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Asymmetric distance and business cycles (ADBC): A new understanding of *distance* in international trade models through the example of Iran's trade corridors

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ABSTRACT

We introduce a new concept of distance, and the way this could affect gravity-based trade modeling. Our motivation is twofold: a) global uncertainty in trade relations allows us to treat distance as an asymmetric shock in economic modeling; b) economies of scale in seaborne trade make geographical distance less relevant in trade models, substituted by economic distance, as this can be proxied by ocean freight rates. This, for instance, allows China to import iron ore from Brazil, at three times the distance compared to Australia. We enhance the New Keynesian Dynamic Stochastic General Equilibrium Model (DSGE) by incorporating a distance shock parameter into the transaction costs function. We test this on Iran's participation in the Shanghai Cooperation Organization as well as in the International North-South Transport Corridor. We conclude that longer physical distances do not necessarily have a negative impact on trade.

1. Introduction

The main objective of macroeconomic analysis is to advance an all-round understanding of the workings of the economy and its response to various policies and external events and shocks. The latter influence significantly the business cycle and can lead to instability (Snowdon & Vane, 2005, p. 4). Prior to the 1970s, macroeconomics was primarily shaped by the perspectives of Keynesian and monetarist theories (Mullineux et al., 1993). Lucas (1975; 1977), however, introduced a novel methodology for examining aggregate fluctuations using the framework of business cycle modeling (Kim, 1988). Models were developed to analyze shocks that could explain changes and trends in major aggregates, such as consumption, investment, and output (Kehoe et al., 2018, p. 143).

Shocks are unexpected events or changes in economic conditions that may impact significantly various sectors, leading to fluctuations in output, employment, and prices (Ramey, 2016). A shock can be considered asymmetric if its impacts invoke different responses of the same economic variables. Business cycle models usually analyze shocks in a general equilibrium framework. Common

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shocks in business cycles literature include monetary, technological, and political developments.

The expansion of international trade, as well as competition among nations (Porter, 1990), have led to efforts to create trade corridors and new trade routes and trade agreements. Examples include the International North–South Transport Corridor (INSTC); the Al-Faw Turkey-Iraq Multimodal Corridor; the India-Middle East-Europe Economic Corridor (IMEC); the China-Pakistan Economic Corridor (CPEC); the China-Myanmar Economic Corridor (CMEC); the Trans-European Transport Network (T-TEN); the Pan-American Highway; the Shanghai Cooperation Organization (SCO); QUAD (Quadrilateral Security Dialogue) and more (Haralambides, 2019b). These efforts depend on many unpredictable economic and geopolitical factors that impact macroeconomic stability. (Bastanifar et al., 2024). In this context, we embark to explore the role of distance as an asymmetric shock; i.e., a shock whose impacts invoke different responses by the same macroeconomic variables (Ascari et al., 2023).

Economies of scale (EoS) enjoyed by mega-ships in ocean transportation have not only facilitated trade but they have also created new trade routes between previously disconnected countries.[1] Physical distance has thus become less significant in determining trade, being replaced by 'economic distance', often proxied by declining transport costs (Haralambides, 2019a). While physical distance may hinder trade, economic distance plays a more ambivalent role in gravity trade models. At the same time, the dissemination of trade information and ensuing decisions depend on factors such as technological progress, political issues, cultural differences, trust, models of business governance, and more. All these are unpredictable, making *economic distance* a stochastic, asymmetric, variable.

For instance, in response to escalating sanctions and the collapse of the Joint Comprehensive Plan of Action (JCPOA), Iran, a central player in the Eurasian landscape, has sought to enhance its international trade, intensifying trade relations with neighboring countries (Russia, and China), focusing on the International North-South Transport Corridor (INSTC). In parallel, the country joined the Shanghai Cooperation Organization (SCO) as its ninth member, thus potentially engaging in China's Belt and Road Initiative (BRI).

The SCO was founded on April 26, 1996, with a focus on human rights and social stability, introduced during the 2000 Dushanbe summit (Gill, 2001). The organization has grown to become the most populous regional cooperation organization in the world. It covers about three-fifths of the Eurasian continent, with a population of over three billion people (Jia, 2007; IISS, 2018). SCO's current members are China, India, Kazakhstan, Kyrgyzstan, Pakistan, Russia, Tajikistan and Uzbekistan. In addition to these, SCO has also observer states and dialogue partners, which participate in various capacities. Observer states include Afghanistan, Belarus, and Mongolia. Dialogue partners include Armenia, Azerbaijan, Cambodia, Nepal, Sri Lanka, and Turkey. INSTC, a trilateral agreement between Iran, Russia, and India, was established in 2002. The aim was to create a multimodal transportation network to facilitate trade between India, Iran, Azerbaijan, Central Asia, Russia, and Europe. The corridor, admittedly of a limited transport capacity, offers shorter transport distances compared to Suez (Khan et al., 2024) (see Fig. 1). Iran is advancing this project, starting from its strategically located gulf port of Chabahar.

Iran's geostrategic importance and vast energy resources add value to the SCO economies, but western political pressure complicates trade relations amongst them (Mousavi & Khodaee, 2013). This creates uncertainties in trade relations and in this light trade routes and distances involving Iran, INSTC and SCO can be seen as asymmetric economic shocks with unpredictable consequences for SCO economies.

Thirteen countries are the official stakeholders of the INSTC. Fig. 2 shows the distances of their capitals from Tehran. Belarus is the farthest country from Iran, with Azerbaijan being the closest.

According to Fig. 2, China is the farthest country from Iran while Tajikistan is the closest.

In terms of physical distances, as shown in Figs. 2 and 3, the average distance between Tehran and the capitals of INSTC is 1854.24 km, which is shorter than the average distance to the capitals of SCO countries (2566.85 km). Therefore, on average, and assuming infrastructures of similar quality, the INSTC may offer lower transportation costs compared to the SCO. However, as we show below, when one considers *economic distance* dynamically as a shock, the findings change significantly, corroborating our working hypothesis that physical distance is not a major factor in international trade, provided that its impact on macroeconomic variables is limited.

2. Literature review

Macroeconomic literature has historically focused on shocks to explain business cycle fluctuations (Blanchard & Gali, 2019). Traditional shocks like technology and politics affect business cycles. The Solow Growth Model (Solow, 1956) provides a foundational framework for understanding the long-term determinants of economic growth, emphasizing the role of technological progress. Real Business Cycle (RBC) theory builds on this by stating that technology shocks—unexpected technological advances—drive productivity, economic growth, salaries, and consumer expenditure. Negative shocks weaken productivity, causing economic recession, lower salaries and spending.

