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ONLINE GAMING AND DELAY OF GRATIFICATION IN CHILDREN: A BEHAVIOURAL ANALYSIS

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ABSTRACT

The rapid expansion of online gaming has transformed children's leisure activities, raising concerns about its influence on self-regulatory behaviours. The present study examined the relationship between online gaming and delay of gratification in children. Using a quantitative, cross-sectional design, data were collected from school-going children aged 8 to 14 years of Begusarai district of Bihar through a gaming behaviour questionnaire and measures of delay of gratification. Online gaming was assessed in terms of frequency, daily duration, and type of games played, while delay of gratification was evaluated through standardized behavioural indicators.

The results revealed a significant negative relationship between online gaming and delay of gratification. Higher gaming frequency and longer daily gaming duration were associated with a reduced ability to delay rewards, indicating a stronger preference for immediate gratification. Children who engaged more extensively in online gaming demonstrated lower levels of self-control in reward-based decision-making. The findings suggested that repeated exposure to fast and immediate digital rewards may influence children's tolerance for waiting and long-term goal orientation.

The study highlights the importance of balanced gaming habits and the need for parental guidance and educational interventions that promote self-regulation skills. The findings contribute to the growing literature on digital media use and child development by focusing specifically on delay of gratification, a foundational component of behavioural regulation in childhood.

KEYWORDS: *Online Gaming, Gratification, Digital Media, And Children.*

INTRODUCTION

The rapid expansion of online gaming has reshaped children's daily routines, creating digital environments filled with fast-paced action, instant feedback, and continuous reward cycles. These design features raise important questions about how digital rewards may influence children's self-regulatory abilities, particularly their capacity to delay gratification. Delay of gratification—first systematically examined by Walter Mischel through the well-known "Marshm allow Test"—refers to the ability to resist immediate temptations in favour of more valuable, delayed outcomes. Research has consistently shown that children with stronger delay-of-gratification skills tend to display better emotional regulation, higher academic achievement, and more adaptive decision-making later in life (Mischel, Shoda & Rodriguez, 1989). As children increasingly interact with digital platforms that prioritise immediate rewards, behavioural psychologists and educators are questioning whether frequent gaming might weaken the developmental foundations of impulse control.

A growing body of research has explored the psychological effects of digital media exposure. Studies on reward sensitivity suggest that environments offering rapid reinforcement can condition children to expect instant outcomes, thereby reducing their tolerance for waiting (Evans & Stanovich, 2013). Research on online gaming specifically has highlighted associations with impulsivity, reduced executive control, and heightened sensitivity to reward cues. For instance, Craig Anderson and Karen Dill (2000) demonstrated that fast-paced video games may activate automatic behavioural tendencies that favour immediate responses over reflective decision-making. More recent studies report that excessive online gaming is linked with diminished self-regulation, attention difficulties, and impatience in everyday tasks (Lemmens, Valkenburg & Peter, 2011). However, evidence is not uniform. Some researchers argue that strategic or cooperative games may enhance cognitive flexibility and problem-solving, suggesting that the impact of gaming may depend on game type, duration, and motivational context.

Despite these insights, significant gaps remain. First, most existing studies focus on broad constructs such as gaming addiction, aggression, or attention problems, while **delay of gratification** as a distinct behavioural outcome has received far less empirical attention. Second, research that directly connects online gaming's reward structures with children's delay-related behaviours is limited, even though the theoretical connection—between immediate digital rewards and reduced tolerance for delayed outcomes—is strong. Third, many studies rely on general screen-time metrics rather than isolating gaming behaviour, making it difficult to understand the unique contribution of online games. Fourth, there is little evidence on whether different gaming genres (e.g., fast-reward action games vs. slower strategy games) differentially influence children's ability to delay gratification.

Given these gaps, a focused investigation into **the relationship between online gaming and delay of gratification in children** is both timely and necessary. Understanding this relationship can inform parents, educators, mental-health professionals, and policymakers as they navigate the challenges of children's digital engagement. It can also contribute to developmental psychology by clarifying how modern digital reward systems may shape fundamental self-regulatory skills in the formative years.

Research Question

The study has been undertaken to answer the question :Does the frequency of online gaming influence children's ability to delay gratification?

Conceptual Framework

The conceptual framework for this study proposes that online gaming, defined in terms of frequency, duration, and type of game played, influences children's ability to delay gratification.

As children engage with digital games that often provide rapid rewards and immediate feedback, their behavioural responses to waiting and reward processing may be shaped by these experiences. The delay of gratification is therefore conceptualised as the outcome variable that captures children's self-regulation capacity and their preference for immediate versus delayed rewards.

Population and Sampling

The population for this study consists of **school-going children**, typically between the ages of **8 and 14 years**, who were actively engaged with digital devices and had some level of exposure to online gaming. This age range is developmentally significant, as children in middle and late childhood are still developing executive functions and self-regulation skills, making them ideal for examining the impact of online gaming on delay of gratification. The population was drawn from selected schools from the Begusarai district of Bihar, ensuring accessibility, cooperation from school authorities, and the ability to collect data in a structured and supervised environment.

The **sample** was selected from this population using a **stratified random sampling technique**, where students were first stratified based on age groups (e.g., 8–10, 11–12, 13–14 years) and gender. This ensures adequate representation of demographic moderators that might influence the relationship between online gaming and delay of gratification. Within each stratum, participants were randomly selected to minimise bias and enhance the generalisability of findings.

The sample size was 150. Inclusion criteria ensured that children must have at least occasional exposure to online gaming, parental consent, and assent from the children themselves. Exclusion criteria included children with diagnosed developmental disorders that significantly affect impulse control, unless specifically accounted for in the research design. By adopting this sampling strategy, the study aimed to obtain a representative and diverse group of participants, enabling a more robust analysis of how online gaming behaviours related to children's ability to delay gratification.

Research Methodology

The present study adopted a **quantitative, cross-sectional research design** to examine the relationship between online gaming and delay of gratification in children. This design is appropriate as it allows the assessment of gaming behaviours and self-regulatory abilities at a single point in time, enabling the identification of patterns and associations among variables. The study followed a **correlational approach**, supplemented with comparative analyses to explore differences across gaming frequency, duration, and types of games. This methodological framework is suitable for investigating behavioural relationships without manipulating variables.

Data was collected in selected schools after obtaining necessary permissions from school authorities and parents. Children who met the inclusion criteria were assessed during school hours in a controlled and familiar environment to reduce anxiety and external distractions. Participants were first completed the gaming behaviour questionnaire. Subsequently, the delay-of-gratification measure a standardized scale was administered individually under the supervision of the researcher.

