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Mapping Extent of Spillover Channels in Monetary Space: Study of Multidimensional Spatial Effects of US Dollar Liquidity

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Abstract: This study aims to analyze the spatial effects triggered by dollar liquidity by constructing a multidimensional spatial matrix that modifies the traditional monetary spatial framework. We utilized a three-level spatial econometric model (Spatial Lag, Durbin, and Generalized Nested Space) to measure Gross Domestic Product (GDP), Consumer Price Index (CPI), and Asset Price Bubbles (BBL) through five spillover channels (geography, linguistics, politics, war, and economy). Our aim is to establish a systematic relationship between the conduction mechanism, means, economic indicators, and dollar externalities to examine liquidity spillover effects at varying distances in the global monetary space. We find that the spatial effects induced by the global circulation of the US dollar behave significantly differently in a single matrix space compared to in a multidimensional space. While the model verifies the existence of a positive correlation between the complexity of a single space and the spillover effect from a conduction mechanism perspective, the measure of the multidimensional matrix shows that the significance of the spillover effect weakens with an increase in abstraction level from a conduction means perspective. It suggests that spatial matrices of different dimensions reflect different economic realities. The former shows hierarchical multivariate details in independent matrices, while the variation in the level of abstraction of matrices of different dimensions in the latter enhances their interactivity and complexity.

Keywords: US dollar liquidity; spatial effects; monetary space; model identification; indirect spillover effects

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1. Introduction

The US dollar's liquidity is a topic of academic interest and gained renewed attention during the COVID-19 pandemic due to increased demand. The US dollar's liquidity gained renewed prominence as global demand for dollar-denominated safe assets surged amid market volatility (Hoek et al., 2022). This aligns with historical patterns observed during crises (S. J. Kim, 2009; Correa et al., 2016), where dollar liquidity shocks propagated through trade and financial channels. The US dollar plays a crucial role in the global money supply system due to its high level of security and rigid demand for international settlement, trade settlement, asset pricing, and official currency reserves in major economies worldwide. Using the US dollar as a financing currency can reduce borrowing costs, and

its high credibility and stability generally have positive implications for global financial and capital markets. Despite economic crises or recessions, the US dollar remains the first hedge target for investors, leading to increased dollar liquidity in global markets. However, there is also a consensus among academics regarding the negative effects of US dollar liquidity. Previous studies have demonstrated the dual role of US dollar liquidity in the context of globalization: while it facilitates global economic development through enhanced capital flows (S. J. Kim, 2009; Correa et al., 2016), its volatility has also exacerbated liquidity mismatches, particularly in emerging markets. For instance, Bekiros (2014) and Hwang (2014) identified abrupt liquidity depletion during Fed tightening cycles, while B. H. Kim et al. (2015) linked dollar surges to speculative excesses in Asian financial markets. Recent work by Hoek et al. (2022) further contextualizes these dynamics post-COVID-19, showing how dollar strength amplifies fiscal stress in economies with currency mismatches. Similarly, Bernoth and Herwartz (2021) quantify the destabilizing effects of dollar appreciation on sovereign risk, underscoring the systemic tensions noted in earlier crises. Several US dollar liquidity crises have occurred in the past few decades, such as the Latin American debt crisis in 1980, the Mexican peso crisis in 1994, the Asian financial crisis of 1997, and the subprime mortgage crisis of 2008. The causes of these crises were similar, with the Federal Reserve raising interest rates and the US dollar flowing back into the US domestic market. This has led to a large amount of research focusing on the spillover effects and patterns of US dollar liquidity.

The examination of US dollar liquidity has primarily focused on its direct effects and associated laws. Interest rates and exchange rates are generally regarded as the main channels for liquidity spillovers. However, in recent years, there has been increasing debate over the significance and directionality of these spillover effects. Over the longer term, numerous empirical studies have shown that changes in Fed policies can have significant negative spillover effects on the price levels, monetary policies, national income, and domestic production of third-party economies, primarily through the channels of interest rates and exchange rates. Aizenman et al. (2016) demonstrated their asymmetric impact on emerging market monetary autonomy, which was later refined by Keefe and Saha (2022) to include nonlinear effects during quantitative tightening. Druck et al. (2018) linked dollar appreciation to emerging market export contraction, while Hoek et al. (2022) recently highlighted the role of currency hedging in amplifying these spillovers. Emerging economies have been particularly affected by this phenomenon. In the aftermath of the subprime mortgage crisis, they often faced significant domestic inflationary pressure and currency appreciation when choosing to raise interest rates to offset these pressures (McKinnon, 2014). On the other hand, US dollar interest rate hikes pose risks and cause a contraction of world US dollar reserves and rapid outflow of capital from emerging economies (Gopinath, 2015; Kalemli-Özcan, 2019). Meanwhile, through the exchange rate channel, the valuation effects caused by fluctuations in the US dollar exchange rate can also have persistent spillover effects on emerging economies (Bernoth & Herwartz, 2021). According to recent research, these spillover effects have been particularly prominent after the COVID-19 pandemic (Hoek et al., 2022).

However, the traditional understanding of the US dollar's spillover effects has been questioned, and positive spillovers have been verified in some studies. Easy or contractionary dollar policies can generate positive spillovers to industry development, production costs, and price levels in emerging economies through exchange rates or interest rates (Xu et al., 2020; Tumala et al., 2021). In response to these different findings, the academic community is re-examining the spillover effects of the US dollar and finding complex and uncertain pathways. As a result, it is becoming increasingly difficult to understand the overall spillover law of US dollar liquidity, which is important to consider. Tillmann et al. (2019)

argue that US monetary policy does not follow a uniform pattern in spillover channels, which affects domestic stock returns, exchange rates, and bond yields of major economies differently. The scale and direction of spillover effects depend on the specific country's circumstances. Durdu et al. (2020) found that the impact and influence of US monetary policy on countries with limited trade connections or a small share of dollar-denominated bonds in a globally integrated economy is not very clear. Similarly, Dedola et al. (2017) found that the Federal Reserve's tightening policy led to a decrease in industrial production and real Gross Domestic Product (GDP) and an increase in unemployment rates in most countries, even for those without close economic and trade relations with the US. This further suggests that US quantitative easing policies, as well as specific transmission factors such as interest rates and exchange rates, are not the main variables causing changes in production and consumption prices in major economies (Bhattarai et al., 2020; Bhattarai et al., 2021).

The growing disagreement over spillover effects has affected the study of externalities, as researchers have focused mainly on major economies. However, with increasing global integration, the economic links between the US and other countries have become more complex. Even economies with no direct interaction with the US have extensive interactions with other economies closely tied to the US, including economic, political, cultural, and military interactions. As the US dollar is the legal currency for the United States' foreign exchanges, the existence of such indirect factors cannot be ignored. In other words, the level of US dollar liquidity not only affects the economic variables of countries that have direct economic activities with the US (direct effects) but also indirectly affects other economies that have no direct economic relations with the US (indirect effects). Indirect effects, unlike direct effects, refer to the influence of an explanatory variable in a "neighboring" region on the explained variable in the local region rather than the current region (LeSage & Pace, 2009). It is not difficult to understand that a monetary space essentially exists between the US and economies that receive US dollars directly or indirectly.

The traditional explanatory approach is mainly based on a "one-to-one" regression relationship, which mainly refers to the econometric form that directly connects the cause and effect of a single unit using the traditional regression form of the VAR equation without any relationship between adjacent independent variables. It assumes that a "one-dimensional" monetary space is formed between the US and the economic entities with which it has direct economic activity. This dimension first comes from "geographical" adjacency, which means that a change in an economic activity or economic variable (independent variable) of a spatial unit in a region not only directly affects the response variable (dependent variable) of a certain economic phenomenon in the local area but also affects the response variables of some economic phenomena in neighboring spatial units (Goodchild, 1992). However, when we think about this space based on indirect effects, the traditional "one-dimensional" setting cannot be applied to the multidimensional interactive relationship. In our study, we use a spatial econometric model with multiple spatial matrices to analyze spillover structures in different fields (dimensions). Unlike the "unidimensionality" of direct effects, this complex measurement method considers the behavior of adjacent units and their degree of association. In a multidimensional monetary space, independent variables are related not only to dependent variables in one dimension but also in other monetary spaces. We measure effects at different distances using spatial matrices, which is an important innovation and contribution of this study.

Although traditional studies primarily focus on the spillover effects transmitted through interest rates and exchange rates, research by Y. Kim et al. (2024) and Bianchi et al. (2021) reveals that the transmission mechanisms of dollar liquidity spillovers are more complex and encompass not only direct financial channels but also indirect effects arising from

bank behavior, capital flows, and exchange rate volatility. The conventional "one-to-one" regression approach, which assumes a unidimensional monetary space between the US and its direct economic counterparts based on geographical adjacency (Goodchild, 1992), fails to capture these intricate spillover pathways, especially amid increasing global economic integration and multidimensional interactions.

To address this limitation, our study employs a spatial econometric model with multiple spatial matrices to analyze spillover structures across different dimensions. Unlike the unidimensional framework that only considers direct effects between isolated units, our approach accounts for the behavior of adjacent units and their degrees of association in a multidimensional monetary space. Here, independent variables correlate not only with dependent variables within one dimension but also across other monetary spaces. By measuring effects at varying distances through spatial matrices, this methodology provides a comprehensive tool to disentangle complex spillover mechanisms, thus representing a significant theoretical and empirical advancement in the field.