On the other hand, Political Business Cycle theory examines how elections and politics affect economic activity. Before elections, politicians slash taxes and increase expenditure to boost the economy and their re-election chances. After elections, contractionary efforts to stabilise the economy may cause downturns. Political events and policy uncertainty delay investment and spending, while regulatory changes and government spending directly affect economic performance (Alesina, 1997). These shocks show how technology and politics affect business cycles.

Until recently, geographic distance, economic barriers, cultural differences, trade policies, and other variables have hindered international economic interaction. Admittedly, the relationship between economic activity and geographic distance is complex

[1] As already said above, China imports more iron ore from Brazil than Australia, at more than three times the distance from the latter country, requiring more than 30 days of extra navigation time.

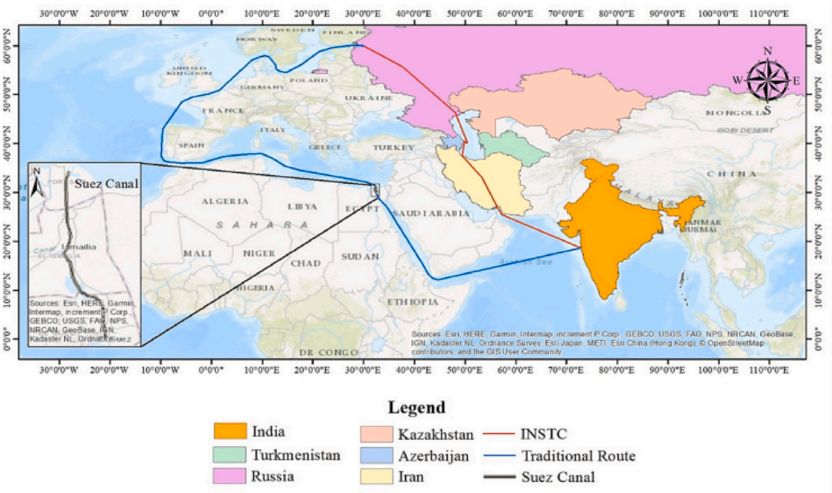


Fig. 1. INSTC, involved countries, and trade routes.
Source: Khan et al. (2023).

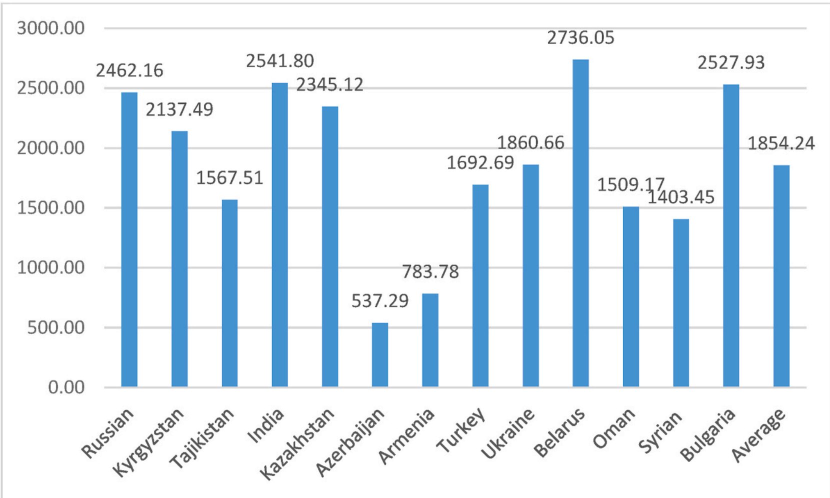


Fig. 2. Distances (km) between Tehran and the capitals of INSTC members.
Source: The authors (from www.mapcrow.info)

(Helpman & Krugman, 1985; Krugman, 1991). However, together with competition and trade liberalization, low cost ocean transportation has shrunk physical distances, facilitating and promoting international trade (Haralambides, 2019a; Head & Mayer, 2014). Hence, the conventional perception of geographic distance, as a determinant of trade, is no longer adequate in comprehending the intricacies of contemporary economic connections; a new understanding of *distance*, and the way it impacts macroeconomic variables is thus required. As early as 20 years ago, in some way this drew the attention of Michael Woodford in his seminal contribution on Distance Business Cycles using New Keynesian Dynamic Stochastic General Equilibrium (DSGE) modelling (Woodford, 2003). The author employed advanced econometric methodologies to quantify the influence of geographic separation on macroeconomic parameters including crucial measures like the GDP growth rate, inflation, unemployment, and interest rates, which collectively describe the state and dynamics of an economy. Pesaran and Pesaran (2010) also illustrated the impact of spatial features on economic dynamics by measuring the coefficient of distance shocks using autoregressive (AR) processes.

Literature on economic asymmetry is significant, also in international trade. The etymology of "symmetry" consists of two Greek words: "Συν", which means "together" and "μέτρον" which means "measure". These concepts are used to explain terms such as stability, balance and equilibrium. Asymmetry, the opposite of symmetry, introduced in economics by Akerlof in 1971, has since been widely used in the field (Alogoskoufis et al., 2023). For example, in the concept of convergence in trade and integration, joining a monetary union, such as the European Union, or the North American Free Trade Agreement (NAFTA), can cause asymmetries in economic variables (Koukouritakis & Michelis, 2006; Malliaris et al., 2008). In this sense, it is crucial to analyze Impulse Response

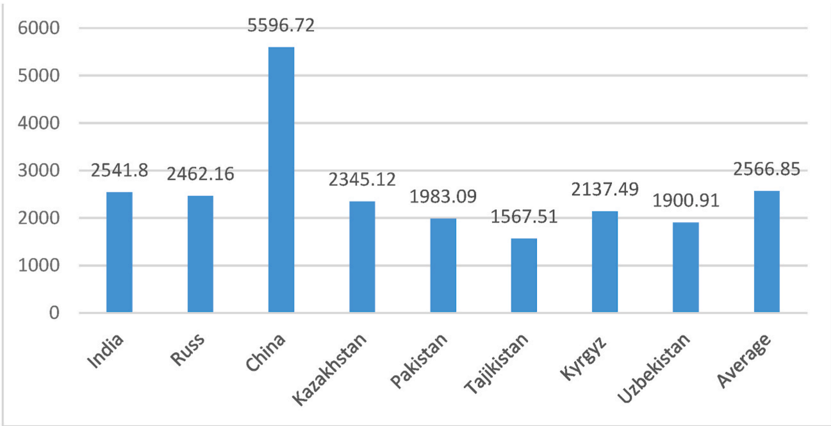


Fig. 3. Distances between capitals of SCO members and Tehran.
Sources: The authors (fromwww.mapcrow.info)

Functions (IRF) for establishing the causal relations among the countries of a union (Michelis & Zestos, 2004).

