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ORIGINAL ARTICLE

The economic burden of COVID-19 in a region with stringent response measures: A case study of Taiwan

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Abstract

The COVID-19 pandemic has imposed a significant economic burden globally, particularly in regions with stringent response measures. This study aims to assess the economic impact of COVID-19 in Taiwan, focusing on both direct and indirect costs. A cost-of-illness analysis was conducted, utilizing data from the Taiwan Centers for Disease Control (CDC), national databases, epidemiological studies, and economic surveys. The analysis included both direct costs (e.g., hospital admissions, outpatient care) and indirect costs (e.g., productivity losses due to long COVID, absenteeism, caregiving duties). The study encompassed Taiwan's population of 23.2 million, with particular attention to age-specific impacts on economic outcomes. The total economic burden of COVID-19 in Taiwan was estimated at USD 4431 million. Direct costs accounted for 24.40% (USD 1081 million), while indirect costs constituted 75.60% (USD 3350 million). The working age population bore the majority of this burden, with 88.68% (USD 3090 million) of total costs attributed to this group. Long COVID significantly contributed to the economic impact, causing a 35% reduction in productivity. Sensitivity analysis revealed that the frequency of outpatient visits among working age and elderly cohorts was a critical factor influencing overall costs. The study underscores the substantial economic burden of stringent COVID-19 policies in Taiwan, highlighting that indirect costs were nearly three times higher than direct costs. The findings emphasize the need for resilient healthcare systems and support for affected workers, particularly in regions with similar response strategies. The methodological approach offers insights that could be applied to other regions facing similar challenges.

Keywords: COVID-19, Cost of illness, Economic burden, Public health policy, Taiwan

1. Introduction

COVID-19, caused by SARS-CoV-2, has led to significant health and economic disruptions globally [1–3]. It spreads primarily through respiratory droplets and can also be transmitted through surface contact [4]. Symptoms range from mild to severe, including fever, cough, shortness of breath, fatigue, body aches, and loss of taste or smell [5–8]. The disease typically incubates for about 5 days [9] with severe cases affecting older adults and those with underlying health conditions [10], with rapid progression potentially leading to acute respiratory distress syndrome (ARDS) or organ failure [11].

In 2022, global COVID-19 cases exceeded 445 million, with over 1.2 million deaths reported [12,13]. Taiwan contributed over 8.8 million cases and 14,000 fatalities [14], while Southeast Asia and Africa struggled with variants amid limited hygiene and vaccination [15,16]. The pandemic caused a significant economic impact, amounting to approximately 14% of the global GDP from 2019. Europe and the USA bore substantial costs, with the

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Eurozone's GDP hit by 16% and the USA facing $13 trillion in economic losses within the first 20 weeks, nearly 90% of its annual GDP [17,18]. Direct costs per patient varied around USD 20,352 in the US, USD 4775 in Asia, and USD 5202 in Europe [19,20]. The global economic impact of COVID-19 has led to significant productivity and income losses, with Europe experiencing USD 1.15 billion lost in paid work and a total impact of USD 3.11 billion, mainly affecting males [21]. The United States has seen over 30 million adults apply for unemployment benefits, akin to the Great Depression Worldwide [22] , the pandemic has caused substantial productivity losses due to sick leave, hospitalizations, and deaths, affecting all sectors [19,21]. Taiwan has also witnessed reduced economic activity across industries, reflecting the pandemic's widespread effect [23,24].

Governments globally adopted various strategies against COVID-19, including quarantine, isolation, travel restrictions, and lockdowns [25]. Taiwan's COVID-19 response strategy differed from Western countries, emphasizing early and stringent border controls, extensive testing, efficient contact tracing, transparent communication, and technology-enabled virus tracking [26,27]. Therefore, affirming and understanding Taiwan's experience is crucial, as it holds significant value for international readers who are navigating similar challenges.

Among the complex health outcomes that have emerged from the pandemic, long COVID, which refers to COVID-related symptoms that persist for at least 12 weeks after acute SARS-CoV-2 infection according to WHO and US CDC criteria [28,29], represents a particularly challenging aspect of post-acute SARS-CoV-2 sequelae. Existing literatures have suggested that approximately 45% of COVID-19 survivors experiencing persistent symptoms such as fatigue, brain fog, and other debilitating manifestations that impact daily functioning [30]. Brain fog, characterized by cognitive disturbances and a prominent symptom of long COVID [31], is especially concerning for its impacts on work and social interactions. Along with other long COVID manifestations, including inflammatory biomarkers [32], neurological complications, and cardiopulmonary issues, these symptoms form a complex clinical picture affecting quality of life and productivity [33,34]. On the other hand, the persistent emergence of new COVID-19 variants, such as XBB and JN.1, serves as a stark reminder that the virus continues to pose a significant health threat, underscoring the importance of addressing the enduring effects of long COVID [6,35].