The rest of this article is structured as follows: In Part II, the theoretical framework of monetary space is described. It explains the development of spatial econometrics, focusing on the transition from the traditional spatial concept dominated by geographic factors to the abstract spatial measurement method, and explains its relationship with monetary space. In Part III, empirical research will be conducted to quantitatively measure the abstract concept of the US dollar using the amount of US dollar bonds and to explore a series of empirical combinations, including the following: (1) empirical research using three spatial econometric models, SLX, SDM, and GNSM, based on model complexity; (2) exploration of five spill-over channels, including geography, language, and military, based on matrix abstraction level; (3) characterization of the target variables using three methods, GDP, Consumer Price Index (CPI), and Asset Price Bubbles (BBL), based on index construction and index risk. These empirical combinations are used to demonstrate the spill-over effects of the US dollar in a multidimensional space. Specifically, this study provides three research results: the construction and explanation of monetary space theory, spatial econometric analysis of the indirect effects of US dollar liquidity, and empirical research on the spill-over effects of the US dollar in a multidimensional monetary space. These three research results together constitute the main contributions and findings of this study. Part IV outlines the three perspectives of empirical research in this article: the relationship between general economic indicators, model identification, matrix construction, and the significance of the externalities of the US dollar. After emphasizing the interpretation of the special empirical results of positive spillovers, Part V concludes the article with a summary and inspiring thoughts.

2. The Theoretical Framework of Monetary Space

Spatial effect refers to the effect generated by the distribution and interaction of a phenomenon or variable in geographic space. When a phenomenon occurs in one region but also affects and spreads to adjacent regions, it is expressed as a phenomenon of spillover. Therefore, the spillover effect can be understood as a special type of spatial effect. When studying the spillover effects of US dollar liquidity, three aspects need to be considered.

First, the general economic level is the basis for studying spillover effects, which can be reflected by measuring indicators such as GDP, CPI, and BBL to reflect the economic conditions of a region, thereby reflecting the positive or negative nature and degree of spillover effects.

Secondly, the transmission mechanism of US dollar liquidity spillover effects needs to be clarified. The conduction mechanism includes factors such as geography, linguistics (culture), politics (system), war (conflict), and economy (trade). By studying the impact of

these mechanisms on various economies in space, we can better understand the rules of spillover effects.

Finally, it is necessary to clarify the conduction means. This study adopts three spatial econometric models, SLX, SDM, and GNSM, as the transmission means for studying the spillover effects of US dollar liquidity. Among them, the SLX model considers the interdependence between adjacent regions, controls spatial autocorrelation through spatial lag terms and avoids the problem of spatial autocorrelation that may occur in ordinary least squares regression (Halleck Vega & Elhorst, 2015; Elhorst & Halleck Vega, 2017). The SDM model adds spatial lag variables on the basis of the SLX model, considering the spatial dependence between adjacent regions and the degree of influence between adjacent regions. The GNSM introduces more spatial lag terms and spatial error terms on the basis of the SLM and SEM, making the model better able to capture spatial dependence and spatial heterogeneity.

Next, we focus on the transmission mechanism of the US dollar liquidity spillover effect in various economies through the construction of a monetary spatial system, which is also the main contribution and focus of this empirical study. In the field of international finance, monetary space refers to the circulation range and usage of a sovereign currency (exchange of cross-border goods, services, and capital, etc.), and its size is related to many factors such as the economic development, political stability, and financial infrastructure of the currency country (Leyshon & Thrift, 1997; Ingham, 2013; Cohen, 2018). For a long time, the interpretation and understanding of monetary space in academia often overlap with geographical factors, and it is believed to have a direct effect on capital flows (Williams, 2010; Narula & Verbeke, 2015). Sokol and Pataccini (2022) maintained that the spatial dimensions of monetary interventions are likely to gain greater relevance in tandem with central banks' enhanced power. This effect is often considered to occur in a static geographic space composed of positions and locations. "Static geographic space" emphasizes the objectivity of space (dependent on real geography) and includes the geographical distance between each location within the space (Cohen, 2018). This situation occurs because, for a considerable period, the use of sovereign currency coincides precisely with the political boundaries of each country/region, and each currency can only flow freely within its own sovereign scope.

Due to distance factors, geopolitical relationships, and the degree of interaction between regions, correlated currency economic fluctuations and asset price changes can occur between related countries. The physical distance between economies has become a critical factor in determining the intensity of financial connections and the stability of financial systems (Flandreau et al., 2009; Bieri, 2009). In the monetary space of the US dollar, the formation of economic regional distribution and financial networks based on geographical factors is a crucial prerequisite. The concentration of other countries/regions' economic regional distribution in the United States stimulates the increase in the proportion of US dollar transactions, leading neighboring countries to use the US dollar more and increase the trading volume of the US dollar in their respective foreign exchange markets (Eichengreen & Flandreau, 2008). At the same time, the intensity of subsequent effects caused by monetary shocks is also closely related to the distance between the economy and the United States (Maćkowiak, 2007; R. Martin, 2011).

The construction of geographic space is based on Tobler's first law of geography, which states that "Everything is related to everything else, but near things are more related than distant things" (Tobler, 1970). In the analysis, researchers often use Euclidean distance, which is the absolute distance between two points in multidimensional space, to measure the proximity of geographic entities and use adjacency matrices to represent whether two geographic entities are connected in space (Miller, 2000; Miller & Wentz, 2003; Miller, 2004).

Spatial econometrics uses distance as the core element of currency space, which has different definitions and connotations. In economics, distance can refer to the proximity of cooperative relationships, while in sociology, it can refer to the closeness of interpersonal relationships (Miller & Wentz, 2003). The flexible definition of distance used in spatial econometrics suggests that the academic community has moved beyond defining space solely at the geographical level and has given more nuanced meanings to the distance between two places beyond physical proximity. Furthermore, the understanding of space has evolved from being static to dynamic as scholars have constructed new spaces and extended new distances by borrowing the concept of geographical space. Space is no longer just an objective and static "container" used to describe physical positions but can also be constructed based on other non-geographical factors such as politics, economy, and culture in the process of social construction. The distance and position between geographical entities are also determined and measured by these factors. The essence of space has thus become an abstract relational effect generated by the interaction between objects, phenomena, and people (Lambach, 2022). Due to the three salient features widely believed to exist in currency space, namely, relationship dependence, hierarchical structure, and spatial asymmetry (Cohen, 2018), the required observation of the transmission path of the US dollar space can be directly introduced into the construction of currency space. Thus, we can reshape the location of economic entities to explore the robust regularities of the US dollar spillover effect. This reconceptualization reflects a significant shift in recent scholarship from static spatial assumptions to dynamic and relational understandings of space. Building on this shift, our study introduces the required observation of the transmission path of the US dollar space directly into the construction of a multidimensional currency space. By doing so, we aim to reshape the relative positions of economic entities beyond physical geography, enabling a more nuanced exploration of the regularities underlying dollar spillover effects across political, cultural, and economic dimensions.

Next, we will elaborate on the dimensions and implications of the currency space involved in this study based on several important branches of spatial concepts in academia.

2.1. Political (System) Subspace

In the study of international relations, political subspace is understood as a dynamic network that includes political elements (Starr, 2013; Rosenboim, 2019). Its characteristic is to determine the "distance" between countries through social, political, and economic factors, such as the political network relations among international organization members, the degree of mutual dependence of trade between economies, and the similarity of social culture (Russett, 1967). This space spans physical barriers, connecting non-adjacent countries in different geographical locations, thus breaking the static connections of countries limited by their geographical positions.

2.2. Linguistic (Culture) Subspace

The construction of cultural space utilizes the concepts of cultural symbol space, scope, and boundary and is a network that reflects cultural activities (Kostogriz, 2006). An organization's cultural network comprises elements such as its history, collective values, organizational structure, power distribution, management system, habits, rituals, symbols, and more. Members of the organization are drawn together by shared cultural beliefs and integrate other cultural elements to reach a consensus and form a unified cultural network. This network, in turn, shapes the behavior of members and gradually becomes the group's code of conduct, contributing to the organization's continuity. Additionally, members within the organization may form subgroups based on cultural differences, each with its own cultural network (Johnson, 1992; J. Martin, 1992; McDonald & Foster, 2013).

Globalization has enabled people of diverse cultural backgrounds to communicate and interact beyond boundaries. Regional languages represent cultural identity and are closely associated with ethnic countries and nations. Using language systems to reflect regional culture and politics indirectly has significant practical and developmental implications. In the global cultural network, language plays a crucial role in influencing social contacts. Languages with greater global influence occupy a central position in the network, connecting countries that speak different languages and facilitating the dissemination of information in that language. Consequently, the position of a language in the global language network reflects the diversity of international information available to its users, the speed at which they receive information, and their ability to disseminate it to other language users. Furthermore, the linguistic and cultural similarity between economies can be used to measure the cultural spatial distance between them, highlighting the impact of cultural migration (colonization) on the relationship between countries (Kostogriz & Tsolidis, 2008; Qian, 2012; Ronen et al., 2014).