The data collected from the participants were systematically organised and analysed using appropriate statistical techniques. Initially, the responses obtained from the gaming behaviour questionnaire and delay-of-gratification measures were coded and entered into statistical software for analysis. Descriptive statistics, including means, standard deviations, frequencies, and percentages, were computed to summarise the demographic characteristics of the sample and to provide an overall understanding of online gaming patterns and delay-of-gratification levels among children.

To examine the research question regarding the relationship between online gaming and delay of gratification, **Pearson's correlation analysis** was conducted to determine the strength and direction of the association between gaming frequency, gaming duration, and delay-of-gratification scores.

Result and Discussion

Table 1 Descriptive Statistics of Online Gaming and Delay of Gratification (RQ1)

Variables	N	Mean	SD
Gaming Frequency (days/week)	150	4.62	1.48
Gaming Duration (hours/day)	150	1.87	0.92
Delay of Gratification Score	150	32.45	6.78

Note. Higher scores on delay of gratification indicate greater ability to delay rewards.

Table 2 Correlation Between Online Gaming and Delay of Gratification (RQ1)

Variables	1	2	3
1. Gaming Frequency	—		
2. Gaming Duration	.58**	—	
3. Delay of Gratification	−.41**	−.47**	—

*Note.***p**< .01

The findings of the present study indicated a significant negative relationship between online gaming and delay of gratification in children. As shown in Table 2, both gaming frequency and gaming duration were inversely related to children's ability to delay rewards. These results suggested that greater engagement in online gaming was associated with a stronger preference for immediate gratification. This pattern was consistent with classical and contemporary theories of self-regulation, particularly the work of Mischel, Shoda, and Rodriguez (1989), who emphasised the role of environmental reward structures in shaping children's delay-related behaviours.

The observed association between higher gaming engagement and reduced delay of gratification aligned with prior research indicating that rapid and frequent reward cycles can condition individuals to expect immediate outcomes. Studies on digital media exposure have reported that environments characterised by instant feedback and continuous reinforcement may undermine patience and impulse control (Evans & Stanovich, 2013). Online games, especially fast-paced and reward-heavy ones, operate on similar reinforcement principles, offering immediate points, levels, or virtual rewards, which may reduce children's tolerance for delayed outcomes in non-digital contexts.

The positive correlation between gaming frequency and gaming duration suggested cumulative exposure effects, where frequent gamers were also those spending longer hours playing. This finding supported earlier studies by Lemmens, Valkenburg, and Peter (2011), who reported that increased gaming time was associated with reduced self-regulation and heightened reward sensitivity in children and adolescents. The present study extended these findings by demonstrating that such gaming patterns were specifically linked to delay-of-gratification abilities, a construct less frequently examined in gaming research.

Furthermore, the variability observed in delay-of-gratification scores (Table 1) indicated that not all children were equally affected by gaming exposure. This finding resonated with developmental research suggesting that self-regulatory capacities are shaped by an interaction of individual differences and environmental influences. Anderson and Dill (2000) argued that repeated exposure to fast-response digital environments can strengthen impulsive response tendencies, particularly in younger users. The present results supported this argument by showing that gaming engagement was meaningfully related to behavioural choices involving waiting and reward evaluation.

Overall, the findings were consistent with a growing body of literature cautioning against excessive exposure to fast-reward digital environments during critical periods of self-regulatory development. While online gaming is not inherently harmful, the results suggested that frequent and prolonged engagement may influence children's reward-processing mechanisms in ways that reduce their ability to delay gratification.

Implications

The findings of the present study carry important implications for parents, educators, mental health professionals, and policymakers concerned with children's behavioural and emotional development in the digital age. The observed negative relationship between online gaming and delay of gratification suggests that excessive exposure to fast-reward digital environments may influence children's self-regulatory capacities, particularly their ability to wait for outcomes and regulate impulses. This highlights the need for a balanced and developmentally sensitive approach to children's digital engagement rather than an outright restriction of gaming activities.

For parents and caregivers, the study underscores the importance of monitoring not only the duration of children's gaming but also the frequency and type of games played. Encouraging structured routines that balance screen-based activities with offline tasks requiring sustained effort—such as reading, creative play, or sports—may help strengthen children's capacity for delayed rewards. Parental guidance that includes setting consistent screen-time boundaries and discussing the value of patience and long-term goals can support the development of healthy self-control.

From an educational perspective, the findings suggest that schools have a vital role in fostering self-regulation skills. Integrating activities that promote persistence, delayed rewards, and goal-oriented behaviour into classroom practices can help counterbalance the immediacy of digital reinforcement. Teachers may also benefit from greater awareness of how excessive gaming might manifest in classroom behaviour, such as impatience or difficulty sustaining attention, enabling early identification and supportive intervention.

At a broader level, the study provides evidence relevant to mental health professionals and policymakers involved in child development and digital well-being. Practitioners may consider assessing gaming habits as part of routine evaluations for impulsivity or self-regulation concerns. Policymakers and child welfare organisations may use these findings to inform guidelines on age-appropriate gaming practices and to advocate for responsible game design that does not excessively rely on instant reward mechanisms. Overall, the study contributes to a growing understanding of how digital environments interact with developmental processes and emphasises the need for collaborative efforts across families, schools, and policy frameworks to support children's long-term behavioural health.

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A COMPARATIVE STUDY OF DIFFERENT GAS CHANNEL STRUCTURES INPERFORMANCE DEGRADATION OFPROTON EXCHANGE MEMBRANE FUEL CELL

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ABSTRACT

The electrochemical performance and durability of proton exchange membrane fuel cells (PEMFCs) are strongly governed by the geometry and topology of the reactant flow field. In particular, the gas channel configuration plays a critical role in regulating reactant distribution, water management, pressure drop and interfacial mass transport between the gas diffusion layer (GDL) and the catalyst layer. PEMFCs generally exhibit enhanced current density and improved polarization characteristics when a larger fraction of the gas flow channel area is in direct contact with the GDL, thereby promoting more uniform reactant utilization and reduced concentration overpotentials. In the present study, a comparative numerical investigation of different gas channel structures and their influence on PEMFC performance degradation was conducted using COMSOL Multiphysics. Two alternative gas flow channel geometries with identical inlet and outlet cross-sectional areas but differing channel–GDL contact areas were developed and analyzed. A conventional rectangular (cuboidal) parallel flow field and a cylindrical parallel flow field design were selected to systematically assess the impact of channel geometry on electrochemical and transport phenomena. We investigated and observed the hydrogen mass fraction, ionic potential and electronic potential include the oxygen, nitrogen, water mass fractionsand the current density across the membrane. The velocity field vectors and the pressure in the anode and cathode compartments is also studied.For a rectangular (cuboidal) structure, it displays better results for pressure, velocity and membrane current density.