3. Empirical models and methods

In this section, the De Tina (2011) model is refined to account for the effects of distance. The model conceptualizes the transaction costs of trade as a Real Resource Cost (RRC) within a DSGE framework. Here, transaction costs function similarly to the *money-in-utility* function or *cash-in-advance* constraints, as described by Brock (1974), Feenstra (1986), and Wang and Yip (1992). We enhance this model by incorporating a distance shock parameter into the transaction costs function. All equations of the model are presented in the Appendix.

3.1. Calibration and estimation procedures

Model parameters are estimated using three methods and three sources of information. Some parameters are quantified from previous studies (see Table 1), others are derived through estimation methods, and some are extracted from the long-term trends of economic variables. Parameters that do not require estimation but must be calibrated are the steady-state values of variables that appear as stable ratios in the equations. The ratios necessary for model calibration are calculated on a quarterly basis, using data from the Iranian economy published by the Central Bank of the Islamic Republic of Iran, covering the period from the first quarter of 2004 to the fourth quarter of 2020. For this purpose, seasonal data on real GDP, capital stock, and oil value-added have been utilized.

To quantify distance shocks, we develop a new panel dataset following the methodology of Ganbaatar et al. (2021). In this dataset, distances from Tehran to the capitals of SCO member states and INSTC countries are multiplied by the annual GDP ratios of Iran relative to those countries, producing two distinct distance datasets. Using the Box–Jenkins test, we demonstrate that both datasets exhibit autoregressive properties, specifically AR (1). These estimation parameters are then employed as proxies for distance shocks. The shocks are used to calibrate selected macroeconomic variables, including gross domestic product, consumption, capital accumulation, investment, real money balances, and inflation. Calibration is conducted through a DSGE model of Iran's economy, focusing on trade relations between Iran and SCO and INSTC countries.

In order to obtain the distance parameter ρ_{dS} and ρ_{dI} shown in Table 2, we take the following steps.

The first step involves creating a dynamic time series for *distance*. This is done by applying the formula of *relative distance*, suggested by Ganbaatar et al. (2021).

Table 1
Parameters valued from previous studies Calibrated ratios.

parameter	Value	Description
Household		
y	1	GDP
$\frac{c}{y}$	0.5	Stable ratio of consumer expenditure to GDP without oil
$\frac{k}{y}$	3.3729	Stable ratio of capital stock to GDP without oil
$\frac{or^{oil}}{y}$	0.13	Stable ratio of oil revenues to non-oil GDP

Source: The authors

$$\mathrm{Dist}_{ijt} = \frac{\mathrm{GDP}_{it}}{\mathrm{GDP}_{jt}} * \mathrm{Dis} \tag{56}$$

Here, Dist_{ijt} is the proxy for the *new distance* between country *i* and its trading partner *j* in year *t*. Dis represents the absolute, or geographic, distance between the two capitals. Dis data are obtained from https://www.mapcrow, while GDP data for *i* (Iran) and *j* are obtained from the Federal Reserve Economic Data of the USA (https://fred.stlouisfed.org). The database covers the period 1990–2019.

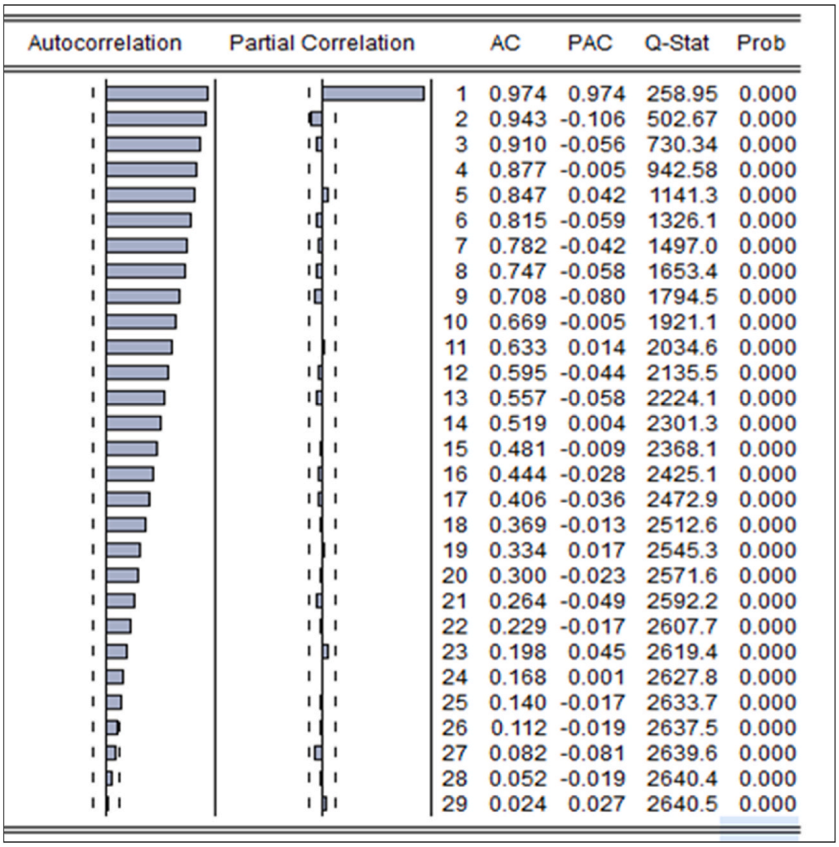
Two-time series are created. One indicates the *new (relative) distance* between Tehran and the capitals of the members of SCO, and the other between Tehran and the capitals of INSTC countries.

The second step is the identification of the time series. Fig. 4 shows the correlogram for SCO, and Fig. 5 that for INSTC. Both series are identified as AR (1) according to the Box–Jenkins unit root test. In this approach, criteria such as Schwartz, Akaike, and Hannan-Quinn can be used to select the optimal model for parameter estimation among AR, MA, and ARMA models (Loganathan & Ibrahim, 2010).

In step three, the distance parameters are estimated. Table 3 shows the F- Leamer and other unit root tests. The first column, 'Cross section F', presents the F-Leamer test while the other columns indicate different unit root tests. From Table 3, since the prob of Cross section F or F- leamer test is more than 0.05, we deem that the appropriate model is the pool model. Other tests indicate that the model is stationary at first differences. Based on the AR (1) and Pool Model of OLS, ρ_{ds} and ρ_{dI} are estimated. The values of the two parameters are shown in Table 2.