To address the current burden of COVID-19's economic impact in regions implementing stringent response measures, this study aims to provide a comprehensive assessment of Taiwan's economic burden of COVID-19. By quantifying both direct healthcare costs and indirect productivity losses—including those associated with long COVID and other post-acute sequelae—this research fills a critical gap in understanding the full economic toll of COVID-19 within rigorous containment policy frameworks. The analysis offers actionable insights for nations considering similar stringent public health approaches and their associated economic trade-offs.

2. Methods

2.1. Model structure and assumptions

This study adopts the methodology and assumptions from the white paper "A Neglected Burden: The Ongoing Economic Costs of COVID-19″ for estimating direct and indirect economic impacts [36]. The economic impact model for COVID-19 includes direct healthcare costs and indirect productivity losses. Direct costs cover inpatient and outpatient care, including hospital admissions, ICU care, consultations, medications, and emergency visits. Indirect costs are analyzed across age groups: pediatric (0–18 years), working age (19–64 years), and elderly (65 years and above). Indirect costs for the working age group include sick leave, reduced work capacity from symptoms, and economic consequences of mortality. For the elderly, indirect costs include necessary care, childcare responsibilities if caregivers are incapacitated, and productivity losses.

2.2. Data source

Data inputs were primarily drawn from the Taiwan Centers for Disease Control (Taiwan CDC) [37], the National Health Insurance Administration [38], the Ministry of the Interior [39], and the Directorate-General of Budget, Accounting, and Statistics (DGBAS) [40]. Additional data were obtained from official press releases, government websites, and online platforms. For international comparison and long COVID assumptions, we incorporated data from the U.S. CDC [29], the World Health Organization [28], and selected peer-reviewed literature retrieved from PubMed.

Non-peer-reviewed sources, such as government press releases and online announcements, were used to supplement parameter estimation and are cited in the footnotes of Tables 1 and 2 for clarity and transparency. These were utilized only when higher-quality or published data were unavailable,

and their influence on final estimates was further evaluated through sensitivity analyses. Key sources cited in the main text include official Taiwanese government repositories and international agencies; remaining supplemental references appear within table footnotes.

2.3. Parameters used in the model

The study's economic impact model for COVID-19 in Taiwan incorporates epidemiologic parameters (infections, mortality, healthcare use, long COVID rates in 2022, sourced from Taiwan CDC and other studies, detailed in Table 1) and cost factors (hospitalization, outpatient and emergency visit expenses, medication costs, quarantine days, sick leave days, work-from-home productivity, average daily earnings detailed in Table 2).

Table 1 summarizes epidemiological parameters from Taiwan CDC, reporting 8,817,192 COVID-19 cases in 2022. Infection proportions were 20.67% (pediatric), 67.77% (working age), and 11.56% (elderly), with case fatality rates of 0.002%, 0.038%, and 1.200%, respectively. Hospitalization was less than 1% (0.49%), and emergency visits occurred in 11.76% of cases. Approximately 3.97% of acute COVID patients received antivirals. Long COVID, defined as COVID-related symptoms that persist for at least 12 weeks after acute SARS-CoV-2 infection [33,34], and age-specific infection rates were sourced from US CDC and other studies.

Table 2 depicts the comprehensive cost parameters, productivity loss assumptions, and healthcare utilization metrics employed in the economic modeling framework. Direct costs included ward bed charges of $440.04 USD per day with an average 14-day hospitalization, outpatient visit costs of $44.95 USD for acute COVID-19 and $93.82 USD for long COVID, emergency department visits at $158.69 USD, and anti-COVID medication regimens at $727.80 USD. Indirect cost parameters encompassed quarantine duration (5 days), sick leave periods varying by age group (3.47 days for working-age adults), average daily earnings ($49.68 USD general population, $61.75 USD healthcare workers), work-from-home capacity (17.5% of population), and productivity loss assumptions. The model incorporated caregiving responsibilities for infected children and elderly, with productivity losses ranging from 25% for mild cases to 100% for severe cases. Long COVID-specific parameters included 75.8% of patients remaining well enough to work with 35% productivity loss, and symptom duration of 90 days for working-age adults and 14.6 days for pediatric and elderly populations.

2.4. Analysis

All cost parameters, including hospitalization rates, consultation fees, medication costs, and productivity loss assumptions, are detailed in Table 2. The study performed cost of illness analyses, with direct costs from inpatient settings calculated based on costs per hospital/ICU admission and the number of admissions derived from the hospitalization rate. For outpatient settings, costs of consultation and medication were separately calculated for acute and long COVID cases. Costs for acute COVID included parameters such as the number of reported cases, costs per primary care visit, and per emergency visit. The proportion of prescribed medication for acute COVID and the proportion of emergency visits per acute infection were used for the calculation of medication and consultation costs, respectively. Costs for long COVID were determined based on the estimated number of cases, assumed clinic visits during long COVID, and costs per visit covering both consultations and medications.