2.3. Economic (Trade) Subspace

The "economic subspace" or "trade subspace" reflects the economic activities and trade transactions between countries or regions. Trade is not only an exchange of goods and services between different countries but also a communication channel describing the spread of economic dynamics across countries. In order to further understand this complex dynamic economic behavior, the academic community has placed the entire world economy in an interconnected international trade network. In such a World Trade Web, each country represents a node, and the spatial distribution of trade and economic activities among countries determines the pattern of trade among and within countries (Li et al., 2003; Rossi-Hansberg, 2005). Hierarchical trade networks display a core–edge structure, which is formed when countries with strong trade ties create trade modules or regional trade clusters. Core countries have numerous trading partners and strong trade relationships, whereas peripheral countries primarily trade with core countries. Economic development and industrial upgrading are led by core countries, while peripheral countries do not engage in frequent trade with each other. Additionally, countries that are geographically close with similar trade systems or development levels may form trade blocs, which can interact with each other to form higher-level blocs. Trade networks formed by larger trade blocs can help countries resist recessionary shocks and recover more quickly from recessions. (Fagiolo et al., 2010; He & Deem, 2010).

2.4. War (Conflict) Subspace

War (conflict) subspace is understood as a network of violent conflicts and wars that occur between multiple groups. Conflicts arise due to various reasons such as economic deprivation, ideological differences, racial hatred, or competition for natural resources, thus connecting two or more groups and forming different spatial network structures. The nature and intensity of the conflict are impacted by the interdependence between groups. A conflict between a central country or organization and neighboring countries or organizations will form a star-shaped core-periphery structure. A bipartite network structure involves two hostile alliances whose members view each other as enemies, but members within the alliance do not conflict because they share the same ideology. The frequency and intensity of conflicts are also affected by the geographical distribution of groups. Areas near ethnic boundaries with a large population in a multi-ethnic or multi-racial country are more likely to experience conflicts and suffer greater casualties. (Franke & Öztürk, 2015; Mueller et al., 2022).

Based on the above multidimensional analysis, this article constructs a multidimensional monetary space to reshape the traditional understanding of the international currency space and to reinterpret the spillover effect of the US dollar. This space includes the following: ① the traditional geographical subspace, which studies the spillover effect of the US dollar from a traditional one-dimensional spatial perspective and plays an important foundational role in the entire space. ② The political (institutional) subspace focuses on examining the Gini coefficient, as the political background often reflects the ideological distance between countries. ③ The language (cultural) subspace focuses on cultural and ethnic history, as similar cultures can often cross geographical boundaries. ④ The economic (trade) subspace considers the spillover effect of the US dollar from the perspective of two countries' trade relations. Countries with frequent economic and trade interactions may have more bilateral relationships. ⑤ The war (conflict) subspace measures spatial political relations through conflicts and wars between ethnic nations. Countries with similar social structures and governance systems often have similar spatial political relations, and their corresponding economic activities are also more closely and frequently connected. The monetary space formed by the merging of subspaces with different meanings is a more dynamic and comprehensive depiction of the monetary space relationship between countries and is, therefore, better able to reveal the rules of the economy as a whole.

This paper will calculate each economy separately in the above-mentioned subspaces for empirical operability. This paper draws on the calculation ideas of abstract vector spaces in linear algebra for each subspace, using some unified fields that reflect specific fields as the basis, thereby measuring the constructed subspaces. In each subspace, the empirical perspective of this paper is to explain and demonstrate from the perspective of the impact of the increase or decrease in US dollar-denominated bonds held by a country/region on the GDP, CPI, and BBL of neighboring countries.

3. Empirical Analysis

3.1. Empirical Background

3.1.1. General Economic Indicators: GDP, CPI, and BBL

In this study, three major general economic indicators are selected: GDP, which reflects the economy; CPI, which reflects inflation; and BBL, which responds to bubbles.

GDP is the core indicator of national economic accounting and an important indicator of a country or region's economic status and development. A significant increase in a country's GDP reflects a booming economy, an increase in national income, and an increase in spending power. In such a situation, the country's central bank will likely raise interest rates and tighten the money supply, and the country's good economic performance and rising interest rates will increase the attractiveness of the country's currency. Conversely, if a country's GDP growth is negative, it indicates that the economy is in recession and its spending power is reduced. The limitation is that GDP does not include the quality of the environment and the value of goods and services produced in households. Imagine that the government abolishes all environmental controls so that firms can produce goods and services without regard to the pollution they cause. In this case, GDP would increase, but welfare would likely decline. Given the above limitations or shortcomings of the GDP indicator in capturing welfare, the GDP variable is more robust, and it implies less economic risk.

CPI is a relative number reflecting the trend and degree of price changes in consumer goods and service items purchased by urban and rural residents in a certain period of time and is the result of a comprehensive summary calculation of the urban consumer price index and the rural consumer price index. The CPI is lagging data, but it is often an important reference indicator for market economic activities and government monetary policy. The influence of substitutes leads to higher prices of a certain product, and people

will naturally choose more substitutes, thus reducing the impact of price increases on the actual quality of life. Thus, CPI tends to actually overestimate the rise in price levels. Given this, the economic risks embedded in the CPI are slightly higher compared to GDP.

BBL is a statistical indicator designed to capture explosive asset price dynamics relative to underlying economic fundamentals. It is important to note that BBL is not a direct measure of the probability of an economic recession in the traditional sense; rather, it is a quantitative tool used to identify deviations of asset prices from their normal economic trajectory, thereby reflecting the potential risk of speculative bubbles in the market.

For the calculation of the BBL, the rolling window method is generally used to obtain the nonlinearities of the system. For example, in "Asset price bubbles and systemic risk", Brunnermeier et al. (2020) suggest that this parameter can be obtained by testing the right-tailed variant of the unit root of the ADF model. In this test, the original hypothesis is that there is no unit root, and the alternative hypothesis is that there is a mild BBL. In order to enhance our ability to capture the explosive process in price data, we refer to the approach of Nguyen and Waters (2022) for detecting stock price bubbles and adopting the BSADF (Backward Supremum ADF) measure. We use a rolling window approach to re-perform a right-tailed unit root test (an ADF variant) at each additional sample point. The maximum ADF statistic (MADF) across these expanding windows is then compared to a critical value. To address potential heteroskedasticity, we generate robust critical values using a wild bootstrap procedure, following the methodology of Phillips et al. (2015). Furthermore, we adopt the BSADF measure, which transforms the ADF test outcomes into continuously fractional values. This conversion enhances our ability to capture the degree of explosiveness in the price series, a method that has proven effective in detecting bubbles in rent and stock price data.

It is important to note that the BBL covariates need to be viewed dialectically. Positive return bubbles refer to certain assets whose prices exceed their fundamental value for some reason and are usually seen as a sign of a favorable economic environment. The existence of such bubbles is justified because market participants may overvalue certain assets or demand them more, which may lead to a shortage of market supply and higher prices. However, such bubbles may also prevent the market from clearing and may, with the passage of time, be perceived as a signal of risk in the market.

3.1.2. Conduction Mechanism: Spatial Matrix and Its Abstraction

A spatial matrix is used as a vehicle in this paper for the mathematical description of the monetary spatial transmission mechanism. A binary symmetric spatial weight matrix is usually defined to express the proximity of spatial individuals (e.g., countries, regions) at n locations. Since it has been recognized theoretically that there is no optimal spatial matrix, we cannot find a spatial matrix that fully and appropriately describes the spatial correlation structure of individuals. However, previous theories have given a principle for constructing spatial matrices, that is, all matrix constructors must satisfy the principle that "spatial correlation decreases with increasing 'distance'".

The above is also called the "first law of geography", and the most traditional spatial matrix guided by this principle is the spatial–geographic matrix, the simplest of which is called the proximity spatial matrix. This is a "binary spatial weight matrix" that uses X_{ij} to represent the proximity between countries/regions. Specifically, when there exists a border between country i and country j, the corresponding X_{ij} element takes the value of true ($X_{ij} = 1$); otherwise, it takes the value of false ($X_{ij} = 0$).

Since the definition of "distance" can be broad and includes, but is not limited to, geographic Euclidean distance or spherical distance, it can be the proximity of cooperative relationships in the economic sense or even the closeness of interpersonal relationships in

the sociological sense. This leads to expressing the concept of subspaces of the "monetary space" mentioned above, i.e., a geographically constructed matrix space can be used to deal with the empirical problem of the overflow of each abstract subspace of the "monetary space" mentioned above.

As shown in Table 1, the first level of abstraction is the extension of geographic distances to other distances, but we will also retain the interpretability of the data. For example, this paper uses the "cultural (linguistic) subspace": i.e., the distance between two countries is defined by the affinity of linguistic families between regions. Specifically, in order to scientifically measure spatial affinity, we traverse each country/region to sample independent languages and create an index by language family. As a result, the language vectors representing each country based on each language family can be obtained statistically. The degree of linguistic and cultural similarity between countries is then calculated by the cosine similarity between the vectors.

Table 1. Definition and composition method of subspaces of the currency space matrix.

