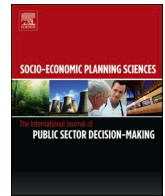




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# Disruption in food supply chain and undernourishment challenges: An empirical study in the context of Asian countries

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## ABSTRACT

Undernourishment and associated health issues are some mammoth challenges that the world currently faces. The poorly design food supply chain (FSC) is considered a root cause of high undernourishment cases worldwide. Since all processes and stages in a supply chain are strongly connected, a slight delay or glitch can trigger a butterfly effect resulting in significant socio-economic losses. The FSC is vital to providing human essentials and a source of bread earning; rank at the top in global industries and any disturbance results in high unemployment and leading social evils like crime and violence in society. Recognize the same; this study examines the impact of food supply chain disruption on undernourished cases in selected Asian countries. Using Generalized Methods of Moments (GMM) estimator, this study provides two key findings. First, a higher intensity of COVID-19 cases translates into higher undernourishment due to direct and indirect effects from higher stringency measures. Secondly, government financial allocations to combat COVID-19 and economic growth significantly mitigate the prevalence of undernourishment. Interestingly, a higher crime index is linked with higher undernourished cases supporting the proposition of socio-economic disorder. These results propose broad policy implications for governments, food regulatory authority, donor agencies, and Non-Governmental Organizations by strengthening the food supply chain and thus reduces undernourishment cases.

## 1. Introduction

SARS-CoV-2 (COVID-19), the pandemic unfolding is very different from past calamities the world has witnessed, resulting in millions of infected and thousands of death worldwide [1]. Without any doubt, the economic catastrophe due to COVID-19 has unleashed recession, which the world has not witnessed since the 2nd World War [2]. The magnitude of the impact is high due to globalization [3]. Many importing countries rely on food-exporting countries to provide essential food items [4]. In this global catastrophe, the United Nations (UN) and constituting bodies are mainly focusing on the food supply chain (FSC). As the intensity of COVID-19 increases, the FSC disruptions will be a

crisis overtaking the contagious disease (Carmen M [5].

Food is a source of sustenance and necessary to provide adequate nourishment for the body to provide resilience against diseases [6]. Proper nutrition encompasses micronutrients that are available by rationing consumption of plant and animal-based diets [7]. Developing and underdeveloped countries in pre-COVID-19 were already struggling with fragile FSC, disrupting even small food security threats [8]. According to an estimate by Ref. [9]; "one person in nine sleeps empty stomach and one in three suffers from malnutrition," and these effects are more pronounced in Asia and Africa. The impact of food scarcity and the supply chain disruptions directly impact one-third of the world population's health and wellbeing. Therefore, UN (2015) unanimously

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passed a resolution on 17 dedicated sustainable development goals (SDGs) to transform the world by 2030.

The most critical SDGs are eradicating poverty and hunger, providing good health and quality education, gender equality, sufficient work, economic growth, and affordable clean energy and environmental protection (United Nations, 2015). For many years, the global community is striving to reach zero hunger targets [11]. The population facing malnutrition has immediate health effects, especially for the elderly, newborns, children, pregnant and lactating females [12–14]. However, the remaining categories, male and nonpregnant and nonlactating females, face immunity issues to fight diseases like COVID-19 or potential long-term health issues [15–17]. The stunted growth in children and its health effects were also significant concerns in the pre-COVID world [18].

The agriculture sector is the primary source of food supply in any country [19]. The farm and Agri-land in rural and peri-urban areas are responsible for supplying both types of food sources (plant and animal) and dairy products [20,21]. The FSC has evolved over time, and recently intermediaries are imperative to complete the supply chain between farmers and retailers. The intermediaries are responsible for the marketability of the Agri-products and control the transaction costs, mainly comprised of logistics operations [22]. The prices of agriculture and food commodities are susceptible to price elasticity and respective market demand and supply. Moreover, continuous fluctuations in transaction cost adversely impact retail prices that leads to higher FSC disruption [23,24].

As a response to confining COVID-19 spread, the authorities worldwide restrict people to people contact and regulate social distancing to keep the number of COVID-19 cases low [25]. Such measures stressed the already fragile midstream and downstream to result in total disruption of the food chain [26]. The intermediary market plays a crucial role in supplying food, particularly in densely populated areas in Asian countries. During the pandemic, markets are closed to minimize infection spread [27]. Apart from the absence of buyer and seller, there is a shortage of labor in the wholesale markets, vegetable Bazaars, and cold storage warehouses to load and unload goods in peri-urban centers. The disruption in FSC is mainly attributed to forced restrictions on inter-city and inter-country movement and the thickness of borders [23, 24].

Although stringency measures are subjective in nature, however, Government Response Tracker (OxCGRT) scientifically gathers information on government policy response that includes 18 indicators scaled from lower to higher (0–100) confinement measures. Fig. 1 visualizes the stringency index of our sample Asian countries, representing

a higher confinement rate (Average > 70) from April 2020 to July 2020 [28]. Moreover, these countries are relatively underdeveloped in logistics infrastructure and supply chain network, highly populated, embodied with poor institutional governance, facing a higher unemployment rate, poverty, undernourishment, and crime [29]. These relative backwardnesses produce a butterfly effect in the presence of higher stringency measures. Halted economic activities and lower socio-economic status translate into extreme poverty, hunger, crime, and undernourishment. Fig. 2 portrays the global spatial map, reiterated our preposition that Asia is the more vulnerable region that accounted for the highest rate (up to 16%) of undernourished. Therefore, this study provides valuable insights to estimate the empirical link between undernourishment and food supply chain disruption. Besides FSC disruption, this study also draws the connection between undernourishment, crime rate, per capita income, and allocation of government health expenditure to combat COVID-19, which has greater policy relevance.