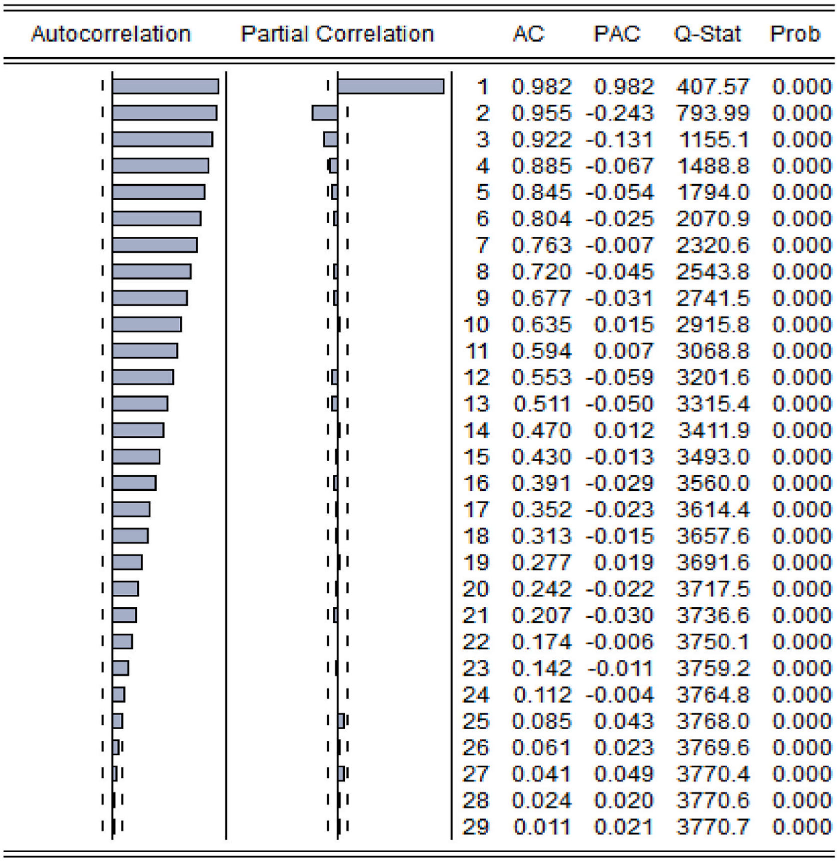
3.2. Performance of the model

To evaluate the validity of the model, its moments were compared with the seasonal data moments of Iran's economic variables. The moments of the real data were selected from the 2004–2020 data, de-seasonalized and detrended using the Hodrick-Prescott filter (lambda = 677). The response shock functions of the model variables against distance impulses also show the validity of the model. The model was found to be suitable for simulation, as shown in Table 4.



Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	0.974	0.974	258.95	0.000
		2	0.943	-0.106	502.67	0.000
		3	0.910	-0.056	730.34	0.000
		4	0.877	-0.005	942.58	0.000
		5	0.847	0.042	1141.3	0.000
		6	0.815	-0.059	1326.1	0.000
		7	0.782	-0.042	1497.0	0.000
		8	0.747	-0.058	1653.4	0.000
		9	0.708	-0.080	1794.5	0.000
		10	0.669	-0.005	1921.1	0.000
		11	0.633	0.014	2034.6	0.000
		12	0.595	-0.044	2135.5	0.000
		13	0.557	-0.058	2224.1	0.000
		14	0.519	0.004	2301.3	0.000
		15	0.481	-0.009	2368.1	0.000
		16	0.444	-0.028	2425.1	0.000
		17	0.406	-0.036	2472.9	0.000
		18	0.369	-0.013	2512.6	0.000
		19	0.334	0.017	2545.3	0.000
		20	0.300	-0.023	2571.6	0.000
		21	0.264	-0.049	2592.2	0.000
		22	0.229	-0.017	2607.7	0.000
		23	0.198	0.045	2619.4	0.000
		24	0.168	0.001	2627.8	0.000
		25	0.140	-0.017	2633.7	0.000
		26	0.112	-0.019	2637.5	0.000
		27	0.082	-0.081	2639.6	0.000
		28	0.052	-0.019	2640.4	0.000
		29	0.024	0.027	2640.5	0.000

Fig. 4. Correlogram for SCO.
Source: The authors.



Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	0.982	0.982	407.57	0.000
		2	0.955	-0.243	793.99	0.000
		3	0.922	-0.131	1155.1	0.000
		4	0.885	-0.067	1488.8	0.000
		5	0.845	-0.054	1794.0	0.000
		6	0.804	-0.025	2070.9	0.000
		7	0.763	-0.007	2320.6	0.000
		8	0.720	-0.045	2543.8	0.000
		9	0.677	-0.031	2741.5	0.000
		10	0.635	0.015	2915.8	0.000
		11	0.594	0.007	3068.8	0.000
		12	0.553	-0.059	3201.6	0.000
		13	0.511	-0.050	3315.4	0.000
		14	0.470	0.012	3411.9	0.000
		15	0.430	-0.013	3493.0	0.000
		16	0.391	-0.029	3560.0	0.000
		17	0.352	-0.023	3614.4	0.000
		18	0.313	-0.015	3657.6	0.000
		19	0.277	0.019	3691.6	0.000
		20	0.242	-0.022	3717.5	0.000
		21	0.207	-0.030	3736.6	0.000
		22	0.174	-0.006	3750.1	0.000
		23	0.142	-0.011	3759.2	0.000
		24	0.112	-0.004	3764.8	0.000
		25	0.085	0.043	3768.0	0.000
		26	0.061	0.023	3769.6	0.000
		27	0.041	0.049	3770.4	0.000
		28	0.024	0.020	3770.6	0.000
		29	0.011	0.021	3770.7	0.000

Fig. 5. Correlogram for INSTC
*Source***:** The authors.

Table 2
Calibrated parameter values.

parameter	Value	Description
Household		
β	0.97	discount factor
σ^c	1.576	substitution elasticity of consumption
η	3.25	inverse of labor supply elasticity
ρ_{ds}	0.21	autoregressive coefficient for SCO
ρ_{dI}	0.54	autoregressive coefficient for INSTC
Ω_1	0.0238	scale parameter
Ω_2	0.8	an elasticity parameter
Production		
δ	0.025	rate of depreciation
θ	4.33	elasticity of demand for each intermediate good
α	0.412	share of labor in output, intermediate goods
Ψ	4.26	the price-adjustment cost parameter
Government		
τ	0.6	Income elasticity of taxes
Shock		
ρ_d, ε_t^d	0.21	Persistence/standard dev., distance shock
ρ_z, ε_t^z	0.72	Persistence/standard dev., productivity shock
ρ_O, ε_t^O	0.798	Persistence/standard dev., oil shock
ρ_g, ε_t^g	0.66	Persistence/government expenditure shock

Source: The authors.

Table 3
F_ Leamer and unit root tests.

Tests	SCO		INSTC	
	Statistic	Prob	Statistic	Prob
Cross section F	0.092	0.99	0.028	1
Common Unit Root/Levin, Lin, Cho test	−6.53	0	−8.77	0
Indivitual Unit Root/Im, Pesaran, Shin	−7.08	0	−8.10	0
ADF-Fisher Chi square	79.85	0	114.2	0
PP-Fisher Chi square	79.81	0	108.3	0

Source: The authors.