KEYWORDS: *Topology,Cylindrical Channel, Rectangular (Cuboidal) Channel, Ionic Density, Boundary, Pressure, PEMFC.*

INTRODUCTION

Due to the fact that conventional energy sources cannot produce enough energy, alternatives to them must also be taken into account together with the rising energy consumption. To lessen the negative effects of generating energy from fossil fuels and other conventional sources, the development of clean and sustainable energy has become essential worldwide [1]. These kinds of energy sources are referred to be alternative energy sources among the different alternative energy sources. The fuel cell is one of the alternatives on this list of alternative energy sources. The most efficient and dependable option with regards to energy conversion technology is the fuel cell. In 1839 American scientist and lawyer William Grove constructed the first quiet basic fuel cell [2]. Two platinum electrodes made up this instrument [3]. Grove's innovation was enhanced by Charles Langer and Ludwig Mond in 1889 by employing a porous mono-conductive electrolyte. Fuel cells are the current name for this technology [4, 5]. A fuel cell is a device that uses electrochemical processes, such as anodic oxidation and catholic reduction reactions, to transform the chemical energy of hydrogen fuel into electricity and create water. When burned with oxygen, hydrogen fuel produces no emissions. Fuel cells is capable of providing long-term answers as efficient and sustainable energy conversion technologies that emit little or no greenhouse gases [6]. Fuel cell classification and features are described based on the electrolyte employed. The various fuel cell types include alkaline fuel cells (AFCs), molten carbonate fuel cells (MCFCs), phosphoric acid fuel cells (PAFCS), solid oxide fuel cells (SOFCs), and proton exchange membranes fuel cells (PEMFCs).

The layout'ssimplicityand operating set-up of thePEMFCmakes it an acceptable replacement energy source. PEMFC systems have appealing qualities such their light weight, greatest energy density, minimal pollutant output, and low operating temperature. The operating set-up, mechanical design, transport mechanisminside the cells, manufacturing process, and rate of electrochemical reactions all have a significant impact on PEMFC cell performance. Anode and cathode PEMFC chemical processes are

Anode: Hydrogen undergoes oxidation to form protons as shown below.

$$2H_2 \rightarrow 4H^+ + 4\,e^- \quad (1)$$

Energy is released in this reaction. At the cathode, the oxygen interacts with theelectrolyte's H^+ ions and the electrons (e^-) released from the electrode. Water is created as a result of this.

Cathode: Oxygen undergoes reduction to from water as given below.

$$O_2 + 4e^- + 4H^+ \rightarrow 2H_2O \quad (2)$$

The hydrogen fuel is burned or undergoes a simple reaction in the entire process [7, 8], which occurs as follows.

$$2H_2 + O_2 \rightarrow 2H_2O \quad (3)$$

The most promising energy converters are PEM fuel cells, particularly for automotive applications. They can be employed in clean hybrid electricity systems and deliver the load with rated power [9, 10]. The restricted use of the PEMFCsare its high economic expenses, durability and fuel availability issues, or the challenge of maintaining effective thermal control. Water management also has a substantial impact on fuel cell efficiency [11, 12]. Membrane dehydrates, when the water removal rate exceedsthe rate of water formation. This results in substantial ohmic voltage drops within the cell, which reduces the performance of Fcs [13].

Between the BPs and the CLs lie porous medium called the GDLs.As a result, they not only enable the uniform distribution of the reactants across the surface of the CLs, but they also create a structural support for the catalyst layers and enable an electrical link (electrons transit) between the catalyst layers and the bipolar plates [14].Although cylindrical configurations have been developed, channels typically have a rectangular structure and shape. The fuel and oxidant flow rates, as well as the water accumulation in the cell, can be impacted by changes in channel form. Condensed water consequently forms a film at the bottom of flow channels that are spherical, whereas in channels with various geometries, the water forms microscopic droplets. The hydrophobic and hydrophilic properties of the porous media and channel walls control the size and shape of the water droplets.

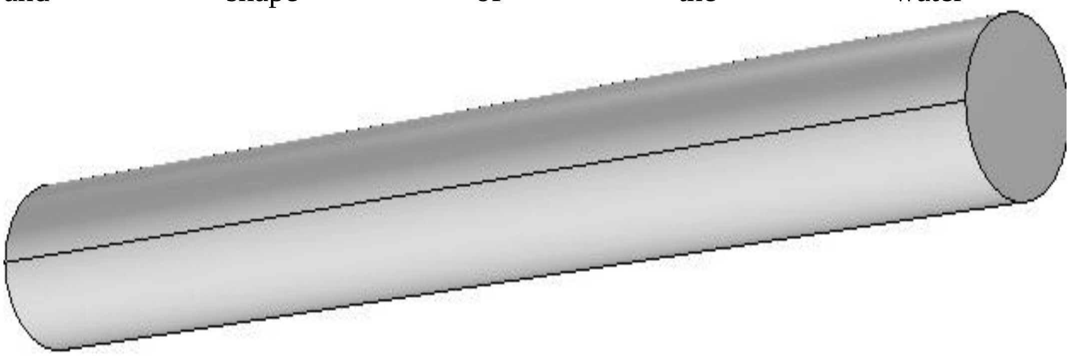

Fig 1 (a) Cylindrical channel

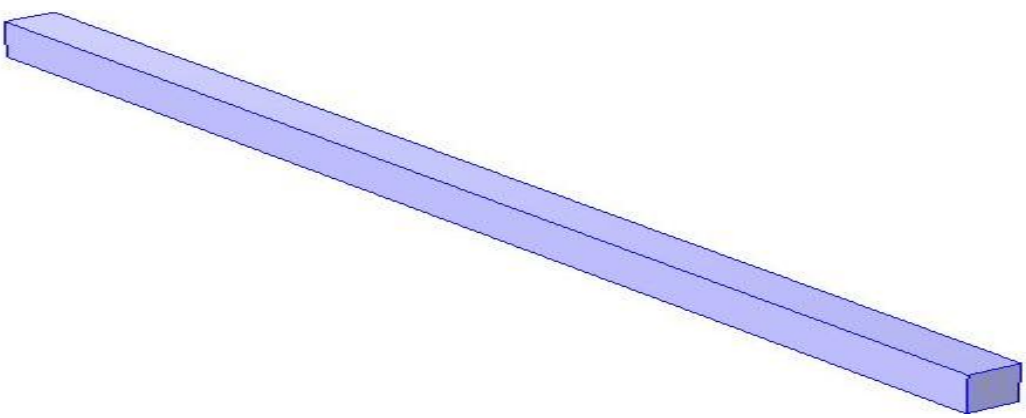

Fig 1(b) Rectangular channel

Simulations and Modeling are widely utilized in research institutes to acquire a better knowledge of the underlying mechanisms in these fuel cells, which helps to lower research expenses and improves the design. Numerous studies, models, and computational simulations have been created recently [15–18] to examine a variety of transport processes. The primary goal of this research is to use a 3D model created with COMSOL Multiphysics software to explore the impact of the contact area of the gas flow channel with the GDLs on the performance of the cell.