Based on the above discussion, this study mainly focuses on the undernourished cases, mostly affected by COVID-19 due to the disruption of the supply chain and halted economic activities. There is no doubt that COVID-19 and its countermeasures affect each stage of FSC (See Table 1). A typical food supply chain is made up of six stages: Sourcing of raw materials, production, processing and packaging, storage, wholesale distribution, retail redistribution to consumers (Siche, 2020). Since all processes and stages in a supply chain are strongly interlinked with each other, a slight delay or glitch can trigger a butterfly effect resulting in a significant loss in the yield and output (FAO, 2020k). Moreover, if any of these stages is compromised, various issues will arise, and the whole supply chain will jeopardy. The post-COVID-19 has aggravated the FSC problems in the developing world [30]. The challenge is not only zero-hunger but also to keep the rate of infection at a minimum. Researchers are still struggling to predict the total eradication of the disease or produce a vaccine to cure it. COVID-19 pandemic is a black swan event that has shaken the whole world and changed our everyday lives [31].

The world's economy faces a meltdown with increasing poverty and decreasing healthcare services opportunities to the poor [32]. The developing and underdeveloped countries have already directed small economic resources to curtail the spread. A higher number of COVID-19 cases significantly impact the trailing economy and health care [33]. To assist developing nations, donor agencies will play a central role in the economic uplift. The International Monetary Fund (IMF) provides debt relief funds for 25 member countries to address the impact of COVID-19 and a further relief of rescheduling of loan payments (IMF, n.d.). The SARS-COV-2 pandemic continues, and the world is observant of how it

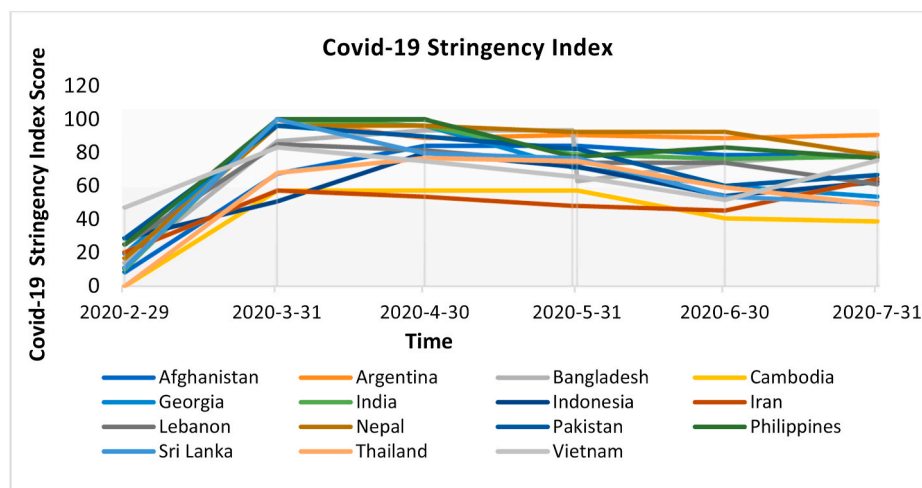


Fig. 1. COVID-19 stringency index of sample countries. source [28].

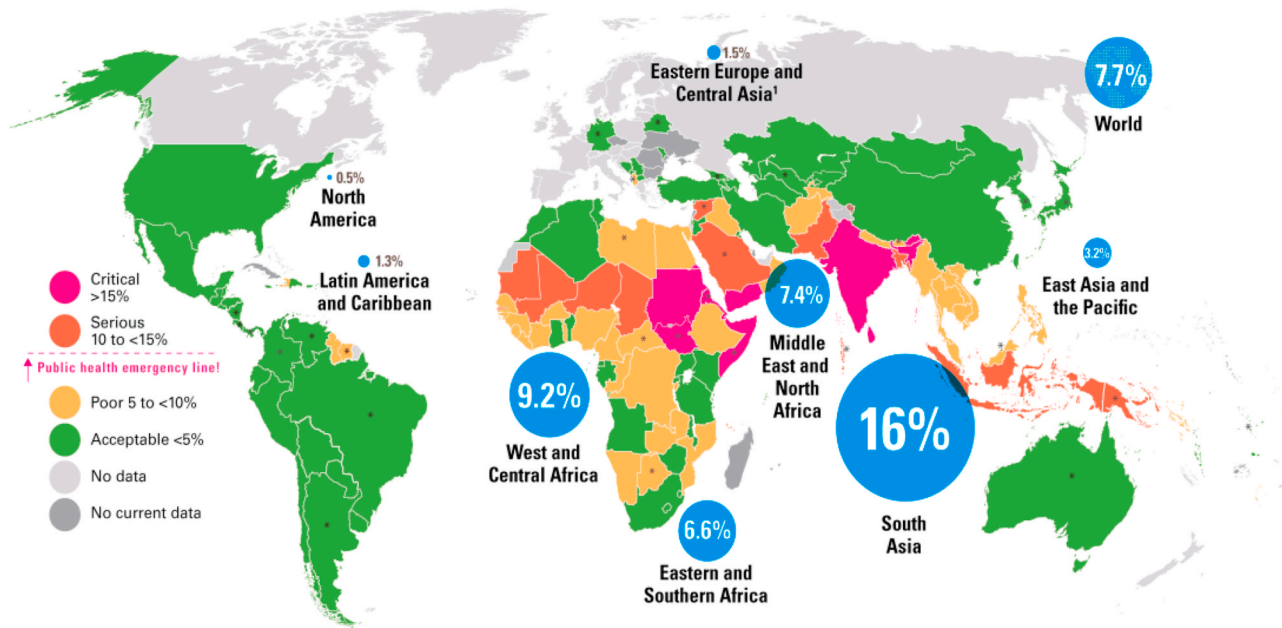


Fig. 2. Undernourishment across the globe.  
Source: UNICEF (2020).

will play out in the year 2021.

The remainder of this paper is as follows: Section two review the literature; Section three explain materials and method; Section four contains results and discussion; Section five provides conclusion and policy recommendations.