Table 4
Hodrick-Prescott filter ($\lambda = 677$).

	Standard Deviation		Relative Volatility	
	model	real data	model	real data
Y	0.025956	0.033427	1	1
C	0.013956	0.02058	0.537679	0.6156
K	0.013292	0.0063	0.51209	0.18847

Source: The authors.

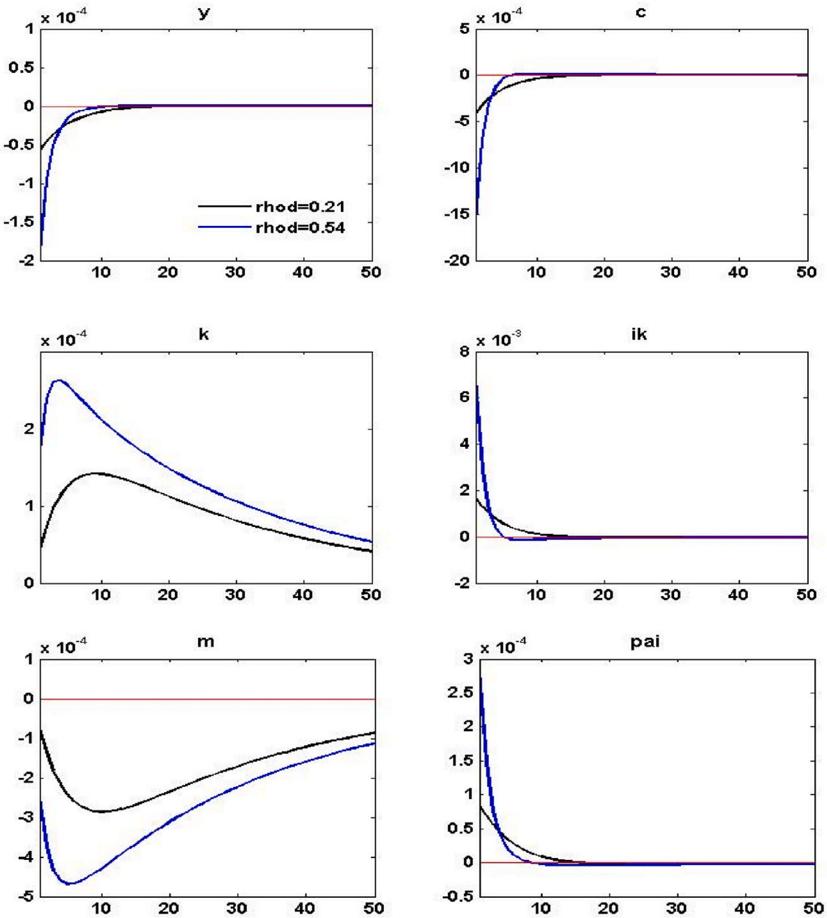


Fig. 6. The IRF effects of distance shock on the model variables.

4. Discussion (IRF analysis)

We have treated distance as a significant, asymmetric, factor of economic shocks. Different business cycles theories, such as real and political cycles, attribute such shocks to various sources, like changes in technology or election timings (Drautzburg, 2019; Drazan, 2008). Recently, countries have shown interest in developing and joining economic corridors or international alignments. A maritime (or overland) corridor consists of a relatively narrow geographical area, attracting trade flows due to shorter distances, superior infrastructure and/or trade agreements among lateral states. However, concentration of shipping and trade in limited areas gives rise to heightened risk, uncertainty and threats (cf. Red Sea). The consequent disruptions make corridors and the redesigned distances stochastic asymmetric variables. For instance, the India-Middle East Europe Economic Corridor (IMEC), introduced at the G-20 meeting in September 2023 in India, presents both political and economic advantages for the USA and several European countries (Khan et al., 2024), but the corridor is bound to cause both positive and negative fluctuations in the Gross Domestic Product (GDP) of member and non-member countries of the corridor.

It can be deduced from the above that the popularity in economic corridors brings a new asymmetric perspective on *distance*. The new concept and its ramifications should therefore be expanded beyond that of physical distance or just transport costs; and this is what has been attempted in this paper. By enhancing the DSGE model to account for distance shocks, we simulated their effect, in the case of the Shanghai Cooperation Organization (SCO) and the International North-South Transport Corridor (INSTC), on Iran's economy. Our model includes households with an unlimited planning horizon, firms producing intermediate and final goods, the government, the oil sector, and the central bank.

Impulse Response Functions (IRF) demonstrate the dynamic behavior of model variables, in terms of the way an impulse (of one standard deviation) affects a shocked variable. In this section, we examine how macroeconomic variables respond to a distance shock. Fig. 6 illustrates the impact of such a shock on the dynamics of the macroeconomic variables of Iran.

All graphs converge, indicating the beneficial effects of Iran's participation in the Shanghai Cooperation Organization (SCO) and the International North-South Transport Corridor (INSTC). As shown in Fig. 6, an increase in the impulse distance causes macroeconomic variables such as gross domestic product (Y), consumption (C), capital accumulation (K), investment (IK), real balance of money (m), and inflation (π) to deviate from their long-term equilibrium paths. In the base scenario with $\rho\_ds = 0.21$ (the continuous black line), increasing distance risk by one standard deviation leads to greater deviations of economic variables from equilibrium.

A distance shock has two main consequences: it negatively impacts consumption (and output) and increases the demand for real balances. Consumption becomes costlier, prompting consumers to hold more cash to reduce transaction costs. The demand for money, being a function of consumption and distance shock, decreases with reduced consumption but increases as people prefer to hold more cash due to higher exchange costs. As capital goods purchases are not subject to transaction costs, households allocate more resources toward investment.

Fig. 6 also shows how the economy reacts to a distance shock under different conditions. In the INSTC scenario ($\rho\_di = 0.54$), the dynamics of the variables are similar to the base scenario, but the shock effect in the SCO case is shorter than in the north-south corridor.

The severity of a shock is determined by the reaction time to it, measured by IRFs (Helmut, 2008). Longer reaction times lead to greater macroeconomic instability. Our research, based on IRFs, indicates that the distance shock of the SCO is shorter than that of the INSTC, suggesting that SCO membership has a more significant impact on Iran's economy compared to INSTC. This also shows that the impact of IRFs on the same macroeconomic variables of SCO and INSTC is different, reaffirming that distance shocks behave in an asymmetric manner.