Modelling:

To determine the performance of the PEMFC with membrane, a 3-dimensional single-stage isothermal model is created. In this modeling we have applied electrochemistry module < Hydrogen fuel cell < Proton exchange membrane and two times fluid flow module < Porous media & Subsurface flowfor anode< Free & Porous media flow for cathode.

Model suppositions:

Water only occurs in vapor form in the PEMFC when it is operating above 150°C at a pressure of about 1 atm [19]. In contrast to the normal the water drag coefficient from the anode to the cathode is considered to be zero in low temperature PEMFCs using Nafion membranes. due to the nature of PBI membranes [20-22]. Furthermore, the proton transfer mechanism uses the acid in the membrane because it is doped with phosphoric acid [23]. An ideal gas is used to describe a gas mixture. The flow is laminarbecause the Reynolds number is low. Polymers that are homogenous and isotropic are used to create the gas diffusion layer (GDL).

Modeling domain —

A portion of the membrane, both cathode and anode GFCs, two catalyst layers, and two GDLs are all included in the 3D computational geometry. Figure 2(a) &2(b) shows seven computational domains of this model.

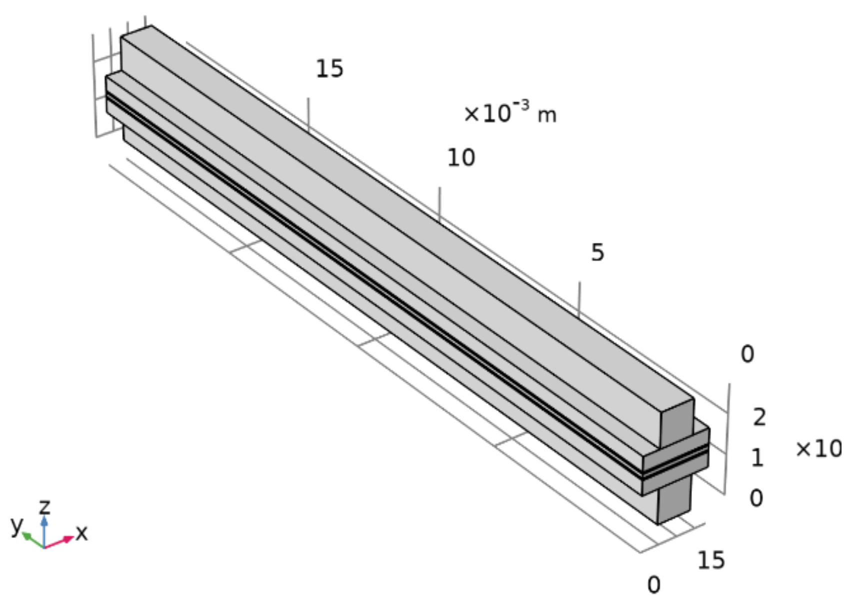

Fig 2(a) Rectangular channel Geometry of PEMFC

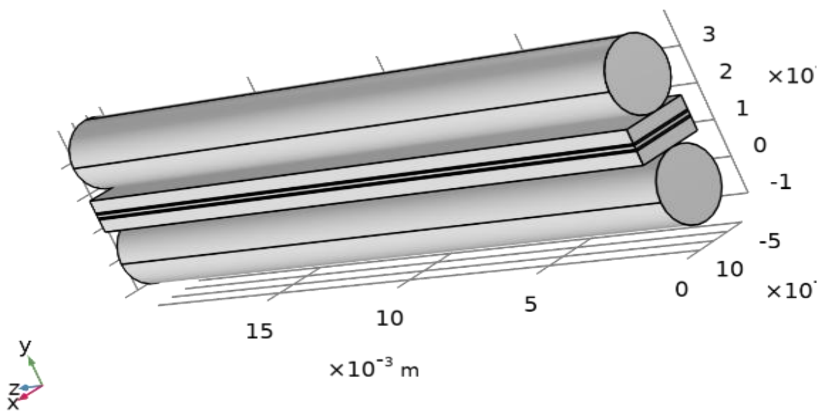

Fig. 2(b)Cylindrical channel Geometry of PEMFC

Governing equations:

The following conservation equations control the operation of the HT-PEMFC under the assumptions made above.

Mass Conservation -

$$\nabla u = \frac{Q}{\rho} \tag{4}$$

Mass transfer to other phases: $Q_m = \sum_i R_i$ (4a)

Momentum Conservation -

$$\rho u \cdot \nabla \mathrm{u} = \nabla\{-pI + \mu[\nabla u + (\nabla u)^T]\} \tag{5}$$

$$\mu = \Sigma x_i \cdot \mu_i \tag{5a}$$

The impact of the porous GDL's porosity is taken into consideration by modifying the effective binary diffusivity.

$$\omega_{oj} = \frac{x_{oj} M_i}{M_{n,o}},\ M_{n,o} = \sum_i x_{oj} M_i \tag{6}$$

$$x_{o,H_2O} = \frac{p_{vap}(T_{hum})}{p_{A,hum}} RH_{hum} \tag{7}$$

$$x_{oj} = x_{oj}\left(1 - x_{O,H_2O}\right) \tag{8}$$

$$D_{ik,eff} = \in_g 1.5 D_{ik} \tag{9}$$

Stefan velocity:

$$\rho u_s = n \cdot \sum_i (j_i + \rho u_s \omega_i n) \tag{10}$$

In a PEMFC, the current can be divided into two components: ionic current and electronic current [24]. An ionic current is created by the movement of protons viamembrane, as opposed to an electronic current, which exclusively involves the movement of electrons through a solid electrode matrix. Using Ohm's law, the current continuity equations are generated.

$$\nabla \cdot (-\sigma_s \nabla \cdot \phi_s) = S_s \tag{11a}$$

$$\nabla \cdot (-\sigma_m \nabla \cdot \phi_m) = S_m \tag{11b}$$

Where the phase potential isϕ, the effective electric conductivity is σ ($S.m^{-1}$), the current source term is S ($A.m^{-3}$), the subscript s stands for the property of the solid phase, and the subscript m stands for the property of the membrane.The source terms for the electron and proton transport equations are produced via the electrochemical reaction, which only occurs in the CLs of the anode and cathode sides [24].$S_m = J_a$ and $S_s = J_a$, and cathode CL, $S_m = J_c$ and $S_s = J_c$. The electrochemical process's transfer current densities at the catalyst layers on the anode and cathode, respectively, are shown here as J_a and J_c [25].