## 2. Literature review

The global population will exceed 9 billion people by 2050, meaning higher demand for available water, food, and arable land. Nutrition deficiencies, food safety problems, consumer attitude, post-harvest damages, inconsistent regulations are all striking challenges that must be met in sustaining food security. These challenges lead to higher undernourishment and hunger worldwide, motivating the global community to take sequester measures. Conceivable solutions comprise improvements in FSC technologies, innovative food formulations, and food engineering [21,34]. The pre-COVID-19 statistics by Global Nutrition Report (2020) approximated 2 billion people worldwide lacking essential micronutrients (vitamin A and iron), and a further 2 billion are obese. Food and Agriculture Association (FAO) (2020) highlighted that the number of undernourished people is exponentially rising worldwide, and their projection shows that this number will exceed 840 million by 2030. The ill-planned FSC, lack of Agri-Resources, and a slow economy are the issues that exacerbate the conditions. Some examples from the vast list of countries are Afghanistan, Pakistan, India, Rwanda, Libya, Tanzania, and Uganda [18] (List of Developing Countries | ISGE 2018, n.d.).

The severity of COVID-19 has put global FSC resiliency at immense risk and disruption inevitable. The downstream witnesses demand shocks due to consumer insecurity on supply infrastructure and thick borders restricting retail market supplies [23]. The upper and middle stream suffers supply shocks due to lack of transportation and workforce shortage because of confinement measurements and lockdown [35]. Table 1 explains the possible effects of COVID-19 at each stage of the FSC network. Although, these stages are highly interlinked and disruption at one stage jeopardizes the whole FSC network. However, we have highlighted their possible individual and integrated effects amid rising COVID-19 shocks.

The growing number of COVID-19 cases are due to densely

populated and ill-planned cities in developed and underdeveloped countries. The dense population stimulates the spread of airborne communicable diseases through higher people interaction. The governments are enforcing lockdown to keep millions infected in confinement and halt the spread further. The confinement measure results in a shortage of labor and hurts demand and supply in the food supply chain [54]. The higher the infection rate at a particular location results in more stringent curfew-like measures to curtail the spread [55]. The lockdown continues as evidence suggests that relaxation in confinement can increase the COVID-19 fatality rate by up to 200% [56]. The confinement measure thus reduced the available labor force in all industries. The FSC is labor-intensive [50], and labor shortage has dislocated the chain [35], creating further adverse effects on people's nourishment, having a multiplier effect of increasing undernourishment.

According to the International Labor Organization (ILO) agriculture is the largest contributing sector that employs more than one billion people, accounted for 26.88% of total employment globally. The employment percentages are different from developed, developing, and underdeveloped countries; the maximum is 92% in Burundi [58]. The FAO statistic reflects 51.1% of in Africa and 31.9% in Asia employees are associated with agriculture [59]. The worth of agriculture, fisheries, and forestry value-added is equivalent to US 3.503 trillion dollars [60], and the food market's revenues to staggering US 7.48 trillion dollars [61]. The economies of developing and underdeveloped countries rely on agriculture and FSC for employment and exports to sustain their economic growth [62]. The agriculture and food sector will continue to employ in low-income countries in the foreseeable future [63].

The aggregated effect of unemployment impacts consumer's buying power in third-world countries, as many food items are income elastic [18,64]. Supply chain distortions and the higher unemployment rate in COVID-19 impacted food security and has led to price hikes of essential food items from animal and plant sources. The labor shortages due to lockdown are also affecting food exports in Agri-based economies [65]. Post-farm-gate economic activities besides basic Agri-products are also at higher risk. The small and medium enterprises (SME's), retail, and foodservice segment provide up to 60% of employment as in the case of Indian's Agri-economy. Many of these SMEs have departed the market because of the COVID-19 income shocks [35].

Other industries also reflect the bleak picture, and company's

**Table 1**  
Effect of COVID-19 on six stages of FSC.

Stages of Food Supply Chain	Impact of COVID-19
<b>Sourcing of raw materials</b>	Labor shortages in primary agricultural sectors (livestock production, horticulture, planting, harvesting, and crop processing) that heavily rely on seasonal labor [37], disruptions to transportation networks (air, road, water), and shortages of third party/middle man adversely affect sourcing and production of materials (Stephens et al., 2020). A large portion of raw material is procured through outsourcing, which mainly relies on a contractual employment network of a large number of people affected significantly due to panic, social distress, labor illness, payment issues/delays, banking closures, financial constraints [38,39]. A significant percentage of inputs are sourced from other countries, and border thickness leaves no option except to replace them with local inputs, which are already undermined (Ker, 2020).
<b>Production</b>	Production was reduced, suspended, or temporarily discontinued in many plants due to the workers who were found to be COVID-19 positive and who were reluctant to go to work, thinking that they would get sick at work, mostly in meat-processing food companies at the time of the outbreak (Devereux et al., 2020; Flynn, 2020). There are two production nodes one is agriculture, and another is food processing. Firstly, Agriculture and dairy output damaged mostly due to delay in cultivation, harvesting, and shipments emerged from labor and transportation shortages globally (ILO,2020). A large number of loss events were reported that farmers burning, disposing or dumping Agri and dairy-based products such as 14 million liters of milk are being dumped every day in US, 5 million liters of milk are at risk in one week in UK due to interrupted supply chain (BBC, 2020a). Also, the production capacity of pork facilities decreased by approximately 25% in late April (Devereux et al., 2020; Flynn, 2020). To back up the rhetoric, several initiatives were launches, such as 'Pick for Britain' campaign was aimed to find 70,000 British to work in the field and during the harvest (Nature Plants, 2020). Secondly, a major share of processed food in the supermarket is produced using different primary inputs. Consumer panic buying behavior puts pressure on demand and production. However, the shortage of inputs, labor, and transportation is a double-edged sword [23]. One input in the production process is an output of the former process. Thus, any disruption in one end disturbs the whole FSC. Moreover, labor and raw material shortages put downward pressure on the production process. Such as farmers failed to transport their perishable products (dairy, vegetables, fruits), and meat/seafood traders jeopardize their business due to the closure of the meat-related business [37, 40]. The restricted input supply and labor shortages are two prime threats raised by COVID-19 and related stringency measures [40].
<b>Processing and packaging</b>	Although advanced FSC is less affected by labor shortages due to atomization, however, 70% of the Asian food economy based on transitional FSC, which is severely hit by stringency measures, restricted movement of labor, social distress, and panic [35]. A large portion of the informal labor force move from nearby villages or countryside to nearby packaging and processing units in Asian countries, and movement restrictions create a labor shortage. These units also faced scarcity of processing and packing material due to disruption in the transport and production network. Food supply chains dominated by a few large concentrated processors (e.g., meat/seafood packing) may be particularly vulnerable and initially created as a source of COVID-19 spread. The hygienic requirement in food processing and packaging further jeopardizes FSC [40]. The majority of food, bakery,