Linguistic (Culture) Subspace	
input	Field Explanation
family_id	Language family number (lowest level of language classification)
legend	Language group number (top level linguistic classification)
countries	Name of country
process	
	1. Count the number of different language families within each country. 2. The minor language families are grouped together according to the legends label and incorporated into the highest level of classification to create a quantitative distribution of the languages spoken in a country according to the highest level of classification. 3. Calculate the linguistic distance between countries by means of vector cosines.
output	
matrix	34 × 4 language submatrix
Note:	
Data source: *Built-in database for the R package Glottospace (Norder et al., 2022)*	
Web link: *Index of /src/contrib/Archive/glottospace (accessed on 27 April 2024)*	
War (Conflict) Subspace	
input	Field Explanation
state_name	Name of country
left_censor	Left Delete
right_censor	Right Delete
defense	Number of defenses
neutrality	Number of neutrality
nonaggression	Number of non-violations
entente	Number of contractual truces
process	
	1. Create a vector of responses to the above response conflicts for each country according to the country labels 2. For each vector, the cosine distance is used to obtain the conflict distance between countries
output	
matrix	34 × 34 War Matrix
Note:	
Data source: *The Correlates of War Project, "Militarized Interstate Disputes (v5.0)"*	
Web Link: *https://www.correlatesofwar.org/data-sets/MIDs (accessed on 27 April 2024)*	

Table 1. *Cont.*

Political (System) Subspace	
input	Field Explanation
Voice and Accountability	"Voice and accountability" reflects the extent to which a country's citizens can participate in choosing their government, as well as freedom of speech, association, and media.
Political Stability and Absence of Violence/Terrorism	Political stability and absence of violence/terrorism measure people's perceptions of the likelihood of political instability and/or politically motivated violence (including terrorism).
Government Effectiveness	"Government effectiveness" measures public perceptions of the quality of public services, the quality of the civil service and its independence from political pressure, the quality of policy formulation and implementation, and the credibility of the government's commitment to those policies.
Regulatory Quality	The quality of regulation reflects the government's ability to develop and implement sound policies and regulations that allow and facilitate private sector development.
Rule of Law	The rule of law reflects the perception of the degree of trust in and compliance with the rules of society, particularly the quality of contract enforcement, property rights, police and courts, and the potential for crime and violence.
Control of Corruption	Controlling Corruption captures public perceptions of the extent to which public power is exercised for private gain, including small and large forms of corruption and the "capture "of the state by elites and private interests.
Country Name	Name of country
Notes	All of the above scores obeyed a normal distribution with a range of −2.5 to 2.5.
process	
	1. Create vectors for each country according to country labels that reflect the above politics 2. Calculated for each vector using the cosine distance to obtain the political distance between countries
output	
matrix	34 × 34 political matrix
Note:	
Data source: *World Bank's Global Governance Index (WGI) database*	
Web link: *https://info.Worldbank.org/governance/wgi*	
https://datatopics.worldbank.org/world-development-indicators/ (accessed on 27 April 2024)	
Economic (Trade) Subspace	
input	Field Explanation
Reporter	Country name (here is the trade A, B is China)
Export	Number of Export
Import	Number of Import
Re-Export	Re-export refers to the national trades from foreign imports of finished products, without processing and manufacturing and exported for sale abroad, which consist of two parts, namely, from the country's free trade zone or customs bonded warehouse re-export and nationalized goods re-export.
Re-Import	Re-importation refers to the trade process in which a domestic manufacturer or trader sells domestic goods abroad and imports them into the country unprocessed.
process	
	1 Create vectors for each country according to the country labels that reflect the above responses to economics and trade. 2 Calculate each vector using the cosine distance to obtain the trade distance between countries.
output	
matrix	34 × 34 Trade Matrix

Note: Data source: UN Comtrade Database; Web link: https://comtrade.un.org/data/ (accessed on 27 April 2024).

By measuring the cultural and spatial distance between countries through linguistic proximity, this space can better portray the relationship between countries due to cultural migration (e.g., colonial expansion); at the same time, through this method, the subspace data we obtain will retain a greater degree of interpretability.

Obviously, the dimensions of the "monetary space" are diverse, and there are obviously more dimensions than the linguistic (cultural) subspace that can be explored, such as political-military, cultural-technical, etc. Then, it is impossible to abstract each dimension in a specific sense, so it is necessary to design a general abstraction law so that it can be further generalized and process the abstraction of the data.

Drawing on the computational idea of abstract vector space in linear algebra, this paper summarizes a set of generalized "currency space" subspace construction methods as follows. The core is that the distance is measured by using some unified fields in the database of a specific field (e.g., war, trade) as a base, and the vector of countries obtained from this measurement is used as a measure of the generalized distance between countries. After obtaining a set of base fields each time, we use cosine similarity for the measure.

Therefore, as mentioned above, we have constructed a series of subspace series of "monetary space matrix" based on the above-unified matrix synthesis method with trade, conflict, war, and politics as the axes, as shown in Table 1.

The above four matrices, in short, a series of spatial matrices abstracted from geography, then language, and finally to politics, war, and trade matrices, can provide a comprehensive view of the spillover effects of the US dollar. Compared with the traditional static spatial matrices that portray economic relationships, the dynamic perspective of such matrices presents a new path of spatial matrix-based research on the spillover externalities of the US dollar.

3.1.3. Conduction Means: SLX, SDM, and GNSM

When discussing global economies, there is always some correlation between economies due to many aspects such as geographic location, trade relations, military relations, and so on, so they cannot simply be assumed to be independent of each other. In this case, the absence of the independence assumption causes the traditional OLS regression analysis to be inapplicable (LeSage & Pace, 2009). In this paper, spatial correlation among economies is considered as a key factor and a spatial econometric model is used to investigate the transmission means empirically.

This research approach has two major advantages for exploring the externality effect of dollar liquidity: 1. It takes into account the effect of spatial interdependence among economies and corrects the endogeneity bias that OLS regressions tend to produce. 2. The estimation of spatial matrix coefficients can reflect the degree of interaction of different macroeconomic indicators.

To improve the robustness, three spatial econometric models are adopted in this paper: SLX, SDM, and GNSM. All three models are built on the basis of OLS: $y = X\beta + \epsilon$.

Among them, the SLX model is primarily employed to examine the effects of explanatory variables X under spatial effects, making it suitable for scenarios where only spatial externality is considered. It is simple and easy to interpret, but it does not account for the spatial lag effect of the response variable. The SDM model addresses this limitation by incorporating not only the spatial effects of explanatory variables but also the spatial lag effects of the response variable. This makes it more flexible in capturing the spatial interdependence among dependent variables. The model is better suited to reflect the interactive influences between economies. The GNSM model extends the SDM framework by further incorporating spatial autocorrelation in the error term. This enhancement enables GNSM

to accommodate scenarios where spatial dependence exists in the error structure, thereby providing a more robust approach for analyzing complex spatial data configurations.

$$SLX : y = X\beta + WX\gamma + \epsilon \tag{1}$$

$$SDM : y = \rho Wy + X\beta + WX\gamma + \epsilon \tag{2}$$

$$GNSM : y = \rho Wy + X\beta + WX\gamma + \mu \tag{3}$$

$$\mu = \lambda W\mu + \epsilon \tag{4}$$

where ρ is the spatial autoregressive coefficient; λ is the spatial autocorrelation coefficient.

The adoption of these models enables a more comprehensive understanding of the transmission mechanisms underlying US dollar liquidity spillovers across different economies. By comparing results derived from these model specifications, we ensure the robustness of our findings across methodological approaches, thereby mitigating potential biases arising from structural incompatibilities between model assumptions and data characteristics.

3.2. Data and Empirical Results

3.2.1. Data Description

In this paper, US dollar-denominated bonds (USDL) are used as the core variable to study the spatial effect of US dollar currency liquidity. The data sources are all from the EIU Country Data database (Economist Intelligence Unit). In this paper, annual data (2008–2013) of the post-subprime mortgage crisis dollar-denominated bonds are used, and the exchange rate against the US in that year is used uniformly for conversion. In the spatial dimension, we use 34 countries/regions of major global economies as the empirical sample, which are "Argentina", "Austria", "Australia", "Belgium", "Brazil", "Canada", "Switzerland", "China", "Czech Republic", "Germany", "Denmark", "Spain", "Finland", "France", "the United Kingdom", "Hong Kong SAR, China", "Indonesia", "Ireland", "India", "Italy", "Japan", "Korea", "Luxembourg", "Mexico", "Malaysia", "Netherlands", "Norway", "New Zealand", "Peru", "Philippines", "Poland", "Portugal", "Romania (Harmonized)", "Russian Federation", "Sweden", "Singapore", and "Thailand".

The 34 countries and regions chosen for this study represent a mix of global economies, including developed countries like the United States, Germany, France, and the United Kingdom, as well as emerging markets such as China, India, and Brazil. This diverse selection allows for a thorough analysis of how US dollar liquidity spillovers affect different types of economies. These countries were picked based on their economic size and their importance in global trade, capital markets, and financial systems. They play key roles in international finance and are heavily involved in dollar-denominated financial markets, especially after the 2008 global financial crisis.

Core explanatory variables:

In this paper, nominal GDP, CPI, and BBL are considered as three dimensions of macro indicators measuring major global economies and logarithmically treated as response variables of the model to characterize the macro effects of dollar liquidity on the economies, with the three variables measuring financial risk in a stepwise manner. The indicators here mainly respond to the direct effect of the dollar spillover.