Constitutive relations—

The transfer current densities J_a and J_c were estimated using a streamlined Butler-Volmer equation, which is supplied as the source terms in both species and charge equations.

$$J_a = a i_{0,a}^{ref} \left(\frac{C_{H_2}}{C_{H_{2,ref}}}\right)^{0.5} \left(\frac{\alpha_a + \alpha_c}{R_T} F \eta_a\right) \tag{12a}$$

$$J_c = a i_{0,c}^{ref} \left(\frac{C_{O_2}}{C_{O_{2,ref}}}\right)^{0.5} exp\left(-\frac{\alpha_c}{R_T} F \eta_c\right) \tag{12b}$$

Where the potential difference between the electrolyte and the solid matrix is represented by the symbol η and is defined as

Anode side: $\eta_a = \phi_s - \phi_e$ (13a)

Cathode side: $\eta_c = \phi_s - \phi_e - U_{oc}$ (13b)

Boundary conditions —

According to the stoichiometric ratio, the active area of FCs, and the GFCs dimensions, the inlet gas velocity is computed and provided as

$$U_{in\_c} = \lambda_c \frac{1}{4F} x_{O_2} \frac{RT}{(P \cdot A_{Channel} \cdot n_{Channel})} \tag{14a}$$

$$U_{in\_a} = \lambda_a \frac{1}{4F} x_{H_2} \frac{RT}{(P \cdot A_{Channel} \cdot n_{Channel})} \tag{14b}$$

$n_{channel}$is the number of the channel, $A_{channel}$ is the channel's cross-sectional area, and $U_{in_c}$and $U_{in_a}$are the average inlet velocities on the cathode and anode sides.

Based on the temperature and humidified air at the entrance, the species fraction is computed. At the flow channel's output, it is set at atmospheric pressure for the back-pressure. The flow is thought to be completely developed. The main plane of the land area's boundary is specified to be symmetrical, and other impermeable walls and surfaces are subject to the no-slip boundary criterion. The fuel cell operating voltage is designed to be the same as the cathode current collector, while changing the anode current collector to zero V. The remaining borders are designed to be insulated or symmetrical.

Results and discussions

A complete mess of 13760 domain elements, 5976 boundary elements, and 860 edge elements is used to solve the FC model utilizing the commercial COMSOL Multiphysicssoftware. The solution time is 2187 seconds (36 minute 27 seconds). Numbers of degree of freedoms solved for 105233 plus 9450 internal degrees of freedoms.Geometrical parameters for cylindrical and rectangular (cuboid) shape in table 1.

Table 1: Modeling parameters

S.No.	Parameters Description for cylindrical channel shape	Parameters Description for rectangular channel shape	Value	Parameters Name
1	L	L	0.02 m	Cell length
2	r_ch	-	0.001 m	Channel radius
3	Pai_const	-	22/7	Pai constant
4	W_rib	W_rib	9.0932E-4 m	Rib width
5	H_gdl	H_gdl	3.8E-4 m	GDL width
6	H_electrode	H_electrode	5E-5 m	Porous electrode thickness
7	H_membrane	H_membrane	1E-4 m	Membrane thickness
8	-	H_ch	1mm	Channel height
9	-	W_ch	0.8mm	Channel width

Table 2- Domain probe table for anode gas diffusion electrode for different channel geometry

V_cell (V)	Rectangular (Cuboidal)channel current density (mA/cm^2)	Cylindrical channelcurrent density (mA/cm^2)
0.95	2.78E-04	0.00027794
0.9	0.0010248	0.0010249
0.85	0.0033023	0.0033022
0.8	0.00837	0.0083572
0.7	0.027023	0.026633
0.6	0.052377	0.049741
0.5	0.079568	0.068859
0.4	0.10282	0.076481

The current density expected by the cylindrical channel numerical model was significantly reduced than the actual current density ofrectangular flow channel design.Fig 3 shows the relationship between voltage and current density. This relationship known as polarization curve.

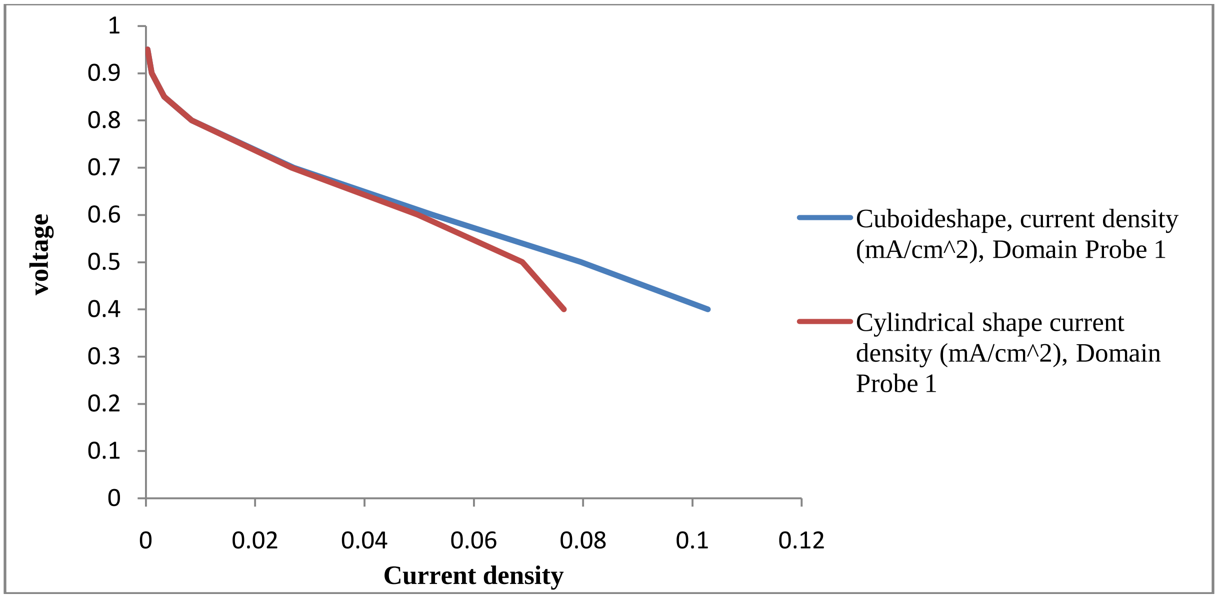

Fig. 3 Polarization curve between current density and cell voltage

Table 3:Comparative results between rectangular and cylindrical channelgeometry

Results	**Rectangular Channel**	**Cylindrical Channel**
Anode compartment Velocity m/s	0·2	14×10^{-3}
Anode compartment Pressure atm	-0· 03	$475{\cdot}29\times10^{-3}$
Cathode compartment Velocity m/s	1	8×10^{-3}
Cathode compartment Pressure atm	7·29	$595{\cdot}75\times10^{-3}$
Membrane Current Density A/cm^2	$1{\cdot}17\times10^{4}$	305×10^{-15}
Electrode potential with Respect to GroundV	0 · 42	0 · 40
Electrolyte Potential V	0 · 35	0 · 30

