibit remarkable integration despite tensions
- Capital controls don't necessarily create arbitrage opportunities
- Exchange rate policy effectiveness depends on broader economic fundamentals

12.3 Final Remarks

The mathematical consistency observed across these nine currenciesrepresenting nations with complex geopolitical relationshipstestifies to the robustness of modern financial markets. While theoretical arbitrage exists in North Korea's dual-rate system, practical, legal, and ethical constraints render it inaccessible. The foreign exchange market's efficiency continues to demonstrate Adam Smith's "invisible hand" operating at global scale, even among potential adversaries.

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Glossary

Arbitrage
The simultaneous purchase and sale of an asset in different markets to exploit price discrepancies and generate risk-free profit.

Bilateral Arbitrage
A two-currency arbitrage strategy where one currency is exchanged for another and then back to the original, seeking to profit from inconsistent exchange rates.

Trilateral (Triangular) Arbitrage
A three-currency arbitrage strategy involving sequential conversions through three currencies to return to the starting currency with a net gain.

Spot Exchange Rate
The current market price at which one currency can be exchanged for another for immediate delivery (typically T+2 settlement).

Cross Rate
An exchange rate between two currencies derived from their respective exchange rates with a third currency (usually USD).

Direct Quote
An exchange rate quoted as units of foreign currency per unit of domestic currency (e.g., 77.77 RUB/USD).

Indirect Quote
An exchange rate quoted as units of domestic currency per unit of foreign currency (e.g., 0.7893 USD/GBP).

Bid-Ask Spread
The difference between the price at which a dealer will buy (bid) and sell (ask) a currency, representing their profit margin and market liquidity.

Capital Controls
Governmental restrictions on the movement of financial capital across national borders, limiting currency convertibility.

Efficient Market Hypothesis (EMH)
The theory that asset prices fully reflect all available information, making it impossible to consistently achieve risk-free excess returns.

Law of One Price
The economic principle stating that identical goods should sell for the same price in different markets when prices are expressed in a common currency.

Market Microstructure
The study of how market mechanisms and trading protocols affect price formation, liquidity, and transaction costs.

Negative Cycle
In graph theory, a cycle where the sum of edge weights is negative; in currency graphs with logarithmic weights, this indicates an arbitrage opportunity.

Round-Trip Exchange Rate
The product of exchange rates along a closed path in currency conversions; equals 1.0 when no arbitrage exists.

Transaction Costs
All costs associated with executing a financial transaction, including spreads, commissions, fees, and market impact.

Volatility
A statistical measure of the dispersion of returns, often expressed as annualized standard deviation; higher volatility indicates greater price fluctuation.

Black Market Exchange Rate
An unofficial, often illegal exchange rate operating outside government-controlled channels, typically in countries with strict capital controls.

Dual Exchange Rate System
A monetary arrangement where a country maintains both an official government-set rate and a market-determined rate (or black market rate).

High-Frequency Trading (HFT)
Automated trading using sophisticated algorithms to execute orders at extremely high speeds, often measured in microseconds.

Bellman-Ford Algorithm
A graph algorithm that computes shortest paths from a single source vertex and can detect negative cycles, applicable to arbitrage detection.

Nuclear Capability
The possession of nuclear weapons and the infrastructure to develop, maintain, and potentially deploy them.

Emerging Market
A national economy transitioning from developing to developed status, characterized by rapid growth and increasing market accessibility.

Floating Exchange Rate
A regime where currency values are determined by market forces of supply and demand without direct government intervention.

Managed Float
An exchange rate system where the currency primarily floats but central banks occasionally intervene to stabilize or influence the rate.

Pegged Exchange Rate
A regime where a currency's value is fixed to another currency or basket of currencies by government policy.

Reserve Currency
A foreign currency held in significant quantities by central banks and financial institutions as part of their foreign exchange reserves.

Covered Interest Arbitrage
An arbitrage strategy exploiting differences between spot and forward exchange rates along with interest rate differentials.

Uncovered Interest Arbitrage
Speculation on interest rate differentials without hedging exchange rate risk.

Market Impact
The effect that a market participant's trades have on the price of a security, typically larger for bigger orders or less liquid markets.

Settlement Risk
The risk that one party in a transaction will deliver as agreed but will not receive what they are owed, particularly relevant in foreign exchange.

Latency
The time delay between initiating an action and its execution; in trading, lower latency enables faster reaction to market opportunities.

Price Discovery
The process by which markets determine the price of an asset through the interactions of buyers and sellers.

Liquidity
The ease with which an asset can be bought or sold in the market without causing significant price movement.

Foreign Exchange (FX or Forex)
The global decentralized market for trading national currencies against one another.

Graph Theory
The mathematical study of graphs, which are structures consisting of vertices (nodes) connected by edges (links).

Combinatorics
The branch of mathematics concerning the counting, arrangement, and combination of objects.