For the indirect effect, we consider WX of the left multiplicative spatial weighting matrix W as a spatially lagged one-period factor and use the variable as a carrier for the indirect effect measure.

To investigate the spatial effect of dollar-denominated bonds, we focus on both the direct and indirect effects, i.e., the regression coefficients of "nominal log" and "spatially lagged one-period dollar-denominated bonds" as described above.

The detailed model and explanation of variables are shown in Table 2:

Table 2. (**a**) BBL model. (**b**) GDP/CPI model.

(**a**)	
Variable Name	**Field Explanation**
USDL	US dollar-denominated bonds: A stronger dollar can depreciate other countries' currencies in relative terms, raising foreign exchange market pressures on emerging market currencies. Since they cannot borrow in their own currencies, a stronger dollar would affect their access to short-term borrowing, thus widening their foreign exchange gap. At the same time, as capital leaves emerging markets, dollar creditors are likely to be reluctant to want to lend to borrowers with weaker currencies. Sudden foreign exchange outflows from emerging markets mean higher default risks, stalled investment and development projects, and further complications for immediate interest repayment.
ENDR	Exchange rate against the US: The exchange rate of a country's currency against the US, an increase in that value, implies a depreciation of the national currency against the US dollar, a decrease in that value. In international trade using the invoice system, an appreciation of the dollar implies an implicit depreciation of the bilateral dollar exchange rate of other countries. On the one hand, this does not reduce the volume of export trade to the dominant economy denominated in dollars, but it increases the cost of imports in non-dollar currencies for both the dominant and non-dominant economies, so exports from all non-dominant economies will contract. On the other hand, the cost of non-dominant imports denominated in domestic currency will rise while the cost of imports for the dominant economy falls. Thus, for the non-dominant economies, an appreciation against the US exchange rate increases inflation by reducing the volume of their exports, thereby reducing economic growth. In addition, an appreciation against the US exchange rate implies capital flight from the non-dominant country. The risk of inflation due to lower export volumes can accelerate financial asset outflows by making investors averse to financial assets denominated in the currencies of non-dominant countries. However, a weaker dollar does not necessarily increase capital from non-dominant countries, as other factors, such as politics in non-dominant countries, may result in higher transaction costs. The exchange rate against the US, expressed as the daily closing price of each country against the US dollar, is used as a control variable to keep asset price bubbles unaffected by changes in the exchange rate against the US
EXPD	Imports: The current value of import trade of each country, measured in billions of dollars, is the control variable of the model. Changes in the exchange rate due to changes in the import value of each country can affect asset price bubbles, and controlling for the constant import value of each country can avoid biased and inconsistent estimation results due to omitted variables.

Table 2. *Cont.*

(b)	
Variable Name	**Field Explanation**
USDL	US dollar-denominated bonds: same questions and explanations as above
FRES	Foreign exchange reserve amount: same question and explanation as above
LRAT	Benchmark interest rate: the benchmark interest rate for each country is expressed as a unit percentage and is taken as the nominal interest rate value, which is obtained from the estimated conversion for countries without benchmark interest rates and is used as a control variable in the model.
PEXP	Imports to GDP ratio: the ratio of countries 'current import trade to countries' current nominal GDP, in percent, as a control variable.

3.2.2. Hypotheses

Hypothesis 1. *Other things being equal, the larger the indicator's measure of risk, the more significant the dollar externality.*

As the metric moves from GDP to CPI to the hyperinflation index BBL, the more risk-sensitive the metric is, the more significant the dollar externality is.

Hypothesis 2. *Other things being equal, the higher the spatial identification of the model, the more significant the dollar externality.*

When the metric model goes from general regression to spatial regression with the introduction of exogeneity and finally to spatial regression with the introduction of endogeneity and exogeneity, the following occurs: the more complex the model, the more significant the dollar externality.

Hypothesis 3. *Other things being equal, the more abstract the currency subspace, the more significant the dollar externality.*

As the metric matrix moves from a geographic matrix to a linguistic matrix with special meanings introduced and finally to a political matrix and a business matrix based on an abstract vector space, the following occurs: the more abstract the matrix, the more significant the dollar externality.

3.2.3. Econometric Approach

To better explore the impact of spillovers on economic risk variables, we model spatial econometric models based on three types of indicators, GDP, CPI, and BBL, and focus on the estimation of regression coefficients on expected assumptions. To explore the dynamics of monetary space, we further build political (institutional) subspace, war (conflict) subspace, and economic (trade) subspace in addition to the traditional geographic space. For the spatial measures themselves, in order to comprehensively explore various spillover effects, we conduct a three-level iterative model of SLX/SDM/GNSM and make policy implications for the related spillovers.

3.2.4. Empirical Results

To test the above statistical hypotheses, we focus on the results of the regressions of the "log of dollar-denominated bonds" and the "log of spatially lagged one-period dollar-denominated bonds" in each currency subspace of the above nested spatial econometric model since the former reflects the direct effect of the dollar spillover, while the latter reflects the indirect effect of the dollar spillover. Specifically, the estimates corresponding to the log (USDL) and Wlog (USDL) variables below and their corresponding significance: the positive and negative values of the regression coefficients here characterize the positive and negative impact of the dollar spillover there, while the significance characterizes the degree of reliability of the positive and negative shape of the spillover here. For example, for a GDP model, we say that a positive log (USDL) and negative Wlog (USDL) is significant in the case of a positive direct spillover effect of the dollar on GDP and a negative indirect spillover effect. The *p*-values corresponding to the regression coefficients indicate significance. In this paper, the regression coefficients are said to be significant when they obtain '*', i.e., $p < 0.1$, and insignificant when the opposite is true.

Thus, we sequentially conducted regression tests on 45 regression equations represented by five major subspaces, three levels of nesting (SLX/SDM/GNSM), and three forms of economic measures (SLX/SDM/GNSM). The specific test results are shown in Table 3, and a large table of detailed parameters is shown in Appendix A Table A1.

Table 3. Combination of test results of the spatial measures.

	Trade Matrix			War Matrix		
	CPI	GDP	BBL	CPI	CDP	BBL
SLX	−*	+	−	−	−	−*
SDM	−*	+	−*	−*	−	−*
GNSM	−*	+*	−*	−*	+	+
	Political Matrix			Language Matrix		
	CPI	GDP	BBL	CPI	CDP	BBL
SLX	−*	+*	+*	−*	−*	−
SDM	−*	+*	+*	−*	−*	−*
GNSM	−*	+*	+*	−*	−*	−
	Geographic Matrix					
	CPI		GDP		BBL	
SLX	−*		−*		−*	
SDM	+		−*		−*	
GNSM	+		−*		−*	

Note: −* indicates a significant negative effect spillover, +* indicates a significant positive effect spillover; − indicates the presence of negative effect spillover but not significant, + indicates the presence of positive effect spillover but not significant.

As shown in Table 3, the nine-pane grid based on the results of 45 regression equations for the five major subspaces, three levels of nesting (SLX/SDM/GNSM), and three forms of economic measures (SLX/SDM/GNSM) summarized above shows that dollar externalities can be tapped in all subspaces of the above monetary space provided that the assumptions are satisfied.

3.2.5. Empirical Conclusions

The regression coefficient of the explanatory variable log (USDL) characterizes the direct spillover effect of the US dollar, while the first-order lagged geographical explanatory variable Wlog (USDL) represents the indirect spillover effect of the US dollar. Therefore, if the values of the above regression coefficients appear significant, this indicates that the original hypothesis of the econometric equation (no spillover) is rejected.

Table 4 summarizes the direct and indirect spillover nature of the dollar in the above currency space in the form of a heat map. It can be seen that out of 45 regression equations with a total of 90 regression coefficients "direct + indirect", 66.7% (60) of the cases show significant spillover, and 95.6% (86) of the cases show spillover. This indicates that in the vast majority of cases, there is a significant spillover effect of the US dollar.

Table 4. Heat map of spillover effects.

Direct Effect									
Sub	GDP			CPI			BBL		
Space	SLX	SDM	GNSM	SLX	SDM	GNSM	SLX	SDM	GNSM
Geo	+*	+*	+*	−*	−*	−*	−	−	−
Tra	+*	+*	+*	−			−		
War	+*	+*	+*	−*	−*	−*	−	−	+
Lan	+*	+*	+*	−*	−*	−*	−	−	−
Pol	−*	−*	−*	−*	−*	−*	−	−	−
Direct Effect									
Sub	GDP			CPI			BBL		
Space	SLX	SDM	GNSM	SLX	SDM	GNSM	SLX	SDM	GNSM
Geo	−*	−*	−*	+*	+	+*	−	−*	−*
Tra	+	+	+*	+*	+*	+*	+	+*	+*
War	−	−	+	+	+*	+*	+*	+*	−
Lan	−*	−*	−*	−*	−*	−*	+*	+*	+*
Pol	+*	+*	+*	+*	+*	+*	−	−	−*

Note: −*: Negative effect spillover is significant; −: Negative effect spillover exists but is not significant; +: Positive effect spillover is present but not significant; +*: Positive effect spillover is significant.