**Table 1 (continued)**

Stages of Food Supply Chain	Impact of COVID-19
<b>Storage</b>	and beverage processing is highly labor-intensive and affects the most due to labor shortages and the relative risk of virus transmission through packaging material [41,42]. Storage cost increased due to lower turnover of stocks, particularly perishable goods such as fruits, vegetables, and dairy products. Meat and seafood processing is highly labor-intensive and falls in SME; faced strict confinement due to highest COVID-19 infection ratio in these cold storage houses. Worker illness, self-isolation, or movement restrictions further disrupt storage management [26,41]. Moreover, logistics barriers that disrupt food supply chains also weaken high-value goods due to their short shelf life (Shahidi, 2020; FAO, 2020j, FAO, 2020k).
<b>Wholesale distribution</b>	Globally, 75% of companies have reported supply chain disruptions because of transportation restrictions, including border closures and other stringency measures [43]. Primarily, the wholesale distribution industry has four major sub-segments: healthcare, industrial, high-tech, and food service. COVID-19 has affected all sub-segments, some more than others and each one in a slightly different way [40,44–46]; Magnus Meier 2020). Disruptions to transportation networks; closure of wholesale markets, financial constraints, market uncertainty, availability of staff, closure of distributor's business spots, shortage of heavy vehicles, shortage of labor for loading unloading goods shipped from storage to wholesale market and their subsequent sales points [39,47].
<b>Retail redistribution to consumers</b>	Retail distribution is a critical factor for the food industry, especially in the global crisis. The biggest issues in the food supply chain are obtaining raw materials from suppliers and ensuring the continuity of food flow from manufacturers to end-users (Alonso et al., 2007). The retail sector heavily relies on salesforce and transportation services. Both of them are poorly affected due to strict stringency measures [48]. Also, the closure of the retail market further jeopardizes the end-node of FSC. The non-essential retail market is mostly affected by COVID-19, such as the sale of the retail clothing market in US is dropped by 89.3% in April 2020, while the grocery retail market grows by 13.2% [49]. Similarly, in the European Union, sales of food items increased by 1.2%, while sales of non-food items decreased by 23.8% in April 2020 (Eurostat, 2020). Social distancing and lockdowns measures affect retailers with physical stores more than online retailers. Although total sales decreased around the globe, however the share of e-commerce retail increased. Such as France (United Kingdom), retailing through e-commerce risen from 6% to 10% (19.1%–30.7%) in April-2020 (National Statistics UK 2020; [51]. Moreover, the risk of riots, theft, crime, burglary, and mob poses a high threat to retail distribution or superstore in the pandemic situation [52,53].

financial conditions severed due to the COVID-19 lockdowns, forcing many businesses to closure and filing bankruptcy [66]. quotes James Hamond, CEO of New Generation Research, which runs bankruptcy data, "I am pretty confident we will see more bankruptcies than in any business person's lifetime." The numbers have surpassed the economic decline of 2008 in the US. One of the most affected industries which the world has witnessed during lockdown is the aviation industry. Due to a decrease in aviation consumption, International Air Transport Association (IATA) expected to book a loss of US 84 billion dollars in 2020, with hundreds and thousands lay off [67,68].

The poor economic conditions worldwide have increased unemployment percent and poverty, leading to social unrest and increased government financial burden [69]. The IMF has forecasted an



unemployment rate for the year 2020 based on 100 countries average is 9.47% with the highest percentage of South Africa, which is 35.31% and lowest in Thailand 1.1%, see Table 2 [70].

The contours of COVID-19 impact economic growth and the unemployment rate globally [2,72]. The rising rate of unemployment and low economic growth leads to higher social distress, crimes, hunger, and undernourishment.

From the above debate, it is concluded that food supply disruptions (supply-side) and panic behavior (demand side) creates excess demand, leaving continuous upward pressure on goods prices. The poor people are more vulnerable to food prices. Also, the people living under the poverty line are mostly engaged in the informal sector as daily wagers. They do not secure by unemployment allowance or any financial compensation from their employers. Therefore, all these factors affect their socio-economic and health conditions, which can be translated into a higher undernourishment rate. Together, these factors increase the vulnerability of undernourished people, who are already on the verge of poverty and hunger. According to the [59] forecast, 14.4 million undernourished people add to the current total due to the COVID-19 pandemic [73]. The above discussion concludes that how COVID-19 and respective stringency measures caused a disruption leads to higher undernourishment cases. Despite its significant importance, there is a dearth of empirical evidence that draws a systematic link using recent socio-economic figures to integrate COVID-19 stringency measures, FSC disruption, and their respective impacts on undernourishment.

### 3. Materials and method

The disruption in the FSC creating several social and economic issues, including unemployment, crime, and under-nourishment. This study examines the connection between under-nourishment and economic growth, health expenditure to combat the pandemic, crime index, and COVID-19 active cases inferred from the panel of 15 Asian countries (see Appendix A). The rationale for selecting Asian countries is mainly attributed to higher stringency measures (>70%) taken by Asian government to control COVID-19 spread, higher undernourishment rate (9.6%), higher unemployment rate (5.51%), contracted economic growth rate (2.7%), and absence of sequester infrastructure and supply chain network (70% traditional logistics). The confinement measures have hampered economic growth and increased the crime rate amid rising poverty and unemployment [65,74,75]. Healthcare infrastructure has been affected due to high reported cases of critically ill patients. To accommodate the health sector, respective governments increased health expenditure funding [76]; J. R [77]. The severity of COVID-19 and its multi-dimensional effects has resulted in FSC disruption and increasing under nourished cases [73]. Based on the former discussion, this study estimates the following model:

$$LUNC_{i,t} = \alpha_0 + \beta_1 LEC_{i,t} + \beta_2 LHEC_{i,t} + \beta_3 LCI_{i,t} + \beta_4 LCAC_{i,t} + \mu_{i,t} \quad (1)$$

Where  $i$  and  $t$  indicate countries and years, respectively,  $UNC$  is undernourished cases,  $EC$  is economic growth,  $HEC$  reflects health expenditure to combat COVID-19,  $CI$  shows crime index, and  $CAC$  is COVID-19 active cases. The precede  $L$  is the natural logarithm, and  $\beta_1 \dots \beta_4$  are

parameter slopes, and the error term is denoted by  $\mu$  in the model.