CONCLUSIONS:

In this study, we have drawn rectangular and cylindrical-shaped 3D channel geometries and these geometries have the same area of inlet and outlet of the gas channel due to which the inlet velocity of the gas channel will also be the same. In case rectangular channel geometry PEM fuel cell is generated a high current density (0.10282 mA/cm^2). Therefore, the following outcomes based on this research is that performance of ionic current density of the HT-PEMFC is higher ($1{\cdot}17\times10^{4}$) in rectangular channel geometry in the z compartment.Thevelocity magnitude at the cathode compartment is greater in rectangular channel geometry ($1>8\times10^{-3}$). Electrode potential with Respect to Ground in rectangular channel geometry is higher than cylindrical channel geometry (0.42 > 0.40).Electrolyte potential in rectangular channel geometry is higher than cylindrical channel geometry (0.35 > 0.30).

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DETERMINANTS OF POOR QUALITY OF WORK LIFE FOR EMPLOYEES IN HEALTHCARE SETTINGS: GLOBAL INSIGHTS

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ABSTRACT

Healthcare systems worldwide face persistent challenges in sustaining a competent and motivated workforce, with the quality of work life (QWL) of healthcare employees emerging as a critical concern. This study synthesizes global empirical evidence on the determinants of poor quality of work life among healthcare workers and proposes an integrated conceptual framework to explain their combined influence. A comprehensive secondary data analysis was conducted using peer-reviewed studies across diverse healthcare settings and geographic contexts. The thematic synthesis reveals that poor QWL is primarily driven by organizational and managementrelated factors, including inadequate compensation, ineffective leadership, and limited organizational support. These determinants interact with adverse work environments, psychosocial stressors, work-life balance disruptions, and individual characteristics to produce cumulative negative effects on employee well-being. The findings further demonstrate that QWL determinants are highly interrelated, with individual and demographic factors moderating their impact and psychosocial conditions often mediating organizational influences. Based on these insights, the study develops a multidimensional conceptual framework grounded in global evidence, highlighting key intervention points for healthcare management and policy. By moving beyond fragmented, singlefactor explanations, this study contributes a holistic perspective that can inform future research, organizational interventions, and policy strategies aimed at improving the quality of work life of healthcare employees.

KEYWORDS: *Quality Of Work Life, Healthcare Employees, Determinants Of QWL, Employee Well-Being.*

INTRODUCTION

Healthcare systems across the globe are encountering unprecedented difficulties in sustaining a competent and motivated workforce capable of providing highquality patient care. Central to these difficulties is a crucial yet frequently neglected element: the quality of work life (QWL) of healthcare employees. Quality of work life refers to the degree to which healthcare professionals are able to meet their personal and professional needs while engaging in their work roles and contributing to organizational objectives (Mohammed J Almalki et al., 2012). Healthcare organizations are intrinsically high-pressure settings because of the life-and-death responsibilities involved, exposing workers to distinctive stressors such as the emotional intensity of patient care, irregular shift schedules, physical risks, and ongoing demands for critical decision-making (L. Clack et al., 2021).

Empirical studies consistently indicate that poor quality of work life among healthcare professionals has reached critical levels worldwide. Evidence points to concerning trends, with 67.2% of nurses in healthcare facilities in Ethiopia (Lolemo Kelbiso et al., 2017), 69.3% of hospital staff in Iran (P. Raeissi et al., 2019), and 74.6% of primary healthcare workers in China (Joseph Obiri Asante et al., 2019) reporting unsatisfactory QWL. The COVID-19 pandemic has further aggravated these issues, as healthcare employees reported markedly low QWL across several dimensions during this period (M. B. Maqsood et al., 2021).

The implications of poor quality of work life go well beyond individual job dissatisfaction. Low QWL has been strongly associated with higher levels of burnoutdiminished job performance alongside increased depression, anxiety, and stress (E. Bakhshi et al., 2018), as well as a greater intention among employees to leave the profession (Yeliz Mercan et al., 2023). Collectively, these consequences generate a self-perpetuating cycle in which poor QWL leads to workforce shortages, thereby worsening working conditions for the remaining healthcare staff.

Despite increasing recognition of quality of work life as a critical concern, substantial gaps persist in the existing body of knowledge. First, although many studies have explored QWL within specific healthcare settings, there is still a shortage of comprehensive analyses that synthesize global evidence across varied healthcare contexts (Giang T. T. Phan et al., 2016). Second, prior research has largely concentrated on isolated determinants, offering limited insight into how multiple factors interact to collectively shape poor QWL outcomes. While some studies have focused on organizational influences (T. Nayak et al., 2017), others have examined psychosocial factors (Mariza Alves Barbosa Teles et al., 2014) or worklife balance issues (H. Zandian et al., 2020), integrated and holistic frameworks remain largely missing.

The present study responds to these gaps by offering a comprehensive global examination of the determinants contributing to poor quality of work life among employees in healthcare settings. Drawing on empirical evidence from multiple countries and healthcare systems, this research seeks to identify and classify the major determinants of poor QWL among healthcare workers worldwide, examine the interrelationships among different determinant categories, assess variations across healthcare contexts, and develop an integrated conceptual framework grounded in global evidence.

This study contributes by synthesizing global empirical findings on healthcare QWL determinants, providing a systematic classification that moves beyond singlefactor approaches, and proposing a framework to inform future research and evidencebased interventions. The findings hold important implications for healthcare managers designing targeted interventions, policymakers formulating comprehensive strategies, and researchers seeking a robust foundation for subsequent studies.

Problem Significance

Healthcare workers, including nurses and physicians, experience distinct pressures such as irregular work schedules, intense emotional demands, and rolerelated conflicts that heighten everyday work demands. These conditions generate continuous strain within highrisk environments where rapid decisions carry critical consequences. Persistently poor quality of work life gradually undermines individual well-being, resulting in fatigue and reduced engagement. Ultimately, this weakens organizational resilience by increasing staff turnover and compromising the quality of healthcare delivery.

Objectives of the Study

- To synthesize global evidence on the determinants of poor Quality of Work Life (QWL) among healthcare employees.
- To identify universal predictors, including workload, burnout, and leadership deficiencies, across different regions, including India.
- To extract common themes from validated secondary sources and develop a conceptual framework.
- To propose actionable recommendations for policymakers aimed at improving QWL through focused interventions.