Indirect costs in the working age cohort were categorized into several aspects: (1) isolation due to acute COVID (inability to work), calculated using the number of infections, quarantine days, and average daily earnings; (2) working with symptoms of acute COVID, calculated based on days lost per infection, the percentage of productivity loss, and average daily earnings; (3) long COVID infection, calculated using the number of long COVID infections, duration of symptoms, and average daily earnings; and (4) premature death before the mandatory retirement age. In the model, premature death was defined as death occurring before the statutory retirement age of 65 years. Based on our data, the average age of death from COVID-19 in the working-age population (19–64 years) was 54.8 years. The economic loss from premature death was calculated by multiplying the number of lost working days until retirement (65–54.8 years $\times$ 365 days) by the average daily earnings ($49.68 USD).

For the pediatric cohort, costs were incurred by working age adults caring for children with acute or long COVID, calculated based on the average duration of acute and/or long COVID, the loss of productivity per day due to caring for children, the severity of symptoms, the number of infections, and average daily earnings. The calculations and assumptions for indirect costs in the elderly cohort were similar to those in the pediatric cohort. The same assumptions, parameters, and calculations used for the working age cohort were applied to elderly individuals still in the workforce.

Table 1. Parameters of epidemiologic characteristics used in the model.

Parameters	Value	Lower	Upper	Sources
Population and infections				
Total population in Taiwan	23,264,640	–	–	a
Total COVID-19 infections	19,809,716	18,809,716	20,809,716	b
Total reported infections	8,817,192	–	8,855,669	c
Proportion of infections with acute COVID	100.00%	–	–	Assumed
Proportion of infections by age group				
Pediatric (0–18 y)	20.67%	17.67%	23.67%	d
Working age (19–64 y)	67.77%	64.77%	70.77%	
Elderly (65+ y)	11.56%	8.56%	14.56%	
Proportion of infections that are symptomatic				
Pediatric (0–18 y)	64.00%	59%	69%	e
Working age (19–64 y)	75.00%	70.00%	80.00%	f
Elderly (65+ y)	100.00%	–	–	Assumed
Mortality due to COVID-19				
Case fatality rate by age group	0.16%	–	–	g
Pediatric (0–18 y)	0.00%	–	–	d
Working age (19–64 y)	0.04%	–	–	
Elderly (65+ y)	1.20%	–	–	
Proportion of mortality by age group				
Pediatric (0–18 y)	0.31%	–	–	d
Working age (19–64 y)	15.50%	12.50%	18.50%	
Elderly (65+ y)	84.18%	79.18%	89.18%	
Healthcare utilization due to COVID-19				
Hospitalization rate	0.49%	0.39%	0.59%	g
Proportion of moderate to severe symptoms due to acute COVID in pediatric cohort	0%	–	–	
Proportion of emergency visits per infection	11.76%	8.76%	14.76%	h
Number of outpatient visits per acute COVID infection	1	–	2	Assumed
Proportion of acute COVID antivirals	3.97%	2.97%	4.97%	i
Long-COVID related parameters				
Incidence of long-COVID	5.10%	4.10%	6.10%	j
Number of reported long-COVID cases	12,633	11,370	13,896	k
Average outpatient visits during long-COVID	3	1	6	l
Age-specific long-COVID infection rate				
Pediatric (0–18 y)	4.00%	–	–	m
Working age (19–64 y)	5.10%	–	–	n
Elderly (65+ y)	3.20%	2.20%	4.20%	n

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Table 2. Parameters for costs, productivity loss, and medical utilization in the model.

Parameters	Value	Lower	Upper	Sources
Direct cost				
Ward bed cost per day (USD)	$440.04	$148.02	–	o
Average days of hospitalization	14	–	–	
Cost per emergency visit (USD)	$158.69	$142.82	$174.55	p
Cost per outpatient visit for acute COVID (USD)	$44.95	$40.45	$49.44	
Cost per anti-COVID regimen (USD)	$727.80	–	–	q
Cost per outpatient visit for long COVID (USD)	$93.82	–	–	m
Indirect cost				
Acute COVID-related parameters				
Average days of outpatient visits due to acute COVID				
Pediatric (0–18 y)	6	3	11	r
Working age (19–64 y)	9.82	4.07	15.57	s
Elderly (65+ y)	9.82	4.07	15.57	s
Average quarantine days due to acute COVID	5	–	–	t
Average earnings per day (USD)	$49.68	–	–	u
Average earnings per day: healthcare workers (USD)	$61.75	–	–	u
Retirement age within working age cohort	65	–	–	v
Average age of death due to COVID-19 in working age cohort (19–64 y)	54.80	49.32	60.28	d
Days of sick leave due to acute COVID in working age cohort (19–64 y)	3.47	3.12	3.82	w
Proportion of people who can work at home	17.50%	14.50%	20.50%	x
Productivity loss due to caring child with acute COVID				
Child with no symptoms	25%	22%	28%	y
Child with mild symptoms	50%	–	–	Assumed
Child with moderate to severe symptoms	100%	–	–	Assumed
Proportion of days requiring care for acute COVID elderly	100%	–	–	Assumed
Proportion of elderly requiring care from non-health professional working age adult	95.50%	90.50%	100%	g
Productivity loss of non-HCP working age adult due to caring elderly with acute COVID				
Elderly with mild illness	25%	20%	30%	y
Elderly with moderate to severe illness	100%	–	–	Assumed
Proportion of elderly providing childcare while parents worked or studied	14.48%	4.00%	21.50%	z
Days of childcare provided per week	1	0	2	aa
Long COVID-related parameters				
Proportion of long-COVID well enough to work	75.80%	70.80%	80.80%	ab
Days of sick leave but well enough to work	9	8.1	9.9	ac
Productivity loss if working with long-COVID	35.00%	–	–	ac
Days of long-COVID by age group				
Pediatric (0–18 y)	14.6	3.50	25.5	e
Working age (19–64 y)	90	–	–	ad
Elderly (65+ y)	14.6	–	–	Assumed
Proportion of days for child requiring care due to mild long-COVID	61.64%	–	–	Assumed
Proportion of days for child requiring care due to moderate to severe long-COVID	100.00%	–	–	Assumed
Proportion of days for elderly requiring care due to mild long-COVID	61.64%	–	–	Assumed
Proportion of days for elderly requiring care due to long-COVID	100.00%	–	–	Assumed