The panel data inherently hold the problem of country-specific effects, endogeneity, and lag dependency, which distort true parameters in case of usual estimators like Fixed effect (FE), random effect (RE), and ordinary least square (OLS) [78]. In contrast, the generalized method of moments (GMM) efficiently deals with those explanatory variables that are correlated with the error term. The use of lagged endogenous regressors as explanatory variables are highly recommended by Ref. [79] to control endogeneity and autocorrelation. Thus, the transformed Eq. (1) by GMM stated as

$$LUNC_{i,t} = \alpha_1 + \gamma LUNC_{i,t-1} + \beta_1 LEC_{i,t} + \beta_2 LHEC_{i,t} + \beta_3 LCI_{i,t} + \beta_4 LCAC_{i,t} + \eta_i + \mu_{i,t} \quad (2)$$

It is further simplifies

$$LUNC_{i,t} = \alpha_1 + \gamma LUNC_{i,t-1} + \beta X_{i,t} + \delta_i + \lambda_t + \mu_{i,t} \quad (3)$$

The  $\delta_i$  records country-specific effects,  $\lambda$  show the period-specific effect, and  $X$  denotes the set of independent variables. The country-specific effects are removed by Difference-GMM (DIF-GMM) as provided by

$$LUNC_{i,t} - LUNC_{i,t-1} = \alpha_1 (LED_{i,t-1} - LED_{i,t-2}) + \beta (X_{i,t} - X_{i,t-1}) + (\lambda_t - \lambda_{t-1}) + (\mu_{i,t} - \mu_{i,t-1}) \quad (4)$$

The lagged endogenous variable  $LED_{i,t-1} - LED_{i,t-2}$  associates with error  $\mu_{i,t} - \mu_{i,t-1}$ , as considered in DIF-GMM, impose bias in the estimation [79]; S. A. R [80]. In DIF-GMM estimator, the use of the lagged level of the independent variables are instrumented that rectifies disturbance term and ensure no auto/serial correlation between error terms and regressors [79]. To this point, the GMM conditions applied as follows:

$$E[LUNC_{i,t-s}(\Delta\mu_{i,t})] = 0 \text{ for } s \geq 2 \quad (5)$$

$$E[LX_{i,t-s}(\Delta\mu_{i,t})] = 0 \text{ for } s \geq 2 \quad (6)$$

This estimation approach does bear a drawback, as highlighted by Blundell & Bond (1998), suggesting that the results of DIF-GMM may not always reveal valid estimations. This exceptionality may occur due to the small sample size and when the data has continuous endogenous and exogenous variables, which may not measure as a reliable instrument [81]. In this study, reverse causality may exist between  $UNC$  and  $CAS$ , suggesting that undernourished people may have relatively lower immunity; thus, they are more vulnerable to catch respiratory viruses such as COVID-19. Few recent studies endorse the same preposition [82]. To address these issues, system generalized method of moments (SYS-GMM) estimator is considered an appropriate option, where reverse causality and endogeneity are removed using lagged endogenous regressors as instruments [78,83]. Moreover, SYS-GMM estimator allows first-order serial correlation while rejects second-order serial correlation in the model. Therefore, it can provide efficient estimates in the presence of auto-correlation and endogenous variables based on the instruments adopted from lagged values of endogenous regressors.

The data of the undernourished population is extracted from Ref. [59]; which provides a headcount of the total undernourished people in millions across sample countries. The data of economic growth is taken in the form of a monthly percentage change sourced from Ref. [84]. This study access [61] to collect data on health expenditure, which are specifically allocated to combat COVID-19 in current USD millions. The governments around the globe allocated financial packages to compensate for exploding health expenditure due to increasing COVID-19 cases. It is important to note that we have only taken additional funds allocation during COVID-19 period and do not consider overall usual annual budgetary allocations to the health sector. The data of the crime index are extracted from Ref. [85]. Numbeo's crime index considers crime levels lower than 20 as very low, between 20 and 40 as

**Table 2**  
Regional Unemployment rate.

Continents	Rate % in 2020	Rate % in 2021	Averages based upon
Asia	6.24	5.51	Based on 22 countries
Europe	9.61	8.07	Based on 41 countries
Africa	15.84	14.08	Based on 8 countries
Australia	9.88	7.84	Based on 4 countries
North America	10.22	8.98	Based on 15 countries
South America	9.62	8.46	Based on 10 countries

Source: International Monetary Fund [71].

low, 40 to 60 as moderate, while levels between 60 and 80 are high. Crime levels higher than 80 are “very high. Finally [86], is used to extract the active number (positively tested) of COVID-19 cases. We used the monthly panel data of Asian developing and least developing countries from January 2020 to July 2020. The list of variables and the sources are presented in Table 3.

#### 4. Results and discussion

The descriptive statistics of the study in Table 4 reveals positive mean and standard deviation. The undernourishment in selected Asian countries tends to increase with the factors tested for this study. The popping undernourished cases in these countries are observed due to their lower socio-economic profile and lack of funds allocation to combat COVID-19 related health expenditure. The economic growth is hampered by halted economic activities as a consequence of COVID-19 confinement measurements. Together, these factor leads to higher unemployment, poverty, disruption of FSC, and translate into higher undernourishment rate. The magnitude of this impact further increases if social evils such as crime and theft are taken into account. The governments do not have sufficient resources to repair the food supply chain or provide a stimulus for economic uplift, causing undernourishment in Asian countries.