In the cross-sectional comparison, the direct effect is most significant in the CPI and GDP models and less significant for the BBL model, while the indirect effect is more prominent in the CPI, GDP, and BBL models. In the longitudinal comparison, a significant direct positive spillover effect appears in the GDP model, but the indirect effect is mostly negative; in the CPI model, the direct effect is expressed as a significant negative spillover, while in the indirect effect, it is positive; in the BBL model, the direct effect is negative, but not very significant, while the indirect effect is positive and very significant.

Now, go back to the three major assumptions in Section 3.2.2 and analyze them, as shown in Table 5.

Table 5. Three major assumptions.

Hypothesis	**Conclusion**
Hypothesis 1: Risk sensitivity	The more sensitive the indicator is to risk, the larger the absolute value of the coefficient of the regression equation, i.e., the more significant the dollar externality
Hypothesis 2: Model Complexity	The higher the spatial identification of the model, the larger the absolute value of the coefficient of the regression equation, i.e., the more significant the dollar externality
Hypothesis 3: Spatial matrix composition	The more abstract the matrix, the larger the absolute value of the coefficient of the regression equation and the more significant the dollar externality

Since this paper involves two effects of triple variables, for better validation of the effect, two significance ratios are defined here to respond to the tie of the equation being

significant in different cases, where the significance ratio 1 is defined as the weighted value of the significant * counts of the current indicator (example: regression coefficients showing '*' count 1, '**' count 2, and '***' count 3 are then summed) divided by the total sum of * that can be obtained in the ideal regression case. For example, if there are five variables, the ideal * count is 15, and there is 1 *** with one *, the significance ratio 1 of this equation is 4/15. Since the *p*-values need to be 0.01, 0.001, and 0.0001 to obtain '*', '**', and '***', respectively, we assume without proof that significance ratio 1 should be a more stringent indicator that reflects the average significance of the current indicator in the current effect. The significance ratio 2 is the weighted average of the direct effect significance ratio 1 and the indirect effect significance ratio 1 of the current indicator, which reflects the combined significance of the current indicator.

Hypothesis 1 focuses on risk variables. As shown in Table 6, the significance ratio 2 decreases as the indicator becomes more sensitive to risk in the same comparison environment, from GDP to CPI to super inflation index BBL. As the significant ratio 2 decreases from 72% → 54% → 17%, the dollar spillover effect it captures becomes progressively weaker, i.e., the dollar externality becomes less significant. Meanwhile, both direct and indirect effects also reflect this trend. However, it is noteworthy that the direct effect drops steeply (95% → 0%), while the indirect effect decreases slowly (48% → 35%).

Table 6. Comparison of significant ratios of risk indicators.

Index	Effect	***	**	*	Base	Ratio 1
GDP	Direct	13	2	0	15	95.56%
	Indirect	6	0	4	15	48.89%
CPI	Direct	8	1	3	15	64.44%
	Indirect	3	1	9	15	44.44%
BBL	Direct	0	0	0	15	0.00%
	Indirect	3	0	7	15	35.56%

Hypothesis 1 is rejected since it is argued in hypothesis 1 that the dollar externality should be significant at this point, i.e., the more stable the indicator is with respect to risk, the more significant the dollar externality is.

Hypothesis 2 focuses on the model spatial recognition degree. As shown in Table 7, in the same comparison setting, the corresponding significance ratio 2 increases gradually as the spatial identification degree increases from the general regression SLX to the spatial regression SDM with the introduction of exogeneity and finally to the spatial regression GNSM with the coexistence of endogeneity and exogeneity, i.e., the spatial identification degree increases. As the significance ratio 2 increases from 43% → 48% → 52%, the dollar spillover effect it obtains gradually varies, i.e., the more significant the dollar externality is. Here, the indirect effect also reflects this trend, with a significant increase in its value (35% → 51%), while the direct effect does not change much (around 53%).

Table 7. Comparison of significant ratio of spatial recognition degree.

Index	Effect	***	**	*	Base	Ratio 1	Ratio 2
SLX	Direct	6	2	1	15	51.11%	43.33%
	Indirect	3	1	5	15	35.56%	
SDM	Direct	8	0	1	15	55.56%	48.89%
	Indirect	4	0	7	15	42.22%	
GNSM	Direct	7	1	1	15	53.33%	52.22%
	Indirect	5	0	8	15	51.11%	

This is consistent with the hypothesis in Hypothesis 2, so Hypothesis 2 is accepted, i.e., the degree of spatial identification of the model increases, i.e., the more significant the dollar externality is.

Hypothesis 3 focuses on the monetary space itself. In the same comparison setting, when the metric matrix is introduced from the traditional subspace to the linguistic subspace with concrete meanings, and finally to the purely abstract political subspace, trade subspace, etc., as shown in Table 8, its corresponding significant ratio 2 gradually decreases as the subspace constructed becomes more abstract. Among them, the significant ratio 2 of geographic and linguistic subspaces is 58%, while the significant ratio 2 of the remaining three decreases to about 44%, and the dollar spillover effect obtained by each subspace variety produces a weakening compared with the concrete matrix, i.e., the less significant the dollar externality is. However, it is worth noting that the direct and indirect effects of different subspaces fluctuate more, but their arithmetic mean significant ratio 2 still reflects a more stable combined effect.

Table 8. Comparison of significant ratio of spatial recognition degree.

Index	Effect	***	**	*	Base	Ratio 1	Ratio 2
Geography	Direct Indirect	6 3	0 0	0 4	9 9	66.67% 48.15%	57.41%
Language	Direct Indirect	5 3	1 0	0 6	9 9	62.96% 55.56%	59.26%
Politics	Direct Indirect	3 3	0 0	3 4	9 9	44.44% 48.15%	46.30%
Conflict	Direct Indirect	6 1	0 0	0 3	9 9	66.67% 22.22%	44.44%
Trade	Direct Indirect	1 2	2 1	0 3	9 9	25.93% 40.74%	33.33%

Hypothesis 3 is rejected since it is argued that the dollar externality should be significant at this point in hypothesis 3.

Since the negative spillover cases have been discussed in detail in the literature and theory-building stage, we will only discuss them here for the positive spillover as well as the insignificant spillover cases. The specific cases are shown in Table 9.

Table 9. Table of positive spillover and spillover non-significant cases.

Case1	Possible reasons
Result Significant positive direct spillover effect on GDP	① The positive effect of lower trade costs between neighboring countries-appreciation of dollar-denominated bonds leads to lower import costs, saving foreign exchange, and increasing domestic output.
Details This occurs in 12 of the 15 equations involving direct effects of GDP, covering all forms of spatial equations in the four major subspaces of geography, trade, and language of war (SLX, SDM, GNSM).	② Increased trade between neighboring countries can improve tariff preferences, customer quotas, and transportation costs, which in turn can increase a country's GDP; in addition, reduced import costs in dollar-dominated trade areas can significantly reduce raw material and energy costs, thus promoting circular domestic economic output.

Table 9. *Cont.*

Case2	Possible reasons
Result Significant positive direct spillover effect on CPI	① Appreciation of dollar-denominated bonds makes other countries' currencies implicitly depreciate. ② Higher dollar-denominated import costs for countries using non-dollar currencies lead to export contraction. The appreciation of dollar-denominated bonds will lead to the relative depreciation of other countries' currencies, which will increase the cost of imports, thus pushing up the consumer price level and causing the CPI to rise; at the same time, the increase in the cost of dollar-denominated imports from countries that are mainly processing
Details This occurs in 10 of the 15 equations involving the indirect effects of CPI, covering almost all forms of spatial equations in the four major subspaces of geography, trade, war, and politics (SLX\SDMGNSM).	③The appreciation of dollar-denominated bonds will leadto the relative depreciation of other countries' currencies.which will increase the cost of imports, thus pushing up theconsumer price level and causing the CPl to rise, at thesame time, the increase in the cost of dollar-denominatedimports from countries that are mainly processing materials and using non-dollar currencies will cause their exports to contract, thus pushing up their domestic price levels; finally, the decrease in the cost of imports from countries that use the dollar as their main currency will lead to economic growth due to the decrease in the cost of imports from dollar-dominated trading areas, which will stimulate the price level to rise.
Case3	Possible reasons
Result Direct effects and indirect spillover effects are not significant	① The impact of US dollar-denominated bonds on a country's GDP takes a long transmission path, and there is no way to consider the specifics. ② Appreciation of dollar-denominated bonds leads to capital flight from non-dollar major trading area countries but is panicky, unpredictable, and difficult to quantify.
Details Out of a total of 45 equations (90 coefficients), 26 insignificant traits emerged; in particular, the direct effect of the BBL model was insignificant for almost all of its coefficients, although they responded to spillover effects in the same direction	③ The impact of US dollar-denominated bonds on a country's GDP needs to pass through a long transmission path, and this process is full of uncertainties, so it is difficult to consider the specific situation; while the appreciation of US dollar-denominated bonds may lead to capital outflows from non-US dollar major trading area countries, but the validity and empirical evidence are relatively weak due to its panic and unpredictability; in addition, the investment environment of non-US dollar major trading area countries is affected by political and war factors, and it is difficult to measure accurately, so CPI and other covariates are not easy to estimate significantly.