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Additionally, costs for caring for children by working age adults were calculated if elderly caretakers were infected by acute or long COVID, based on the days needed for childcare, the productivity loss per day due to caring for children, the estimated number of infections in elderly caretakers, and average daily earnings.

One-way sensitivity analyses were conducted to assess the influential impact of parameters on economic cost estimations, using ranges of values defined based on standard deviation, inter-quartile range, or assumed intervals (Tables 1 and 2). Additionally, scenario analyses were also performed to account for variations in data sources or assumptions for key parameters. As shown in Supplementary Table S2 (https://doi.org/10.38212/2224-6614.3558), these scenario analyses included modifications to infection definitions (e.g., including imported cases), healthcare utilization patterns (e.g., doubling outpatient visits per infection), long COVID duration and age-specific infection rates, ward bed costs, daily earnings, and productivity loss assumptions. The impact of each scenario on total economic burden was quantified by comparing modified estimates with the base-case model results.

All costs in this analysis were calculated using 2022 as the base year. Costs were initially computed in New Taiwan Dollars (NTD) and subsequently converted to US dollars (USD) using the average 2022 exchange rate of 29.813 NTD per USD.

3. Results

3.1. Overview of economic burden of COVID-19 in Taiwan

The study estimates the economic impact of COVID-19 in Taiwan for 2022 at USD 4431 million. Direct costs, covering testing and treatment, represent 24.40% (USD 1081 million), while indirect costs, mainly productivity losses, make up 75.60% (USD 3350 million) of the total burden. These findings, illustrated in Fig. 1, highlight the significant indirect economic burden and inform policy and recovery strategies.

The cost estimations were based on epidemiological and economic parameters detailed in the Methods section (Tables 1 and 2), which include infection distributions, case fatality rates, hospitalization rates, and unit costs associated with healthcare use and productivity loss. These parameter