The correlation Table 5 exhibits that economic growth negatively correlates to undernourished cases, indicating that higher economic growth can reduce undernourishment. The crime index positively correlates to undernourished cases suggesting that higher crime rates and undernourishment move together in the same direction. The negative correlation between the crime index and economic growth means that economic growth can decrease society’s crime rate. Lastly, health expenditure negatively correlates with the undernourished population and crime index while positively correlates with economic growth and active COVID-19 cases. The inverse relations suggest that health expenditure decreases the undernourishment and minimizing the severity of COVID-19 cases in the country.

Table 6 represents the estimates from fixed effect (FE), random effects (RE), and ordinary least square (OLS) estimators. The results show that higher economic growth significantly reduces UNC in FE, RE, and OLS by 0.195%, 0.190%, and 0.190%, respectively. The results imply that a higher economic growth in host countries increases the living standards and income pool of inhabitants that reduces UNC through two-channel. Firstly, a country’s income growth leads to higher funds allocation and food security programs, leading to lower UNC and improving public health. With a surplus budget, the government provides employment opportunities and direct compensation programs, particularly in the underdeveloped areas, where UNC is most prevalent. Secondly, higher employment opportunities increase per capita income, motivating the parents to provide healthy food to their kids. Several empirical studies endorse that higher income leads to higher living standards in food, housing, and education (Ross et al., 2006; Pearson et al., 2019) (see Table 7).

Extending a similar argument, public health expenditure allocated for COVID-19 significantly reduce UNC. It is mainly attributed to the excellent health infrastructure, where UNC decreases with increased

**Table 3**

Source of data.

Variable	Description	Source
Under-Nourished	Population in millions	[59]
Economic Growth	Annual Percentage	[84]
Health Expenditure to combat COVID-19	Current USD in Millions	[61]
Crime Index	Index scaled from Lower to higher crime rate (0–100)	[85]
Covid-19 Active cases	Total number of people who test positive	[86]

**Table 4**

Descriptive statistics.

Variable	Acronyms	Mean	Std. Dev.	Min	Max
Under-Nourished cases	UNC	3.508	0.338	3.021	3.751
Economic Growth	EC	1.354	0.050	1.308	1.461
Health Expenditure to combat COVID-19	HEC	1.714	0.081	1.623	1.869
Crime Index	CI	7.381	3.751	1.005	11.385
COVID-19 Active cases	CAC	3.878	0.060	3.788	3.925

**Table 5**

Correlational matrix.

Variables	UNC	EC	CI	CAC	HEC
UNC	1				
EC	−0.520	1			
CI	0.999	−0.546	1		
CAC	0.245	−0.595	0.279	1	
HEC	−0.876	0.067	−0.558	0.250	1

**Table 6**

Empirical results from Static Panel Models (FE, RE, OLS).

Variables	FE	RE	OLS
EC	−0.195*** (0.047)	−0.190*** (0.042)	−0.190*** (0.040)
HEC	−0.414*** (0.069)	−0.441*** (0.049)	−0.431*** (0.045)
CI	4.974*** (0.101)	4.941*** (0.073)	4.971*** (0.060)
CAC	.0004 (.0005)	0.0005 (0.0003)	0.005*** (0.0002)
Observation	78	78	78
No. of Countries	15	15	15
Hausman test	0.8369		

**Table 7**

System GMM estimations.

Variables	DIF-GMM	SYS-GMM
Lag UNC	0.005*** (0.0004)	0.005*** (0.0003)
EC	−0.368*** (0.006)	−0.368*** (0.005)
HEC	−0.318*** (0.007)	−0.318*** (0.006)
CI	5.091*** (0.014)	5.091*** (0.024)
CAC	0.050*** (0.002)	0.051*** (0.006)
A-B test for AR (1)	0.000	0.000
A-B test for AR (2)	0.689	0.587
Hansen Test	0.186	0.163
No. of Instruments	8	

Note: AR-1 test confirms the existence of first-order autocorrelation, and AR-2 shows that the model has no second-order correlation. Also, the Hansen test confirms the validity of instruments used in GMM estimators. These three tests confirm the stability of GMM estimators.

health structure quality. From a social perspective, the crime rate is significant, which emerges primarily from poverty and inequality. A major strand of literature highlighted that a higher unemployment rate, poverty, and low living standards compel the inhabitants to indulge in robbery, extortion, and theft. In the same pursuits, the results report a positive link between crime and UNC, indicating that a lower crime rate leads to lower UNC and vice versa. Any policy initiative that caters to UNC significantly helps to control the crime rate. Various empirical studies reveal that the crime rate is more dominant in areas where people have lower means and poor health conditions. Besides UNC, crime and poverty are a more significant concern for social imbalance in recent years. The number of COVID-19 cases represents a positive association with UNC. This relationship links through the countermeasures of COVID-19, such as lockdown of economic activities, shut-down of the whole supply chain process, closure of the border, and transportation; all these factors further decrease food supply. Uncertainty and

unexpected food demand increase food prices. Lower supply and higher costs of food items further increase the number of UNC. Globally, several incidents are reported, such as in India many adults, women, and children kept undernourished or even died of hunger due to the food shortages and food supply chain's disruptions [87].

#### 4.1. Empirical results from dynamic panel model (SYS-GMM)

Unlike FE, RE, and OLS, the GMM modeling framework integrates dynamic and endogenous relationships among variables. Historical data and studies reveal that the current year of UNC has positively correlated with the previous year's UNC. Therefore, UNC is also derived by its own lagged values. The dynamic GMM models help to incorporate last year's effects while dealing with endogeneity by generating instruments for endogenous variables. The sign and significance of both difference GMM and system GMM are similar to prior findings of static models (FE, RE, and OLS); however, their magnitude shows significant variations. The lag dependent variable is significant and positive at a 1% level, confirming the rationality of dynamic SYS-GMM estimates.

The dependent variable's lag coefficient shows a 1% increase in last year's UNC increases in the current year's UNC by 0.005% in both GMM estimators. Economic growth negatively influences UNC, which shows that a higher income significantly reduces the UNC by 0.368% in both GMM estimators. Although similar to static models, the magnitude of the EC coefficient doubles than the static model. In panel data, static models usually underestimate/overestimate the coefficient values due to possible endogeneity and country-specific effects; however, GMM based estimators efficiently deal with these issues and produce robust estimates. The allocation of public health expenditures to tackle COVID-19 pandemic are negatively links with UNC. The coefficient values show that a 1% increase in health allocations reduce UNC by 0.318% in GMM estimators. The results suggest that reasonable health funds allocation and infrastructure significantly improve the living conditions and mitigate the malnutrition problem.