5. Conclusions

Our research advances the theoretical development of dynamic stochastic general equilibrium (DSGE) models by incorporating distance as an asymmetric shock, caused by today's worrisome global economic uncertainty. By shifting the interpretation of distance from a simple geographic measure to an economic factor, we transform distance from a deterministic to a stochastic and asymmetric variable. In this context, considering the dynamic nature of economies, global uncertainty, and the unpredictability of trade-related information, distance can be seen as an economic shock. In so doing, our results offer empirical and theoretical insights, opening new avenues to future research.

Our Iranian case study, fully generalizable in similar geographical circumstances, furnishes all the required validations. As illustrated in Figs. 2 and 3, Iran's trading distances with INSTC countries are shorter than with SCO members. However, we show in Fig. 6, the impact of trade on macroeconomic variables is greater in the case of SCO. This finding challenges traditional gravity models and has implications for transportation studies, international trade, and macroeconomics. In conventional trade models, shorter distances are *ceteris paribus* generally associated with greater trade volumes. However, when distance is treated as an economic shock, *conventional wisdom* may not always hold. Indeed, our research challenges the conventional view of distance in gravity models, which typically posits that longer distances pose greater disadvantages to trade. Instead, we demonstrate that distance, when acting as an asymmetric shock, does not significantly impede international trade in the way this was traditionally assumed.

This new understanding of distance calls for a reevaluation of the way distance is treated in economic theory and models. As distance shocks influence economic performance, strategic efforts to reduce the impulse response functions to these shocks can bolster economic resilience against other shocks, including those deriving from business cycles, political fluctuations, and natural disasters like pandemics. In practice too, our findings suggest that policymakers should prioritize the minimization of the impact of distance shocks in international trade, rather than focusing solely on reducing physical distances. This perspective leads to a paradigm shift in transportation, international trade, and macroeconomic policy.

To test model results in the macroeconomic framework of our Iranian case study, we have measured the responses of macroeconomic variables to distance shocks in two instances: Iran's accession to the Shanghai Cooperation Organization (SCO) and to the International North South Transport Corridor (INSTC). We find that, in spite of the shorter physical distances of Iran to INSTC, our *new distance* concept, if used the way it has been proposed here, bestows greater economic advantages from SCO membership than INSTC. Differently, the response of macroeconomic variables to Iran's joining SCO is more pronounced and positive compared to that of INSTC (Rashidi & Shabani, 2022). Our results, thus, enhance our understanding of Asymmetric Distance Business Cycles (ADBC) and their ramifications for macroeconomic policy (Obstfeld & Rogoff, 2009). By integrating economic distance into macroeconomic models, policymakers can obtain significant insights into the impact of (economic) distance on economic dynamics, thus facilitating more informed decision-making in an increasingly interconnected global economy (Krugman, 1999).

Finally, as in all research of this type, limitations are present here too. Since our focus was on distance shocks, the period of study (1990–2019) was purposely chosen so as to exclude the significant shock of COVID-19. It would be interesting to see the expansion of our work in assessing the impact of other shocks such as new trade corridors, labor strikes, the Red Sea crisis, trade chokepoints, tsunamis, and more.

CRediT authorship contribution statement

Hercules Haralambides: Writing – review & editing, Validation, Supervision, Project administration, Formal analysis, Conceptualization. **Iman Bastanifar:** Investigation, Data curation. **Kashif Hasan Khan:** Formal analysis, Data curation. **Zahra Shahryari:** Resources, Investigation, Data curation.

Declaration of competing interest

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Appendix

1.Households

We consider a representative household that benefits from the consumption of goods and leisure time. The utility function of the household is:

$$E_t \sum_{t=0}^{\infty} \beta^t \left\{ \frac{{c_t}^{1-\sigma^c}}{1-\sigma^c} + \psi \frac{\left(1-h_t^s\right)^{1-\eta}}{1-\eta} \right\} \tag{1}$$

where $\beta \epsilon (0,1)$ is the discount factor; c_t is household consumption; h_t^s is work time and $1-h_t^s$ is leisure time; σ^c is the consumption substitution elasticity; the parameter η is the inverse of labor supply elasticity; and ψ represents a preference parameter over leisure (De Tina, 2011, p. 52).

The calculation of the capital accumulated by households in the economy is adjusted each period as follows:

$$k_{t+1} = (1-\delta)k_t + i_t \tag{2}$$

where δ is the rate of depreciation. The transaction cost function appearing in the budget constraint is given in equation (3):

$$\Upsilon(c_t, m_t) = \Omega_1 \frac{(c_t)^{\Omega_2+1}}{(m_t)^{\Omega_2}} \tag{3}$$

where transaction costs are positively related with real consumption (c_t) and decrease with money in real terms (m_t); $\Omega_1 > 0$ is a scale parameter and $\Omega_2 > 0$ is an elasticity parameter. To fully understand (3) it is useful to define the unitary real transaction cost (i.e., real cost associated with one unit of consumption, q_t) as follows:

$$q_t = \Omega_1 \left(\frac{c_t}{m_t}\right)^{\Omega_2} \tag{4}$$

The following convention is used to simplify the notation:

$$\upsilon_t = \frac{c_t}{m_t} \tag{5}$$

Using (3), (4) and (5), one can re-write total transaction costs as:

$$\Upsilon(c_t, m_t) = c_t q_t \tag{6}$$

According to the above, the representative household faces the following budget constraint in maximizing its utility function:

$$c_t + i_t + m_t + b_t + \Upsilon(c_t, m_t)d_t \leq w_t h_t^s + r_{t-1}k_{t-1} + \frac{m_{t-1} + I_{t-1}b_{t-1}}{\Pi_t} + \frac{\pi^f}{P_t} \tag{7}$$

where: w_t, r_{t-1} is respectively income from supplying labor and capital k_t; $\frac{I_{t-1}}{\Pi_t}b_{t-1}$ is the principal and interest of bonds (b_t) issued by the government; and $\frac{\pi^f}{P_t}$ is the profit of household-own firms. It is assumed that the distance shock (d_t) follows a first-order autoregressive process.

$$\ln d_t = (1 - \rho_d)\ln d + \rho_d \ln d_{t-1} + \varepsilon_t^d \tag{8}$$

where ; ρ_d is the autoregressive coefficient (with $0 \leq \rho_d \leq 1$) and ε_t^d is a random variable serially uncorrelated and normally distributed, with zero mean and constant variance ($\sigma^2_{\varepsilon^d}$). The representative household seeks to maximize the utility stream (equation (1)) subject to the budget constraint (equation (7)). From the optimization of utility function c_t, m_t, b_t and k_t, the following equations are derived that show the optimal path of the variables:

$$1 = \beta E_t \left(\frac{c_t}{c_{t+1}}\right)^{\sigma^c} \left(\frac{1 + \Upsilon_t^c d_t}{(1 + \Upsilon_{t+1}^c d_{t+1})}\right) \frac{I_t}{\Pi_{t+1}} \tag{9}$$

$$\frac{\psi(1 - h_t^s)^{-\eta}}{c_t^{-\Phi}} = \frac{w_t}{(1 + \Upsilon_t^c d_t)} \tag{10}$$

$$\frac{c_t^{-\sigma^c}}{(1 + \Upsilon_t^c d_t)} = \beta E_t \frac{c_{t+1}^{-\sigma^c}}{(1 + \Upsilon_{t+1}^c d_{t+1})} \{r_t + 1 - \delta\} \tag{11}$$

$$\Upsilon_t^m d_t = \frac{1 - I_t}{I_t} \tag{12}$$

where the partial derivatives of the total transaction costs function with respect to real consumption and liquidity are denoted respectively by Υ_t^c and Υ_t^m.