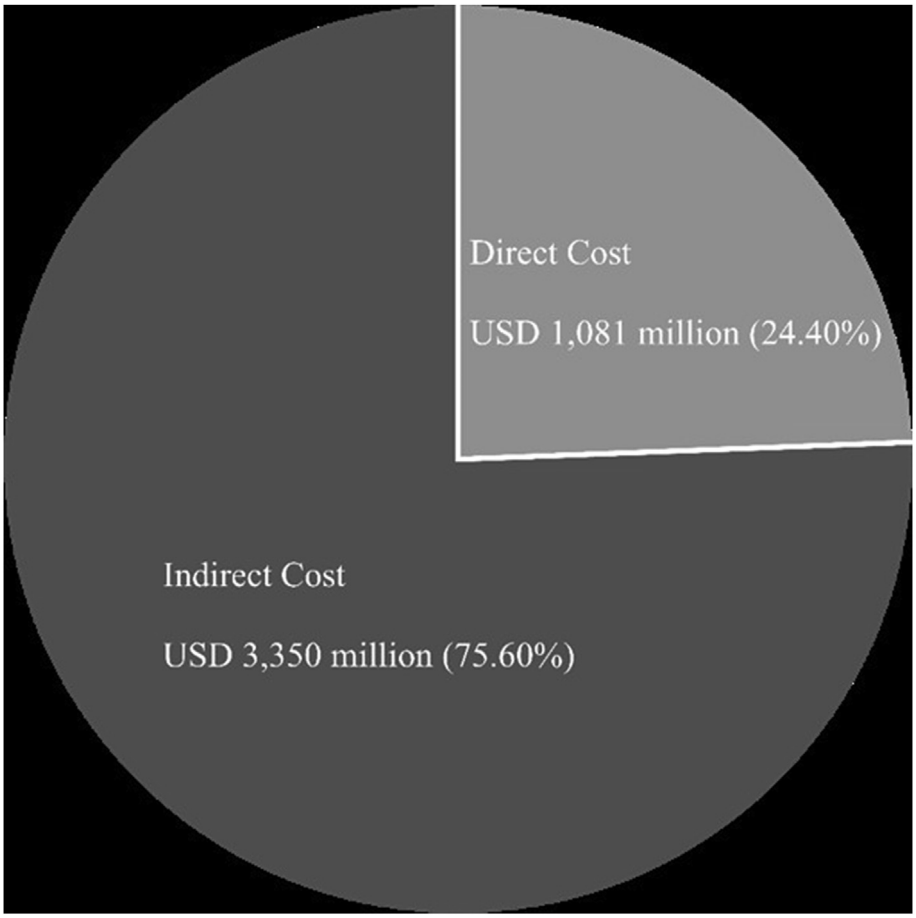

Fig. 1. Comprehensive Analysis: Direct and Indirect Costs of COVID-19 in Taiwan. The economic burden of COVID-19 in Taiwan includes both direct costs (such as healthcare expenditures for testing, treatment, and hospitalization) and indirect costs (account for productive loss and long-COVID). Total cost was estimated at $4,431,686,236 US dollars (USD).

values served as the foundation for calculating direct and indirect costs by age group and clinical condition (acute and long COVID).

To provide a comprehensive overview of cost allocation, Table 3 presents a detailed breakdown of direct and indirect costs segmented by age group (pediatric, working-age, elderly) and clinical phase (acute and long COVID). This breakdown highlights the differing healthcare and productivity burdens across populations.

3.2. Direct cost born by the health system

Direct costs were split into outpatient and inpatient services. Outpatient costs covered medical consultations and medications for acute and long-term COVID-19, totaling USD 811.6 million for acute and USD 3.6 million for long COVID-19. Inpatient services included hospital stays, ICU use, and emergency visits, totaling USD 266.2 million.

3.3. Indirect cost born by economic productivity losses

Indirect costs of COVID-19 were highest in the working age group, totaling USD 2740 million or 81.77% of the total burden. Within this group, costs for acute COVID, long COVID, and deaths were USD 1485.6 million, USD 857.8 million, and USD 396.1 million, respectively. Acute COVID costs were significantly higher than long COVID costs in the pediatric (USD 356.7 million vs. USD 29.7 million) and elder (USD 150.4 million vs. USD 20.6 million) cohorts. Fig. 2B shows the economic burden variations among age groups.

3.4. Economic burden of COVID-19 by age groups

The economic impact of COVID-19 varied significantly by age group. Indirect costs accounted for 88.68% of the working age cohort's total burden, totaling USD 3090 million. In the pediatric cohort, indirect costs were 61.52%, amounting to USD 386

Table 3. Direct and indirect costs of COVID-19 economic impact, by categories.

	Cost (USD)	%	Parameters used		
			Number of patients	Days	Costs per day
Total Cost	4,431,686,236	100.00%			
Direct Cost	1,081,335,264	24.40%[a]			
Outpatient	815,171,171	100.00%			
Acute COVID	811,615,558	99.56%	Total reported infections Hospitalization rate Proportion of emergency visits per infection Proportion of acute COVID prescribed medication		Cost per emergency visit Cost per outpatient visit for acute COVID Cost per anti-COVID regimen
Long COVID	3,555,613	0.44%	Number of reported long-COVID cases Average outpatient visits during long-COVID		Cost per outpatient visit for long COVID
Inpatient	266,164,093	100.00%	Total reported infections Hospitalization rate	Average days of hospitalization	Ward bed cost per day
Indirect Cost	3,350,350,973	75.60%[a]			
Pediatric Cohort	386,434,533	100.00%			
Acute COVID	356,691,902	92.30%	Total reported infections Proportion of infections by age group	Average days of outpatient visits due to acute COVID Average quarantine days due to acute COVID Productivity loss due to caring child with acute COVID	Average earnings per day
Long COVID	29,742,630	7.70%	Total reported infections Age-specific long-COVID infection rate	Days of long-COVID by age group	Average earnings per day
Deaths	0	0.00%			
Working age Cohort	2,739,555,946	100.00%			
Acute COVID	1,485,638,412	54.23%	Total reported infections Proportion of infections by age group Proportion of people who can work at home	Average days of outpatient visits due to acute COVID Average quarantine days due to acute COVID Days of sick leave due to acute COVID in working age cohort Productivity loss if working with COVID	Average earnings per day
Long COVID	857,790,077	31.31%	Total reported infections Age-specific long-COVID infection rate	Days of long-COVID by age group Proportion of long-COVID well enough to work Days of sick leave but well enough to work	
Deaths	396,127,457	14.46%	Total number of deaths due to COVID-19 Proportion of mortality by age group	Retirement age within working age cohort Average age of death due to COVID-19 in working age cohort	

(*continued on next page*)

Table 3. (continued)

	Cost (USD)	%	Parameters used		
			Number of patients	Days	Costs per day
Elder Cohort	224,360,494	100.00%			
Acute COVID	150,439,904	67.05%	Total reported infections Proportion of infections by age group	Average days of outpatient visits due to acute COVID Average quarantine days due to acute COVID Proportion of days requiring care for acute COVID elderly Productivity loss of non-HCP working age adult due to caring elderly with acute COVID Days of sick leave due to acute COVID in working age cohort Productivity loss if working with COVID	Average earnings per day
Long COVID	20,614,673	9.19%	Total reported infections Age-specific long-COVID infection rate	Days of long-COVID by age group	
Deaths	53,305,917	23.76%	Total number of deaths due to COVID-19 Proportion of mortality by age group	Average days lost	

[a] Calculated by dividing direct/indirect costs by total cost (USD 4,431,686,236)

million. The elderly cohort had a higher proportion of direct costs, USD 490 million, or 68.60% of its total costs (Fig. 2C). Long COVID costs were estimated at USD 1183 million, with direct and indirect costs at 0.30% and 99.70%, respectively (data not shown here).