The coefficient value of the crime index shows that a 1% increase in the crime index increases UNC by 5.09%. The magnitude of the crime index is substantially higher, indicating the importance of social evils in terms of UNC. Usually, UNC emerges from a low social structure that is more prone to unemployment and indulges in criminal activities. This result implies that if policy intervention controls the crime rate, it is also equally helpful to reduce UNC amongst other tools. With addressing social issues, direct economic benefits underperformed to deal with poverty and malnutrition in children. Also, a higher population is the leading cause of UNC in Asian countries; therefore, education and awareness help decrease dependency and improve life quality. Recently, COVID-19 possess a lot of socio-economic impacts on human life. Our results show that a 1% increase in the intensity of COVID-19 leads to a 0.05% increase in UNC. A higher intensity of COVID-19 disrupts the food supply chain due to strict lockdown and other stringency measures. Also, the shortage of food supply and uncertainty in society boost local food prices, which harms poor people's health in general and malnutrition of children in particular. The unemployment rate has also shown a rapid increase for daily wagers and workers in the informal sector, which further imposes a harmful effect on their life and UNC (Blustein et al., 2020).

These results are endorsed by Agee (2010), suggesting that greater access to health infrastructure and higher income leads to lower undernourished cases. On the other hand, Rosegrant and Meijer (2002) argued that food policies and investments significantly reduced malnutrition by 43% in 2020. A recent study emphasized that poverty and lower-social economic status are the main factors of malnutrition in Africa (Adeyeye et al., 2017). Our findings are also echoed by Inoue and Todo (2020), who found that lockdown measures in megacities help control the spread of COVID-19; however, it distorts the food supply chain. On a global scale, the food supply chain is adversely affected by transport and economic activity closure, which left far beyond impact on

humans, particularly on poor's lives, such as no proper food or increase number of undernourished cases (Guan et al., 2020).

Furthermore, the consistency of the outcomes acquired through the dynamic System-GMM estimator depends on the validity of the instrument. The bottom portion of Table 6 presents the Hansen test relevant figures for over-identification with its concerned P-values for all instruments of the additional orthogonality conditions for the level equation, indicating that the other instruments associated with the system GMM estimator are valid. The test hypothesis of AR-1 is rejected while AR-2 cannot reject, pointing towards the assumption that the residuals are serially un-correlated at the second-order is fulfilled.

Global food security always remains a key agenda reflected in SDGs. Although food deprivation and hunger rate are marginally decreasing since 2000 [88]; however, few regions such as Asia and Africa are extremely vulnerable to a worsening of food and nutrition insecurity caused by the overlapping economic, health, and COVID-19 crises [89]. A similar trend is witnessed in our sample countries by the Global Hunger Index (GHI). GHI provides a holistic picture of undernourishment, stunting, and mortality of children that categorizes and ranks countries on a 100-point scale, where 0 is the best score (no hunger), and 100 is the worst. Table 8 exhibit most of our sample countries are categorized as "Serious" in GHI, indicating the vulnerability of their inhabitants toward hunger and undernourishment due to COVID-19 and related disruption in FSC. Globally, more than forty countries are falling on a serious scale (20–34.9), out of which eight countries fall in our sample list [88]. Several global initiatives are taking place to divert food waste towards poor people, which can be a tool to mitigate undernourishment [90,91].

## 5. Conclusion

Undernourishment exacerbates by the COVID-19 pandemic, and the measure applied to combat the further spread of the infectious viral disease. The epidemic has compelled countries worldwide to regulate and restrict populace mobility and transportation, affecting to reduce the consumer buying power due to uncertainties. The buying power has shrunk to the lowest, as witnessed during the historic great global economic depression. As the catastrophe is global, the resulting financial implication observes worldwide. However, the magnitude of severity depends on the economic muscle of the country. The shrunk buying power is forcing many companies closure, thus resulting in an interruption in global trade. The state's economic growth rate has declined, and the forecast suggests the trend will continue in the coming years. Conjoin with economic growth is the increasing unemployment rate, which is also the main contributor to reducing consumer buying power

**Table 8**

Global hunger index severity in sample countries.

Rank1	Country	2005	2010	2019	GHI Severity Scale
108	Afghanistan	43.2	34.3	33.8	Serious
102	India	38.9	32	30.3	Serious
94	Pakistan	37	35.9	28.5	Serious
88	Bangladesh	30.7	30.3	25.8	Serious
77	Cambodia	29.4	27.6	22.8	Serious
73	Nepal	31.3	24.5	20.8	Serious
70	Indonesia	26.8	24.9	20.1	Serious
70	Philippines	21.4	20.5	20.1	Serious
66	Sri Lanka	21.2	18	17.1	Moderate
62	Viet Nam	23.8	18.8	15.3	Moderate
53	Lebanon	10.3	8	11.6	Moderate
45	Thailand	13.2	12.7	9.7	Low
39	Georgia	10.4	8.4	9.2	Low
31	Iran	9.4	8.2	7.9	Low
19	Argentina	6.2	5.9	5.4	Low

GHI Severity Scale 0–9.9 (low), 10–19.9 (Moderate), 20–34.9 (serious), 35–49.9 (Alarming), 50 & Above (extremely alarming).

Source [88].

globally.

The developing and under-developed countries are the most hard-hit by pandemic due to the scarcity of economic resources. The third world lists unfortunate countries already suffer from many undernourished cases, and COVID-19 increases the magnitude. The rate increases and the trend continues until the environment is congenial to make resources available to reduce undernourishment. The large populace of these countries is compelled to consume affordable food from plant sources, which also a significant cause to increase undernourished as the source lacks essential micronutrients.