2. The final-good-producing firm

The final good is produced from a continuum of intermediate goods. Assuming that all intermediate goods are imperfect substitutes with a CES, θ, the corresponding Dixit-Stiglitz Aggregator (Dixit & Stiglitz, 1977) can be defined as:

$$y_t \leq \left[\int_0^1 y_{jt}^{\frac{(\theta-1)}{\theta}} dj\right]^{\frac{\theta}{\theta-1}} \tag{13}$$

where y_t is the quantity of the final good produced; y_{jt} is the amount intermediate good j used in production; and $\theta > 1$ is a nonnegative parameter governing elasticity of demand for intermediate goods; p_t is the price index of final good while p_{jt} is the price index of intermediate good j. The firm maximization problem can be written as:

$$\max_{y_{jt}} \left[p_t \left[\int_0^1 y_{jt}^{\frac{(\theta-1)}{\theta}} dj\right]^{\frac{\theta}{\theta-1}} - \int_0^1 p_{jt} y_{jt} dj\right] \tag{14}$$

The first-order condition implies the following demand function for firm j:

$$y_{jt} = \left(\frac{p_{jt}}{p_t}\right)^{-\theta} y_t \tag{15}$$

which expresses the demand for good j as a function of its relative price (p_{jt}) and final output. The final-good price (p_t) index satisfies

$$p_t = \left(\int_0^1 p_{jt}^{1-\theta} dj\right)^{\frac{1}{1-\theta}} \tag{16}$$

3. The intermediate-good-producing firm

Producers of intermediate goods act in a monopolistic competition market. They employ k_{jt} units of capital and h^s_{jt} units of labour to produce output according to the following constant-returns-to-scale technology:

$$y_{jt} \le z_t {k_{jt}}^{\alpha}\left(h^s_{jt}\right)^{1-\alpha}, \alpha\epsilon(0,1) \tag{17}$$

where z_t is a technology shock, common to all intermediate-good-producing firms, assumed to follow the autoregressive process in eq. (18).

$$\ln z_t = \rho_z \ln z_{t-1} + \varepsilon^z_t, |\rho_z| < 1, \varepsilon^z_t \underset{iid}{\sim} N\left(0.\sigma^2_z\right) \tag{18}$$

where $\rho_z\epsilon(-1,1)$ and ϵ_{zt} is a serially uncorrelated shock that is normally distributed with zero mean and standard deviation σ^2_z.

Another assumption of the model is that firms producing intermediate goods face a kind of nominal price stickiness, based on the Rotemberg (1982) model and the Dibb (2003) quadratic adjustment cost as follows:

$$\frac{\Psi}{2}\left(\frac{P_{jt}}{P_{j,t-1}(1+\pi_{ss})} - 1\right)^2 y_t \tag{19}$$

Where $\Psi \ge 0$ is the price-adjustment cost parameter. If $\Psi = 0$, prices are completely flexible; if $\Psi > 0$, prices are then sticky.

The problem of firm j is to choose contingency plans for h^s_{jt}, k_{jt}, y_{jt} and P_{jt} that maximize its expectation of the discounted sum of its profit flows conditional on the information available at time zero:

$$\max_{k_{jt},\, h^s_{jt}, P_{jt}} E_0\left[\beta^t \lambda_t \frac{\pi^f_t}{p_t}\right] \tag{20}$$

where the instantaneous profit function is given by:

$$\pi^f_t = p_{jt} y_{jt} - p_t r_t k_{j,t} - p_t w_t h^s_{jt} - p_t \frac{\Psi}{2}\left(\frac{P_{jt}}{P_{j,t-1}(1+\pi_{ss})} - 1\right)^2 y_t \tag{21}$$

subject to constraints (15) and (17). The firm's discount factor is given by the stochastic process $\beta^t\lambda_t$, where λ_t denotes the marginal utility of real wealth; β^t is the dividend discount factor; and $\beta^t\lambda_t$ is the value of the marginal utility of a unit of additional profit. The first-order conditions with respect to k_{jt}, h^s_{jt}, P_{jt} and ξ_t are given by:

$$r_t = \alpha q_t^{-1} . \frac{y_t}{k_t} \tag{22}$$

$$w_t = (1-\alpha) q_t^{-1} \frac{y_t}{h^w_t} \tag{23}$$

$$q_t^{-1} = \frac{\theta - 1}{\theta} + \frac{\Psi}{\theta}\Pi_t(\Pi_t - 1) - \frac{\beta\Psi}{\theta}\frac{\lambda_{t+1}}{\lambda_t}\frac{y_{t+1}}{y_t}\Pi_{t+1}(\Pi_{t+1} - 1) \tag{24}$$

$$y_{jt} = {k_{jt}}^{\alpha}\left(h^w_{jt}\right)^{1-\alpha} z_t \tag{25}$$

Where $q_t = \frac{\lambda_t}{\xi_t}$ measures the gross price-markup over marginal cost. In the absence of price-adjustment costs ($\Psi = 0$), equation (23) implies that the markup is constant and equal to $\frac{\theta}{\theta-1}$.

4. Oil sector

Oil revenues can be interpreted as an exogenous shock (Rubaszek, 2021; Khiabani & Amiri, 2014). The shock follows an autoregessive (AR) process. In equation (26), or_t is the flow of real oil revenue and $\overline{or}$ is the stable level of oil revenue (Motavaseli et al., 2011). These shocks are summarized in ε^{or}_t. Thus, the flow of oil revenues enters the model as follows:

$$\ln or_t = (1-\rho_{or})\overline{or} + \rho_{or} \ln or_{t-1} + \varepsilon^{or}_t \tag{26}$$

5. Government Budget

Equation (27) summarizes the government budget. The lefthand side indicates government expenditure (g_t) and the right consists of government revenues such as taxes (t_t), oil exports revenue (or_t), bond issues $\left(b_t - \frac{I_{t-1}}{\Pi_t}b_{t-1}\right)$, and money creation $(m_t - \frac{m_{t-1}}{\Pi_t})$.

$$g_t = t_t + or_t + b_t - \frac{I_{t-1}}{\Pi_t}b_{t-1} + m_t - \frac{m_{t-1}}{\Pi_t} \tag{27}$$

The government expenditure shock is also modeled as an AR (1) process.

$$\ln g_t = (1-\rho_g)\overline{g} + \rho_g \ln g_{t-1} + \varepsilon_t^g \tag{28}$$

where $\rho_g \epsilon (-1,1)$ and ε_t^g is a serially uncorrelated shock that is normally distributed with zero mean and σ_g^2 standard deviation.