3.5. Sensitivity and scenario analysis

Fig. 3 presents a significant one-way sensitivity analysis, highlighting the top 10 parameters impacting the total economic cost of COVID-19. The number of average outpatient visits in the working age and elderly cohorts emerged as the most significant parameter, affecting the total cost by ±11.88%. This was followed by the average age at death due to COVID-19 in the working age cohort, showing a ±5.05% change, and the incidence of long COVID, accounting for a ±3.80% change. Supplementary Table S1 (https://doi.org/10.38212/2224-6614.3558) details these effects on total, direct, and indirect costs.

Scenario analyses in Supplementary Table S2 (https://doi.org/10.38212/2224-6614.3558) show significant variations in key parameters impacting the total economic cost of COVID-19. For instance, substituting average salary per day for earnings per day leads to a 22.64% increase in total costs to USD 5435 million. Conversely, adjusting the hospitalization cost per day results in a 10.77% decrease in total costs. Using the WHO's long COVID definition reduces costs by 6.78%. Other parameter modifications have minor effects on the pandemic's overall economic impact.

4. Discussion

The study highlighted COVID-19's economic impact in Taiwan, emphasizing significant indirect costs exceeding direct costs (75.60% vs. 24.40%). Working age adults bore 88.68% (USD 3090 million) of the total burden, indicating the disproportionate effect. Direct costs to the health system were substantial, with acute COVID-19 costs at USD 811.6 million and long COVID-19 at USD 3.6 million in outpatient services alone. Long COVID, affecting 45% of survivors, leads to over 35% productivity loss, highlighting its economic toll. Frequency of outpatient visits is a key cost factor. Tailored policies are needed for workforce productivity, healthcare resilience, and supporting vulnerable populations.

We observed that direct costs, including outpatient and inpatient services, constitute a substantial financial strain on the healthcare system. This strain results from high demand for hospitalizations, emergency services, and outpatient care, requiring