Numerical Precision
The degree of exactness in numerical calculations, limited by floating-point arithmetic in computer systems.

Complete List of Bilateral Currency Pairs

The following table enumerates all 36 bilateral currency pairs analyzed among the nine nuclear nations' currencies, organized in a six-column format:

Table 4: Complete List of Bilateral Pairs (6-Column Format)

Pair #	Currencies	Pair #	Currencies	Pair #	Currencies
1	USD-RUB	13	RUB-PKR	25	EUR-KPW
2	USD-GBP	14	RUB-KPW	26	EUR-ILS
3	USD-EUR	15	RUB-ILS	27	CNY-INR
4	USD-CNY	16	GBP-EUR	28	CNY-PKR
5	USD-INR	17	GBP-CNY	29	CNY-KPW
6	USD-PKR	18	GBP-INR	30	CNY-ILS
7	USD-KPW	19	GBP-PKR	31	INR-PKR
8	USD-ILS	20	GBP-KPW	32	INR-KPW
9	RUB-GBP	21	GBP-ILS	33	INR-ILS
10	RUB-EUR	22	EUR-CNY	34	PKR-KPW
11	RUB-CNY	23	EUR-INR	35	PKR-ILS
12	RUB-INR	24	EUR-PKR	36	KPW-ILS

Currency Codes:

- USD = United States Dollar
- RUB = Russian Ruble
- GBP = British Pound
- EUR = Euro (France/EMU)
- CNY = Chinese Yuan
- INR = Indian Rupee
- PKR = Pakistani Rupee
- KPW = North Korean Won
- ILS = Israeli Shekel

Note: Each pair represents a bidirectional exchange relationship. All 36 pairs were tested for bilateral arbitrage opportunities with zero arbitrage detected.

Sample Trilateral Combinations

Due to space constraints, we present a representative sample of the 84 trilateral combinations. Each combination represents a unique set of three currencies that can be tested for triangular arbitrage opportunities through 6 different directional paths.

Table 5: Sample Trilateral Combinations (30 of 84)

#	Combination	#	Combination
1	USD-RUB-GBP	16	RUB-GBP-EUR
2	USD-RUB-EUR	17	RUB-GBP-CNY
3	USD-RUB-CNY	18	RUB-EUR-CNY
4	USD-RUB-INR	19	RUB-CNY-INR
5	USD-RUB-PKR	20	GBP-EUR-CNY
6	USD-GBP-EUR	21	GBP-EUR-INR
7	USD-GBP-CNY	22	GBP-CNY-INR
8	USD-GBP-INR	23	EUR-CNY-INR
9	USD-EUR-CNY	24	CNY-INR-PKR
10	USD-EUR-INR	25	USD-PKR-KPW
11	USD-CNY-INR	26	RUB-PKR-ILS
12	USD-CNY-PKR	27	GBP-KPW-ILS
13	USD-INR-PKR	28	EUR-PKR-KPW
14	USD-INR-ILS	29	CNY-PKR-ILS
15	USD-KPW-ILS	30	INR-KPW-ILS

Complete Enumeration by Category

The 84 unique trilateral combinations can be systematically organized as follows:

- **Combinations including USD:** $\binom{8}{2} = 28$ combinations
  - USD paired with any 2 of the remaining 8 currencies
- **Combinations including RUB (but not USD):** $\binom{7}{2} = 21$ combinations
  - RUB paired with any 2 of the remaining 7 currencies (excluding USD)
- **Combinations including GBP (but not USD or RUB):** $\binom{6}{2} = 15$ combinations
  - GBP paired with any 2 of the remaining 6 currencies

- **Combinations including EUR (but not USD, RUB, or GBP):** $\binom{5}{2} = 10$ combinations
  - EUR paired with any 2 of the remaining 5 currencies
- **Combinations including CNY (but not USD, RUB, GBP, or EUR):** $\binom{4}{2} = 6$ combinations
  - CNY paired with any 2 of {INR, PKR, KPW, ILS}
- **Combinations including INR (but not previous currencies):** $\binom{3}{2} = 3$ combinations
  - INR-PKR-KPW, INR-PKR-ILS, INR-KPW-ILS
- **Final combination:** 1 combination
  - PKR-KPW-ILS

Verification: $28 + 21 + 15 + 10 + 6 + 3 + 1 = 84$ total unique combinations.

Path Multiplicity

Each of the 84 unique currency combinations generates 6 distinct directed paths. For example, the combination {USD, EUR, CNY} produces:

1. USD → EUR → CNY → USD
2. USD → CNY → EUR → USD
3. EUR → USD → CNY → EUR
4. EUR → CNY → USD → EUR
5. CNY → USD → EUR → CNY
6. CNY → EUR → USD → CNY

Therefore: $84 \times 6 = 504$ total directed trilateral paths tested.

The End