As most developing countries are Agri-based economies, the food supply chain and related services disrupt confinement measures. The effects are two ways on the food chain as demand decreases domestically, along with supply disruptions make it volatile to impact economic growth and labor opportunities for the masses. The country with poor economic conditions has limited financial funds, routed to address most current pressing issues, the priority for all countries to combat COVID-19 increasing active cases. The only way to reduce is by confinement measures, lockdown, and social distance as there is no medical cure. By nature, the virus communicable only spreads from human inhalation of the infected patient's droplets through the nose, mouth, and eyes. Healthcare budgets have increased many folds since the start of the pandemic, and the tradeoffs are economic growth and food supply. Both contribute directly and indirectly to increase the undernourished cases.

Finally, the COVID-19 pandemic has resulted in increased reported crimes. The rise in the crime rate relates to poor economic conditions and lack of labor opportunities, food supply disruptions, and no funds available by countries to assist the masses in this regard. The future unfolds every day with an increasing number of undernourished cases. The United Nations and developed countries should remain vigilant as the increased undernourishment cases can switch government priorities from combating COVID-19 to the food supply for most poorly. The priority shift will make it difficult for the rest of the world to control and eradicate COVID-19 and uplift and better the global economy.

### Policy implications

The rate of undernourishment has increased in the COVID-19 pandemic. The primary cause of undernourishment is unreliable FSC and its disruption. To combat undernourishment, we would suggest the government food authorities, global agencies, Non-Government organizational, and food businesses the following practical implications in making FSC resilient in low-income countries.

1. The right information is the key and essential solution to the problem. Every node in the food supply chain network should be digitally connected to share information. The information-sharing must be to and from in both directions of the chain. Upstream should continuously update stock position and arrivals from farms in the chain. Downstream should share stock position in the middle and at the end to ascertain real demand removing the risk of bullwhip creation. The critical success factor depends on the complete integration with members throughout the chain. It envelopes farmers, cold storage facilities, intermediaries, distributors, export intermediaries, customer warehouses, retailers, and restaurants. In the case of domestic FSC, export intermediaries will not be part of the chain.
2. The government food regulation authority should enact a law to establish collaboration between all team members in the FSC. A centralized regulating body should ensure that upstream and downstream are well connected and correct information is shared. The regulating body should also audit sites must verify to increase the reliability of the data transmitted. Collaboration and information sharing would impact three "Vs." (increase visibility and velocity to reduce variability in the food supply chain). The importance is manifold, like Corps arrival and animal available for supply are vital to control prices in the whole chain.

3. Cellular devices are economical ICT (information communication technology) equipment best suited for the purpose. The cellular technology based on the triple "A" (accessibility, availability, and affordability) concept and 4G technology is fast, reliable, and very affordable in this regard. Cellular devices and apps are very human-friendly for public use, so the information sharing will not be cumbersome for team members in the chain.
4. For such vital information on agri-stock demand and supply to circulate in the food supply chain, blockchain is inevitable to secure data and avoid tamper. The data is crucial, and information disruption or tampering can result in national and international crises. The wrong information can cause unrest in public leading to insecurity and buying spree to create artificial demand and FSC disruption.
5. Farming in developing and underdeveloped countries must digitally transform to increase efficiency. The advantages are enormous to better FSC and farm management. Industry 4.0 and its ingredients are most beneficial in this regard. RFIDs are one good example that could help in tracking animal stock for treatments and medical records. Industry 4.0 would also help trace products throughout the chain and increase overall quality standards to expand export opportunities to developed countries and reduce FSC disruption.
6. The government should invest by providing zero scheme loans, low-interest loans, or subsidies to farmers, food factories, and restaurants. The loans to farmers will assist in BMR (balancing, modernization, and replacement) activities to implement modern agriculture practices and use technology blessings to better yield of agri-products. The introduction of new irrigation technology on farms is also very crucial in this regard. The BMR will improve overall profit and reduce any wastages in the process. Availability of economic-financial resources for food factories and restaurants will reduce unemployment and create demand to encourage farmers to increase yield. The encouragement for farmers will remove any risk of disruption in FSC, resulting in undernourishment.
7. The government should set up an R&D agency. The agency will equip farmers with the right information and raw material, seeds, and animal breeds. The information and better material increase productivity and help farmers focus on agri-supply, which is available in the shortest time to sell in the market. The lead time is vital to avoid any liquidity issues for investment in more crops and animal breeds. The agency should also provide modern farming training to improve farming practices.
8. The government should introduce chicken coop schemes in rural areas. The chicken coop is an economic startup and will eradicate poverty, especially in rural women, also reduces undernourishment in the locality. Chicken and eggs are a good source of protein and even an adequate supply of essential micronutrients to most countries. The excess is traded and beneficial for the overall FSC of the country.

### Limitations and future direction

Although this study attempts to integrate the possible impacts of FSC disruption on undernourishment due to stringency measures in COVID-19, however, several other factors can affect the prevalence of undernourishment, such as socio-political status of host countries, level of institutional governance, geographical location, human resource quality, FSC infrastructure and logistics quality. Therefore, future research can explore the link between FSC infrastructure, institutional governance, human capital development, and undernourishment. Also, the effect of COVID-19 and respective stringency measures can be investigated using different country's samples such as Africa, Europe, or the United States to compare the relative impact of FSC disruption on undernourishment in underdeveloped and developed countries.



## CRediT authorship contribution statement

**Syed Abdul Rehman Khan:** Conceptualization, Methodology, Software, Supervision, Writing - review & editing. **Asif Razzaq:** Conceptualization, Methodology, Software, Visualization, Investigation, Supervision, Writing - review & editing. **Zhang Yu:** Conceptualization, Methodology, Software, Visualization, Investigation, Supervision, Writing - review & editing. **Adeel Shah:** Data curation, Writing - original draft, preparation, Writing - review & editing. **Arshian Sharif:**

Visualization, Investigation. **Laeq Janjua:** Data curation, Writing - original draft, preparation, Software, Validation.

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## Appendix A

## List of sample countries

S.No	Name of countries	S.No	Name of countries	S.No	Name of countries
1	Afghanistan	6	India	11	Indonesia
2	Bangladesh	7	Thailand	12	Lebanon
3	Nepal	8	Cambodia	13	Philippines
4	Pakistan	9	Iran	14	Armenia
5	Sri Lanka	10	Vietnam	15	Georgia

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