Literature Review

Giang T. T. Phan et al., (2016) systematically reviewed the global landscape of quality of work life research in healthcare and identified 56 studies addressing QWL, of which 16 met the specified inclusion criteria. Their findings indicated that Asia, America, and Europe contributed seven, six, and four studies respectively, with nurses representing the most frequently examined group, accounting for 52.9% of the included research. This distribution underscores that concerns related to healthcare employees' QWL are widespread across diverse healthcare systems and cultural settings.

G. N. Saraji et al., (2006) reported that employees working in hospitals affiliated with Tehran University of Medical Sciences experienced poor quality of work life, particularly expressing dissatisfaction with occupational health and safety, managerial practices, income levels, and worklife balance. Similarly, Lolemo Kelbiso et al., (2017) found that 67.2% of nurses employed in Ethiopian public health facilities were dissatisfied with their overall quality of work life.

Mohammed J Almalki et al., (2012) found that primary healthcare nurses in Saudi Arabia reported dissatisfaction stemming from inadequate management and supervision, limited opportunities for professional development, and unsuitable working conditions. P. Raeissi et al., (2019) highlighted that major factors affecting QWL included insufficient and inequitable pay, lack of organizational problem-solving mechanisms, poor managerial support, and unfair promotion practices.

Mariza Alves Barbosa Teles et al., (2014) found that employees experiencing an imbalance between effort and reward had a higher likelihood of poor quality of life, particularly in physical and environmental aspects. S. Dolan et al., (2008) showed, using cross-sectional, retrospective, and longitudinal approaches, that high job demands coupled with inadequate supervisory support are significant predictors of low QWL and adverse health outcomes.

Joseph Obiri Asante et al., (2019) reported that 74.6% of primary healthcare workers in China experienced poor quality of life, with elevated burnout levels strongly linked to lower overall QWL. The study also found that employees who lacked social support and opportunities for professional development were more likely to report poor quality of life in social domains.

H. Zandian et al., (2020) found that 93% of hospital nurses in Iran experienced moderate to high levels of workfamily conflict, with 83% reporting low to moderate quality of work life. Yeliz Mercan et al., (2023) demonstrated that higher workloads, performing tasks beyond their job descriptions, and intentions to leave the profession were negatively associated with QWL scores.

O. Akinwale et al., (2024) identified that balanced workload, access to stress management resources, and effective self-management serve as key predictors of worklife balance, while organizational support, a healthy work environment, and positive organizational culture are crucial for enhancing quality of work life from an organizational standpoint.

E. Bakhshi et al., (2019) found that 36.7% of healthcare employees reported low quality of life and recommended improvements in work conditions, workplace relationships, and financial support. J. Opollo et al., (2014) reported that healthcare workers in Uganda experienced particularly poor quality of work life, especially in areas of work conditions, job control, and the homework interface.

S. Neupane et al., (2016) identified that more than 52% of healthcare employees reported musculoskeletal pain at multiple sites, with poor worklife balance, exposure to physical hazards, and psychosocial risks emerging as significant predictors.

E. Nena et al., (2018) conducted a study involving 312 healthcare employees in Greece and found that 58.2% of shift workers reported being somewhat or completely dissatisfied with their sleep quality. Their regression analysis highlighted key determinants of sleep impairment, including parenthood, age between 36 and 45 years, working more than three night shifts per week, and over five years in an irregular shift schedule. The study further demonstrated that shift work substantially reduces quality of life across multiple dimensions of the WHO-5 Well-Being Index, with diabetes mellitus being the most frequently reported medical condition among shift workers.

E. Bakhshi et al., (2018) investigated 158 healthcare network employees in Iran and found significant negative correlations between quality of work life and depression (r = -0.255; P = 0.001), anxiety (r = -0.260; P = 0.001), and stress (r = -0.242; P = 0.002). Their results indicated that enhancing QWL is crucial for reducing depression, anxiety, and stress among healthcare workers, with marital status significantly linked to depression and residential status associated with stress levels.

L. Clack et al., (2021) emphasized that healthcare organizations are inherently highstress environments because of their life-or-death responsibilities, placing healthcare professionals at greater risk of occupational stress, burnout, and workplace violence compared to other sectors. The review highlighted that addressing these challenges effectively can positively influence the quality of life of healthcare workers.

Reetta Kesti et al., (2023) examined public healthcare employees in Finland and found that work dissatisfaction, burnout, and workforce shortages remain significant global issues, all closely linked to quality of work life. Their cross-sectional study further confirmed that previous research consistently reports moderate to low QWL levels among healthcare professionals, even within well-developed healthcare systems.

Meltem Saygılı et al., (2020) examined 328 healthcare workers in Ankara, Turkey, and found that while employees reported a ‘good’ perceived quality of work life, they experienced ‘moderate’ levels of burnout, with a statistically significant but weak correlation between QWL and burnout ($\rho = 0.184$; $p = 0.0008$). This indicates that even in settings where QWL is considered satisfactory, burnout continues to be a persistent concern.

Zakerian Seyyed Abolfazl et al., (2013) investigated hospital staff to examine how workload directly affects different dimensions of quality of life. Their study contributed to understanding the physical demands faced by healthcare workers and the resulting effects on overall well-being.

Ruthann Cunningham et al., (2022) conducted a quantitative review of factors influencing job satisfaction among healthcare professionals globally, using data from the International Social Survey Programme. Their analysis showed that overall job satisfaction was highest among health service managers and generalist medical practitioners, and lowest among environmental hygiene staff and nurses. The study identified four primary drivers of job satisfaction: intrinsic rewards, work relationships, extrinsic rewards, and worklife balance.

Mohannad Alkhateeb et al., (2025) conducted a systematic review of factors influencing job satisfaction in Gulf Cooperation Council countries, examining 73 studies from Saudi Arabia, UAE, Bahrain, Kuwait, Oman, and Qatar. Their analysis identified 14 key determinants: pay, promotion, co-workers, supervision, fringe benefits, contingent rewards, working conditions, nature of work, communication, workload, leadership style, relationships with patients, demographic factors, and hospital type. This comprehensive framework offers deeper insights into job satisfaction determinants beyond conventional models.

Prithivi S et al., (2024) examined the relationship between quality of work life and worklife balance in the health sector, finding that work environment and rewards, recognition are the most influential factors affecting employees’ work-life balance. Their study highlighted that, given evolving employee lifestyles, it is essential to improve working conditions and welfare facilities to ensure proper work environments and enhance satisfaction levels.