4. Research Findings and Policy Recommendations

As a major global reserve and transaction currency, the US dollar's liquidity is crucial for the stability and growth of the international economic and financial system. However, as global economic integration deepens and the Federal Reserve continues to raise interest rates, the negative spillover effects of excess US dollar liquidity have become increasingly significant. Empirical evidence shows that the level of dollar liquidity not only affects countries with direct economic relations with the dollar but also has indirect effects on other economies. Unlike direct effects, indirect effects imply that changes in one unit's outcome are correlated with the behavior of all neighboring units. Therefore, measuring the indirect effect of dollar liquidity requires deconstructing and redefining the traditional monetary space. In this paper, we construct a three-layer spatial econometric iterative model of SLX, SDM, and GNSM, along with multiple spatial matrices of language (culture), politics (system), war (conflict), and economy (trade), in addition to traditional geographic space. We focus on indicator construction and use GDP, CPI, and BBL as measures of target variables, attempting to create a more systematic and spatial model compatible with the current complex monetary relationship. We use 34 major global economies as empirical samples to measure the effects under different distances in the multidimensional monetary space, which complements the limitations of the existing discussion of spillover effects to some extent. The specific findings are as follows:

First, we observe that the dollar triggers significant indirect spillovers at different regional economic levels, observing respectively a decline in the level of output (GDP), an increase in the level of inflation (CPI), and an increase in the risk of bubbles (BBL), all of which may be harmful to a country's economic stability. Specifically, 8 out of 15 regressions on GDP demonstrate a decline in the level of output; 12 out of 15 regressions on CPI demonstrate an increase in the level of inflation; and 8 out of 15 regressions on BBL demonstrate an increase in the risk of bubbles.

In the empirical process, as the model moves from general regression to spatial econometric regression, gradually increasing the means of identification of spatial measures, we can see the nonlinear effects that arise when several factors such as language, culture, and political relations are combined (see Table 8, with a significant ratio of 257.41% relative to the geographical matrix, such as 59.26% for language and culture and 46.30% for political relations the same for the data of other matrices, whose results do not reflect linear effects), interaction effects (see Table 7, the significant ratio 1 corresponding to the direct solution interaction effect oscillates around 53%, while the significant ratio 1 corresponding to the indirect interaction effect increases significantly) and other complex multivariate effects are identified. The above findings, while demonstrating the complexity of the dollar spillover effect, also enhance the accuracy of the measure of this effect.

Finally, compared to the traditional static spatial economic relationships, based on the perspective of matrix dynamics, we observe that the degree of abstraction of the spatial matrix meaning is inversely proportional to the significance of the effect, other things being equal. The reason for this is that as the degree of matrix abstraction increases, the detailed information in the original data may be blurred or lost, resulting in a large amount of information being extracted from the macro part, and the identification of the details of the spillover effect becomes more difficult, which is reflected in the data as a less significant externality.

The above findings indicate that the indirect effects triggered by the global circulation of the US dollar exhibit significant differences in a single matrix space compared to a multidimensional space. While the model confirms that the complexity of a single space positively correlates with the spillover effect, the measure of the multidimensional matrix shows the opposite trend, as the spillover effect's significance weakens with increasing

abstraction. These differences prompt further reflection. Indeed, the individual spatial matrix and the multidimensional spatial matrix reflect different economic realities. The former provides more hierarchical details of multivariate variables in an independent single matrix. The latter, however, focuses more on the discussion of different factors and correlations in the system. The change in the level of abstraction means that the variable relationships between different matrices may be more ambiguous and intersecting, and the interaction and complexity between different dimensional matrices are no longer simple linear relationships, making it challenging to identify variable details. This leads to entirely different empirical results than those of a single matrix. Addressing the above limitations requires the academic community to further explore and clarify the interactions between different matrices.

The practical implications of the above findings have significant implications for the monetary functions of major economies and the global financial and monetary markets. The results suggest that there are widespread indirect spillover effects that reflect the complexity of the dollar transmission and mechanism of action. This reveals a decision dilemma that has prevailed among private and official investors, including central banks, in recent years. To address this, it is crucial to have more comprehensive cooperation among the countries concerned in multiple dimensions of monetary space. Studies have shown that the risks and losses of major economies in the dollar space are widespread across multiple dimensions, including trade. Therefore, it is necessary to carry out in-depth bilateral and multilateral cooperation among economies in political, military, and cultural fields and take more comprehensive and coordinated policy measures to establish long-term effective cooperation mechanisms in different fields. This not only effectively copes with the risks and adjustments of spillover effects in the dollar space but also gives new connotations to traditional diplomatic objectives, promoting the overall development and deepening of relations among countries. Moreover, this study further validates the necessity and urgency of a long-driven international agenda—the diversification of the global monetary system. A diversification process targeting the expansion of the functions of key currencies other than the US dollar, including the euro, the yen, and the renminbi, can promote the participation of more economies in the international monetary system and reduce the global risks associated with the economic instability of a single country. It can also help alleviate the trade frictions and imbalances caused by the current distortions in global monetary policy. Therefore, while promoting multi-dimensional cooperation, major economies should actively promote the diversification of the monetary system and the establishment of an international monetary competition mechanism to reduce dependence on the US dollar and reduce the risk of externalities in the monetary space.

Finally, as mentioned above, to address the limitations in the multidimensional matrix model, the authors will further reflect on the interactive effects among different matrices and the possible cross-sectional, nonlinear, and asymmetric effects arising from their interactions in subsequent studies to further validate and enrich the findings of the matrix model to better capture and explain the complex social and economic phenomena in the real world.

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Appendix A

Table A1. Detailed parameters.

Trade Subspace	GDP			CPI			BBL		
	(1) SLX	(2) SDM	(3) GNSM	(1) SLX	(2) SDM	(3) GNSM	(1) SLX	(2) SDM	(3) GNSM
Explanatory variables									
log_USDL	0.189 **	0.008 ***	0.014 **	−0.008	0.000	0.000	−0.057	0.000	0.000
	(0.002)	(0.001)	(0.001)	(0.348)	(0.536)	(0.536)	(0.533)	(0.910)	(0.943)
Wlog (X)	165.2	6.730	25.27 *	71.65 **	9.390 **	9.391 ***	11.81	0.201 *	0.208 *
	(0.359)	(0.372)	(0.061)	(0.002)	(0.000)	(0.000)	(0.258)	(0.034)	(0.038)
Control variable									
log (ENDR)							0.015	0.000	0.000
							(0.667)	(0.160)	(0.175)
log (EXPD)							0.280 *	0.003 **	0.003 **
							(0.024)	(0.007)	(0.007)
log (LCPI)							0.229 **	0.003 ***	0.003 ***
							(0.009)	(0.000)	(0.000)
label11							−0.041	−0.002	−0.002
							(0.968)	(0.854)	(0.860)
label12							0.096	−0.001	−0.001
							(0.942)	(0.908)	(0.916)
log (USDL): label 11							0.004	0.000	0.000
							(0.961)	(0.850)	(0.856)
log (USDL): label 12							−0.015	0.000	0.000
							(0.899)	(0.969)	(0.976)
log (FRES)	0.167 *	0.009 ***	0.017 ***				−0.067	−0.001 *	−0.001 *
	(0.015)	(0.001)	(0.001)				(0.258)	(0.066)	(0.071)
lag_log_FRES	76.53	6.674	1.871						
	(0.550)	(0.214)	(0.843)						
LRAT	0.004	−0.001	0.000	0.003 *	0.000 **	0.000 **			
	(0.865)	(0.561)	(0.871)	(0.046)	(0.007)	(0.007)			
lagLRAT	5.744	0.857	0.018	−34.88 ***	−2.541 ***	−2.541 ***			
	(0.736)	(0.230)	(0.989)	(0.000)	(0.000)	(0.000)			
LRAT2	0.000	0.000	0.000						
	(0.487)	(0.858)	(0.819)						
PEXP	−0.0035 **	−0.002 ***	−0.004 ***	0.004 *	0.000	0.000			
	(0.000)	(0.000)	(0.000)	(0.050)	(0.953)	(0.954)			
lagPEXP	−38.31 *	−1.587 *	−3.475 **	−10.18 *	−1.005 **	−1.005 **			
	(0.022)	(0.023)	(0.003)	(0.012)	(0.002)	(0.002)			