The gross growth rate of money in period t is defined as follows:

$$\mu_t = \frac{m_t}{m_{t-1}}\Pi_t \tag{29}$$

The following rule is considered for the gross growth rate of money:

$$\widehat{\mu}_t = \rho_\mu \widehat{\mu}_{t-1} + \beta_\pi \widehat{\Pi}_t + \beta_y \widehat{y}_t + \varepsilon_t^\mu \tag{30}$$

where $\rho_\mu \epsilon (-1,1)$ and ε_t^μ is a serially uncorrelated shock that is normally distributed with zero mean and standard deviation σ_μ^2.

6. Market clearing conditions

Additional relationships had to be added to the model to complete and close it, and clear the total economy.

$$y_t + or_t = c_t + g_t + ik_t + \frac{\Psi}{2}\left(\frac{P_{jt}}{\pi P_{jt-1}}\right)^2 y_t \tag{31}$$

For equilibrium in the goods markets, we require production (The lefthand side of eq. (31) is the sum of non-oil final goods and oil production) to equal aggregate demand (The righthand side of relation 31 is the sum of consumption, government, private investment and the price adjustment cost).

7. Equilibrium Conditions

The equilibrium conditions in the linear form, using the Taylor approximation method, are as follows:

$$\eta \frac{h^s}{1-h^s}\widehat{h}_t^s = \widehat{w}_t - \sigma^c \widehat{c}_t - \widehat{\Upsilon_t^c} - \frac{\Upsilon^c}{1+\Upsilon^c}\widehat{d}_t \tag{32}$$

$$\widehat{\lambda}_t = -\sigma^c \widehat{c}_t - \widehat{\Upsilon_t^c} - \frac{\Upsilon^c}{1+\Upsilon^c} - \widehat{d}_t \tag{33}$$

$$\sigma^c \widehat{c}_{t+1} - \sigma^c \widehat{c}_t + E_t \widehat{\Upsilon_{t+1}^c} - \widehat{\Upsilon_t^c} + \frac{\Upsilon^c}{1+\Upsilon^c}(E_t \widehat{d_{t+1}} - \widehat{d}_t) = \widehat{I}_t - E_t \widehat{\Pi}_{t+1} \tag{34}$$

$$\sigma^c \widehat{c}_{t+1} - \sigma^c \widehat{c}_t + E_t \widehat{\Upsilon_{t+1}^c} - \widehat{\Upsilon_t^c} + \frac{\Upsilon^c}{1+\Upsilon^c}(E_t \widehat{d_{t+1}} - \widehat{d}_t) = \beta r \widehat{r}_t \tag{35}$$

$$\widehat{k}_{t+1} = \delta \widehat{ik}_t + (1-\delta)\widehat{k}_t \tag{36}$$

$$\widehat{\Upsilon}_t = \widehat{c}_t + \widehat{q}_t \tag{37}$$

$$\widehat{q}_t = \Omega_2 \widehat{\upsilon}_t \tag{38}$$

$$\widehat{\upsilon}_t = \widehat{c}_t - \widehat{m}_t \tag{39}$$

$$\widehat{\Upsilon_t^c} = \widehat{q}_t \tag{40}$$

$$\widehat{\Upsilon_t^m} = -\widehat{q}_t - \widehat{\upsilon}_t \tag{41}$$

$$\widehat{m}_t - \widehat{c}_t = \frac{1}{1+\Omega_2}\left(\widehat{d}_t - \frac{1}{I-1}\widehat{I}_t\right) \tag{42}$$

$$\widehat{d}_t = \rho_d \widehat{d_{t-1}} + \varepsilon_t^d \tag{43}$$

$$\widehat{y}_t = \alpha\widehat{k}_t + (1-\alpha)\widehat{h}_t^s + \widehat{z}_t \tag{44}$$

$$\widehat{z}_t = \rho_z \widehat{z_{t-1}} + \varepsilon_t^z \tag{45}$$

$$\widehat{r}_t = \widehat{y}_t - \widehat{k}_t - \widehat{q}_t \tag{46}$$

$$\widehat{w_t} = \widehat{y}_t - \widehat{h}_t^s - \widehat{q}_t \tag{47}$$

$$-\frac{1}{q^{ss}}\widehat{q}_t = \frac{\Psi}{\theta}.(2\Pi^2 - \Pi)(\widehat{\Pi}_t - \beta.E_t\widehat{\Pi}_{t+1}) - \frac{\beta\Psi}{\theta}(\Pi^2 - \Pi)(E_t\widehat{\lambda}_{t+1} - \widehat{\lambda}_t + E_t\widehat{y}_{t+1} - \widehat{y}_t) \tag{48}$$

$$g^{ss}\widehat{g}_t = t^{ss}\widehat{t}_t + o^{ss}\widehat{o}_t + m^{ss}\widehat{m}_t - \frac{m^{ss}}{\Pi^{ss}}(\widehat{m}_{t-1} - \widehat{\pi}_t) \tag{49}$$

$$\widehat{g}_t = \rho_g \widehat{g_{t-1}} + \varepsilon_t^g \tag{50}$$

$$\widehat{t}_t = \tau\widehat{y}_t \tag{51}$$

$$\widehat{O_t} = \rho_O \widehat{O_{t-1}} + \varepsilon_t^{or} \tag{52}$$

$$\widehat{\mu}_t = \widehat{m}_t - \widehat{m}_{t-1} + \widehat{\Pi}_t \tag{53}$$

$$\widehat{\mu}_t = \rho_\mu \widehat{\mu}_{t-1} + \beta_\pi \widehat{\Pi}_t + \beta_y \widehat{y}_t + \varepsilon_t^\mu \tag{54}$$

$$\left(1 - \frac{\Psi}{2}(\Pi^{ss} - 1)^2\right)y^{ss}\widehat{y}_t + O^{ss}\widehat{O_t} = c^{ss}\widehat{c}_t + g^{ss}.\widehat{g}_t + k^{ss}.\widehat{k}_{t+1} - (1-\delta)k^{ss}.k_t + \Psi(\Pi^2 - \Pi)y^{ss}.\widehat{\Pi}_t \tag{55}$$

Data availability

Data will be made available on request.

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