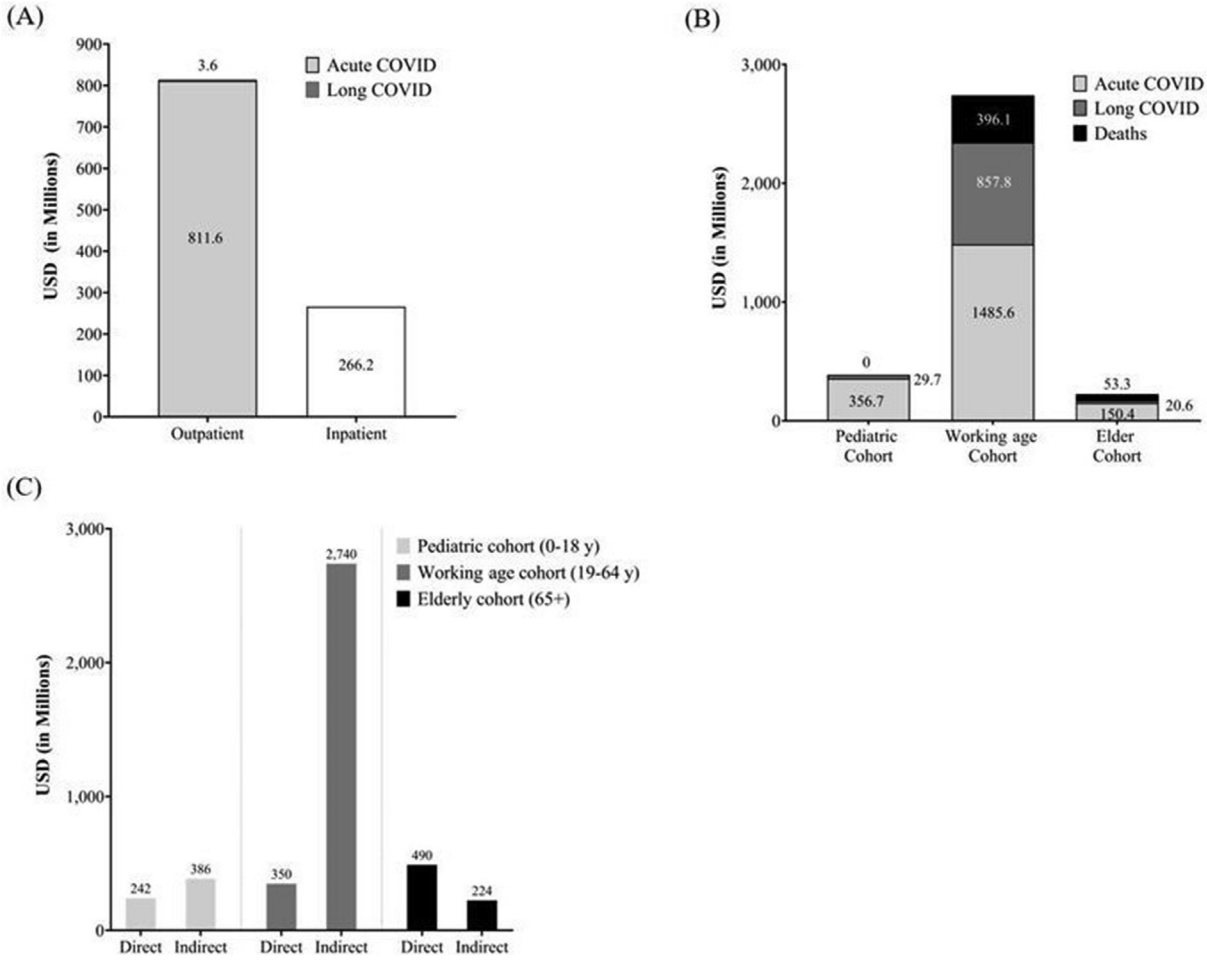

Fig. 2. Economic Burden Breakdown: COVID-19 Costs Analysis in Taiwan. The economic burden of COVID-19 in Taiwan, focusing on (A) Outpatient and inpatient costs of acute COVID and long COVID. (B) Economic impact of COVID-19 by age groups. (C) Direct and indirect costs of COVID-19 across age groups.

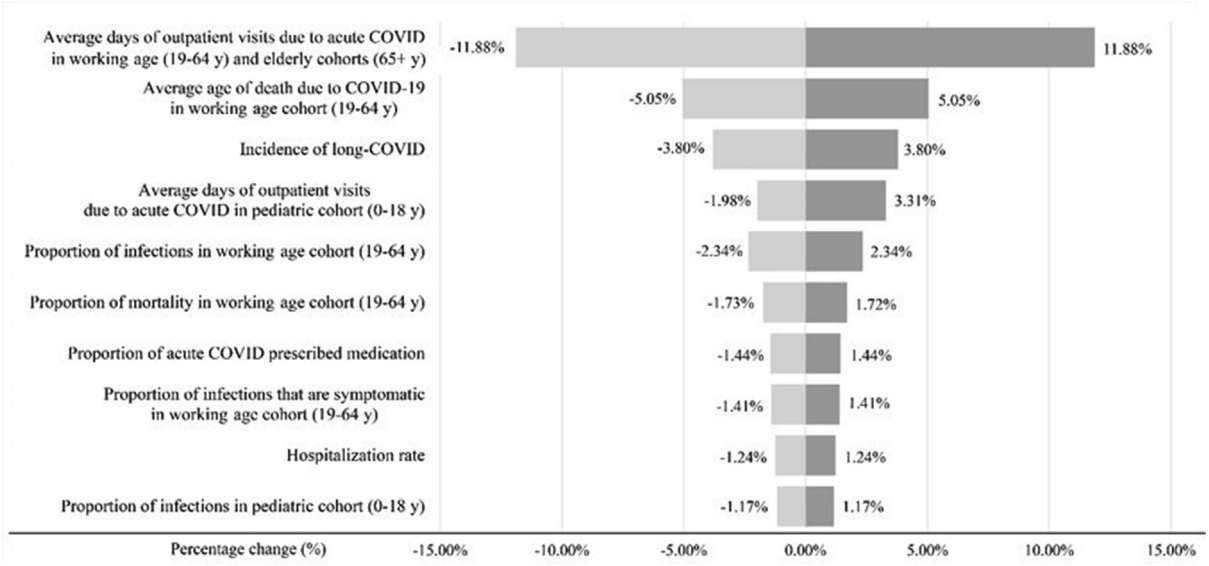

Fig. 3. Tornado Diagram: Top Ten Parameters Influencing Cost Estimates of COVID-19 Impact in Taiwan. The tornado diagram displays the top ten parameters that have the greatest impact on cost estimates related to COVID-19 in Taiwan.

extensive resources like specialized care, equipment, medications, and healthcare professionals. Hospitalizations are the primary expense, elevating overall medical expenditures, in line with existing literature on elevated costs and healthcare resource demands due to COVID-19 [41–43]. Together, these results and the corroborating literature highlight the critical economic burden of COVID-19's direct healthcare costs, emphasizing the need for effective cost-management strategies within healthcare systems grappling with the pandemic.