Table A1. *Cont.*

Political Subspace	GDP			CPI			BBL		
	(1) SLX	(2) SDM	(3) GNSM	(1) SLX	(2) SDM	(3) GNSM	(1) SLX	(2) SDM	(3) GNSM
Explanatory variables									
log_USDL	−2.698 ***	−2.980 ***	−2.877 ***	−0.145 *	−0.144 *	−0.140 *	−0.002	−0.039	−0.030
	(0.000)	(0.000)	(0.000)	(0.035)	(0.027)	(0.031)	(0.984)	(0.817)	(0.872)
Wlog (X)	0.031 ***	0.034 ***	0.033 ***	0.001 *	0.001 *	0.001 *	−0.001	−0.001	−0.002 *
	(0.000)	(0.000)	(0.000)	(0.055)	(0.045)	(0.055)	(0.057)	(0.104)	(0.058)
Control variable									
log (ENDR)							0.003	0.028	0.024
							(0.941)	(0.656)	(0.729)
log (EXPD)							0.203 *	0.379	0.362 *
							(0.066)	(0.044)	(0.087)
log (LCPI)							0.138	0.212	0.175
							(0.115)	(0.156)	(0.2925)
label11							0.043	0.036	0.067
							(0.966)	(0.983)	(0.972)
label12							0.271	0.458	0.538
							(0.836)	(0.838)	(0.829)
log (USDL): label 11							−0.004	−0.001	−0.004
							(0.969)	(0.994)	(0.980)
log (USDL): label 12							−0.029	−0.049	−0.056
							(0.805)	(0.890)	(0.804)
log (FRES)	2.979 ***	3.376 ***	3.528 ***				−0.015	−0.061 *	−0.047 *
	(0.000)	(0.000)	(0.000)				(0.795)	(0.529)	(0.667)
Conflict Subspace	GDP			CPI			BBL		
	(1) SLX	(2) SDM	(3) GNSM	(1) SLX	(2) SDM	(3) GNSM	(1) SLX	(2) SDM	(3) GNSM
Explanatory variables									
log_USDL	−0.491 ***	−0.498 ***	−0.521 ***	−0.031 *	−0.028 ***	−0.026 ***	−0.104	−0.106	0.092
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.239)	(0.212)	(0.206)
Wlog (X)	−0.019	−0.01	0.133	0.017	0.018 *	0.018 ***	0.004 *	0.004 *	−0.001
	(0.692)	(0.818)	(0.104)	(0.124)	(0.073)	(0.000)	(0.034)	(0.025)	(0.775)
Control variable									
log (ENDR)							0.051	0.053	−0.091 **
							(0.197)	(0.161)	(0.006)
log (EXPD)							0.268 *	0.269 *	−0.104 *
							(0.008)	(0.013)	(0.096)
log (LCPI)							0.211 **	0.231 **	0.006
							(0.008)	(0.004)	(0.933)
label11							0.051	0.055	0.297
							(0.959)	(0.954)	(0.713)
label12							0.212	0.217	0.349
							(0.871)	(0.864)	(0.746)
log (USDL): label 11							−0.005	−0.005	−0.033
							(0.960)	(0.956)	(0.656)
log (USDL): label 12							−0.027	−0.028	−0.04
							(0.820)	(0.808)	(0.684)
log (FRES)	−0.052	−0.052	−0.107 *				−0.058	−0.064	−0.099 *
	(0.377)	(0.351)	(0.039)				(0.289)	(0.232)	(0.035)
LRAT	−0.015	−0.020	−0.029	0.004 *	0.003 *	0.003 *			
	(0.501)	(0.823)	(0.136)	(0.014)	(0.047)	(0.042)			
lagLRAT	0.012	0.012	0.057 **	−0.002 *	−0.002	−0.002 ***			
	(0.251)	(0.218)	(0.000)	(0.040)	(0.057)	(0.000)			
LRAT2	0.000	0.001	0.002						
	(0.921)	(0.858)	(0.607)						
PEXP	−0.014 *	−0.013 *	−0.009	0.010 ***	0.010 ***	0.010 ***			

Table A1. *Cont.*

Geographic Subspace	GDP			CPI			BBL		
	(1) SLX	(2) SDM	(3) GNSM	(1) SLX	(2) SDM	(3) GNSM	(1) SLX	(2) SDM	(3) GNSM
Explanatory variables									
log_USDL	0.378 ***	0.380 ***	0.400 ***	−0.035 ***	−0.032 ***	−0.044 ***	−0.084	−0.076	−0.073
	(0.026)	(0.024)	(0.019)	(0.007)	(0.007)	(0.006)	(0.077)	(0.073)	(0.073)
Wlog (X)	−0.285 ***	−0.257 ***	−0.199 ***	0.027 *	0.020	0.021 *	−0.012	−0.016 *	−0.016 *
	(0.044)	(0.041)	(0.039)	(0.011)	(0.011)	(0.010)	(0.008)	(0.007)	(0.007)
Control variable									
log (ENDR)							0.036	0.049	0.047
							(0.032)	(0.031)	(0.031)
log (EXPD)							0.256 *	0.306 **	0.301 **
							(0.100)	(0.095)	(0.096)
log (LCPI)							0.294 ***	0.309 ***	0.309 ***
							(0.069)	(0.043)	(0.067)
label11							0.172	0.197	0.198
							(0.867)	(0.828)	(0.824)
label12							0.455	0.498	0.504
							(1.131)	(1.080)	(1.075)
log (USDL): label 11							−0.015	−0.017	−0.017
							(0.080)	(0.076)	(0.076)
log (USDL): label 12							−0.048	−0.052	−0.053
							(0.102)	(0.098)	(0.097)
log (FRES)	0.203 ***	0.197 ***	0.204 ***				−0.090 *	−0.118 *	−0.115 *
	(0.030)	(0.028)	(0.023)				(0.045)	(0.043)	(0.043)
lag_log_FRES	0.285 ***	0.282 ***	0.211 ***						
	(0.034)	(0.031)	(0.030)						
LRAT	0.013	0.030	0.042 **	0.005 **	0.006 ***	0.004 **			
	(0.018)	(0.017)	(0.015)	(0.002)	(0.002)	(0.002)			
lagLRAT	0.004	0.003	0.005	0.003	0.003	0.004 *			
	(0.008)	(0.007)	(0.007)	(0.002)	(0.002)	(0.002)			
LRAT2	0.000	−0.001 *	−0.001 **						
	(0.000)	(0.000)	(0.000)						
PEXP	−0.054 ***	−0.054 ***	−0.051 ***	0.009 **	0.009 ***	0.011 ***			
Languag Subspace	GDP			CPI			BBL		
	(1) SLX	(2) SDM	(3) GNSM	(1) SLX	(2) SDM	(3) GNSM	(1) SLX	(2) SDM	(3) GNSM
Explanatory variables									
log_USDL	0.381 ***	0.381 ***	0.415 ***	−0.023 ***	−0.024 ***	−0.023 ***	−0.095	−0.111	−0.077
	(0.029)	(0.026)	(0.027)	(0.006)	(0.006)	(0.006)	(0.075)	(0.073)	(0.071)
Wlog (X)	−0.012 *	−0.090 *	−0.048 *	−0.014 *	−0.014 *	−0.014 *	0.003 ***	−0.003 ***	0.002 ***
	(0.042)	(0.038)	(0.019)	(0.005)	(0.005)	(0.005)	(0.001)	(0.001)	(0.001)
Control variable									
log (ENDR)							0.018	0.001	−0.029
							(0.031)	(0.031)	(0.030)
log (EXPD)							0.320 **	0.373 ***	0.227 *
							(0.099)	(0.096)	(0.089)
log (LCPI)							0.304 ***	0.299 ***	0.248 ***
							(0.068)	(0.067)	(0.060)
label11							0.240	0.213	0.487
							(0.843)	(0.819)	(0.776)
label12							0.497	0.450	0.492
							(1.100)	(1.070)	(1.015)
log (USDL): label 11							−0.022	−0.018	−0.047
							(0.077)	(0.075)	(0.073)
log (USDL): label 12							−0.054	−0.049	−0.057
							(0.100)	(0.097)	(0.094)
log (FRES)	0.121 **	0.134 ***	0.160 ***				−0.088 *	−0.120 **	−0.066 *
	(0.036)	(0.033)	(0.036)				(0.044)	(0.043)	(0.041)

Table A1. *Cont.*

lag_log_FRES	0.026	−0.008 ***	−0.029			
	(0.040)	(0.036)	(0.023)			
LRAT	−0.051	−0.051 *	−0.002 **	0.011 ***	0.010 ***	0.011 ***
	(0.021)	(0.019)	(0.002)	(0.002)	(0.002)	(0.002)
lagLRAT	0.003	−0.003	−0.005	−0.006 **	−0.006 **	−0.006 **
	(0.008)	(0.007)	(0.006)	(0.002)	(0.002)	(0.002)
LRAT2	0.001	0.001 *	0.000			
	(0.000)	(0.000)	(0.000)			
PEXP	−0.027 ***	−0.019 *	−0.024 ***	0.007 **	0.007 *	0.007 **
	(0.007)	(0.006)	(0.006)	(0.002)	(0.002)	(0.002)
lag PEXP	0.010	0.008	0.003	0.000	0.000	0.000

Notes: Observations: GDP = 429; CPI = 429; BBL = 222. The numbers in parentheses indicate the standard errors of the estimates, not t-statistics. All lag prescripts are spatially lagged, and the resulting values are spillover effects. wvp = wx = weight kronecker volume. R square is the fitted value of the corresponding combined SLX model as a proxy for the degree of fit. USDL: US dollar-denominated bonds, nominal, in millions of US dollars. ENDR: Exchange rate against the US, nominal, in US dollars (xxx/USD), end-of-period value. An increase in the exchange rate means a depreciation of the national currency. EXPD: Imports, nominal, in billions of dollars, current period value. FRES: Amount of foreign exchange reserves, nominal, in billions of dollars, excluding gold. LCPI: Consumer Price Index, nominal, calculated as the average of the current year in the local currency. LRAT: Prime rate, nominal, unit percentage; some countries do not have a prime rate, so conversion is based on estimates (automatically generated by the EIU database). PEXP: Imports as a percentage of GDP, nominal, unit percentage, and current period value.

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