Our study not only quantifies the direct costs of COVID-19 in Taiwan but also highlights that indirect costs surpass these direct costs by more than three times, illustrating the vast economic ramifications beyond immediate healthcare expenses. Factors such as absenteeism, reduced productivity from remote work, and caregiving duties have a profound economic impact, significantly contributing to the global GDP's burden. This critical view on indirect costs finds support in the literature, emphasizing these aspects as key to grasping the pandemic's overall economic footprint [44,45]. Furthermore, the quantification of these indirect effects amplifies the economic loss and underscores our findings on the paramount importance of indirect costs in understanding COVID-19's comprehensive economic impact [46]. With a population of around 24 million, Taiwan has effectively managed the COVID-19 pandemic. This achievement is largely due to the government's strategic implementation of a strict blend of case-based interventions like testing, contact tracing, and quarantine, along with population-based practices, including widespread physical distancing and the mandatory use of face masks. The rigorous enforcement of these policies, though crucial for public health, has likely led to increased indirect costs associated with their implementation.

Compared to neighboring and Western countries with varying pandemic strategies, Taiwan's total annual economic burden in 2022 was estimated at USD 4.431 billion (approximately 0.9% of GDP). This is in contrast to higher estimates from countries like Australia (USD 17.0 billion, 1.0% of GDP), South Korea (USD 27.5 billion, 1.6% of GDP), Hong Kong (USD 5.3 billion, 1.4% of GDP), and Singapore (USD 2.6 billion, 0.6% of GDP) [47]. While these figures differ due to population size, healthcare structures, and policy implementation, they emphasize that even with stringent containment strategies, such as Taiwan's, the economic toll—particularly from indirect costs—remains substantial. This cross-country comparison highlights the global challenge in balancing health protection with economic sustainability.

In addition to the tangible direct and indirect costs associated with the COVID-19 pandemic, the Taiwanese government has invested considerable effort into maintaining strict and effective policies [48,49]. These rigorous measures not only aimed at immediate containment but also addressed long-term impacts. Our study underscores the significant long-term economic burden of long COVID on productivity and healthcare utilization, highlighting the substantial challenges these indirect costs pose to economic stability. This aligns with findings from the Brookings Institution, which noted significant workforce reductions in the U.S., and a Harvard Kennedy School study by David Cutler that estimated high economic costs associated with long COVID [18,50]. Additional research supports these findings, revealing that nearly half of long COVID sufferers experience symptoms that hinder their return to work, with over 30% unable to resume employment even 15 months post-infection [51]. Those who returned to work took over eight months, incurring a total of USD 4847.25 in indirect costs per person in one year [52]. Collectively, these studies affirm our findings that long COVID has precipitated a 35% reduction in productivity and a marked increase in healthcare expenses.

Methodologically, this study stands out for its detailed analysis of indirect costs categorized by different age groups—children, working age adults, and the elderly, allowing for tailored policies to address the diverse economic impacts on these segments [19]. The majority of studies primarily focus on generalized experiences and clinical manifestations of living with long COVID, along with its overall economic burden [53,54]. Additionally, the findings provide insights applicable beyond Taiwan, offering a transferable model for international application. This enables other countries to estimate their COVID-19 impact using similar parameters and develop tailored policy-making strategies based on this framework.

4.1. Limitations

This study faces several limitations that warrant consideration. Firstly, comparing cost-of-illness studies across different countries is challenging due to variations in healthcare systems and policy enforcement, which can significantly influence the study's outcomes and limit its external validity. Additionally, while the reliance on publicly available data introduces a potential for bias, we have endeavored to minimize discrepancies by validating data against WHO international statistics and employing cross-checks where possible. Furthermore, for some parameters, such as days

lost due to illness or emergency department costs, precise estimates are lacking. We have relied on existing literature and conducted sensitivity analyses to gauge the impact of these variations, leading us to believe that the influence of these limitations on our findings is minimal. The economic burden imposed by long-COVID is substantial, highlighting the urgent need for dedicated investment in future research. It is imperative to develop and implement strategies that can mitigate the impact of long-COVID.

5. Conclusion

In conclusion, this study assesses the economic burden of COVID-19 under Taiwan's stringent pandemic policies, revealing a total cost of USD 4431 million in 2022. Indirect costs accounted for 75.60% of this burden, with the working age group bearing the most substantial financial strain. The challenges of long-COVID further compounded these costs, underscoring the necessity for policies specifically tailored to mitigate its impacts.

Additionally, the methodological approach of this study offers valuable insights that could be applied globally. However, if other regions were to adopt similarly strict strategies as Taiwan's, they might also face high indirect costs.

Key message

This study reveals Taiwan's substantial economic burden from COVID-19, with indirect costs, driven by long COVID and productivity losses, significantly outweighing direct medical expenses.

Author contributions

Conceptualization: Tan EC, Hsiao FY, and Yang MC. Data curation: Tan EC, Hsiao FY. Formal analysis: Tan EC, Hsiao FY Funding acquisition: None. Methodology: Tan EC. Project administration: Tan EC, Hsiao FY, and Yang MC. Visualization: Tan EC, Hsiao FY Writing—original draft: Tan EC, Hsiao FY, and Yang MC. Writing—review & editing: Tan EC, Hsiao FY, and Yang MC

Data statement

The datasets produced and/or examined in this study can be obtained from the corresponding author upon a reasonable request.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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