Darla Fortune et al., (2006) highlighted the significance of organizational interventions by examining healthcare staff experiences with QWL initiatives. Their study found that high work demands reduced the ability to provide care and strained relationships with managers, negatively affecting quality of care. However, QWL initiatives offered valuable opportunities for staff social interaction, strengthening connections that improved working relationships and team cohesion.

The expanded literature demonstrates that poor QWL in healthcare settings is a multifaceted problem requiring comprehensive organizational responses. The evidence suggests that interventions must address not only traditional factors like compensation and working conditions but also emerging challenges such as shift work patterns, pandemicrelated stressors, and evolving employee expectations regarding work-life integration. The consistent findings across diverse geographic and cultural contexts underscore the universal nature of QWL challenges in healthcare, while also highlighting the need for culturally sensitive and context-specific intervention strategies.

Research Gap

Although individual studies highlight contextspecific influences, very few integrate global evidence to identify shared determinants of poor QWL, thereby constraining the transferability of policies across national contexts. This paper consolidates findings from secondary sources to map key predictors and proposes a conceptual framework to support the improvement of QWL across diverse healthcare settings.

Methodology

This study utilized a comprehensive secondary data analysis approach, conducting an extensive search of peerreviewed academic databases such as PubMed, Scopus, Web of Science, and specialized healthcare journals to identify relevant studies. Data extraction focused on pinpointing specific determinants of poor QWL, their interrelationships, and contextual factors across diverse healthcare settings and geographic regions. The synthesized evidence was then analyzed thematically to develop a comprehensive conceptual framework, integrating global insights into the complex and multifaceted nature of poor quality of work life in healthcare environments.

Conceptual Framework

Based on a thorough review of existing literature, this study proposes a multidimensional conceptual framework that explains the key determinants of poor quality of work life (QWL) among healthcare employees. The framework synthesizes global empirical evidence, providing a structured understanding of how various factors interact to influence QWL outcomes in healthcare settings.

1. Framework Development and Theoretical Foundation

The framework is grounded in the theoretical model of David Lewis et al., (2001), who categorized determinants of QWL into extrinsic factors (e.g., salaries and tangible benefits), intrinsic factors (e.g., autonomy, skill levels, and task challenge), and individual characteristics. Building upon this foundation, the framework incorporates contemporary global evidence and the multidimensional measurement of QWL proposed by Darren van Laar et al., (2007), which identifies six core dimensions: Job and Career Satisfaction, General Well-Being, Home-Work Interface, Stress at Work, Control at Work, and Working Conditions.

II. Core Framework Components

• Central Construct: Poor Quality of Work Life

At the center of the framework is the construct of Poor Quality of Work Life, conceptualized as a multidimensional phenomenon reflecting dissatisfaction across the six key domains identified by Darren van Laar et al., (2007). This construct serves as the primary outcome variable, influenced by determinants operating at organizational, environmental, and individual levels. The framework recognizes that poor QWL is not a singular issue but results from the cumulative effect of multiple interacting factors, leading to both individual and organizational consequences over time.

• **Primary Determinant Categories**

The framework identifies five primary categories of determinants that contribute to poor QWL among healthcare employees. The key components and empirical support for these determinant categories are summarized in Table 1.

a) Organizational & Management Factors

Organizational and managementrelated conditions represent a central determinant of quality of work life in healthcare settings. These factors include inadequate compensation and reward systems, ineffective management and supervision, limited organizational support, unfair promotion practices, job insecurity, and weak grievance redressal mechanisms. Together, these elements shape healthcare employees' perceptions of fairness, recognition, and institutional support, thereby exerting a strong influence on their overall work life quality

b) Work Environment & Physical Conditions

Work environment and physical conditions significantly influence the everyday experiences of healthcare workers. Poor infrastructure, unsafe working environments, inadequate equipment, and ergonomic challenges expose employees to continuous physical strain and occupational hazards. Over time, these conditions generate cumulative stress and discomfort, contributing to declining quality of work life and increased physical health risks.

c) Psychosocial Work Factors

Psychosocial work factors play a critical role in determining healthcare employees' quality of work life. High job demands combined with limited resources, lack of supervisory support, ineffective communication, constrained autonomy, and limited empowerment create persistent psychosocial stress. These conditions foster emotional exhaustion and reduced engagement, gradually deteriorating employees' work-related well-being.

d) Work Life Balance Factors

Worklife balance has emerged as a prominent determinant of quality of work life, particularly in high-pressure healthcare environments. Factors such as workfamily conflict, excessive workloads, irregular and demanding shift schedules, long working hours, and difficulty managing professional and personal responsibilities significantly disrupt employees' ability to maintain balance. Such imbalances intensify stress and fatigue, ultimately undermining overall work life quality.

e) Individual & Demographic Characteristics

Individual and demographic characteristics function as moderating factors within the framework, influencing how other determinants affect quality of work life outcomes. Variables such as age, gender, marital status, educational attainment, work experience, tenure, and employment status shape employees' vulnerability or resilience to adverse workplace conditions. These characteristics explain variations in QWL experiences among healthcare workers exposed to similar organizational and environmental factors.

Table 1: Summary of Quality of Work Life (QWL) Determinant Categories and Supporting Evidence

Determinant Category	Key Components	Primary Supporting Evidence
Organizational & Management Factors	Inadequate compensation; poor management practices; lack of organizational support	Lewis et al. (2001); Raeissi et al. (2019); Nayak et al. (2017); Akinwale et al. (2024)
Work Environment & Physical Conditions	Poor infrastructure and facilities; safety hazards; ergonomic problems	Saraji et al. (2006); Almalki et al. (2012); Neupane et al. (2016); Bakhshi et al. (2019)
Psychosocial Work Factors	Imbalance between job demands and resources; ineffective communication; limited autonomy	Dolan et al. (2008); Teles et al. (2014); Opollo et al. (2014); Nayak et al. (2016)
WorkLife Balance Issues	Workfamily conflict; excessive workload; challenges related to shift work	Zandian et al. (2020); Nena et al. (2018); Mercan et al. (2023); Maqsood et al. (2021)
Individual Characteristics	Demographic attributes; educational level; work experience	Lewis et al. (2001); Kelbiso et al. (2017); Raeissi et al. (2019); Almalki et al. (2012)

Source : (Compiled by author)

• Integrated Conceptual Framework

While the preceding section outlined the major determinants of poor quality of work life, the following conceptual framework integrates these factors to illustrate their interrelationships and collective impact on healthcare employees' QWL.Figure 1 presents the integrated conceptual framework that emerged from this analysis, illustrating the complex relationships between determinant categories and their collective impact on healthcare worker QWL. The diagram demonstrates how multiple factors operate simultaneously to influence QWL outcomes, with individual characteristics serving as moderating variables.

Although not explicitly depicted in the diagram, the framework acknowledges that these relationships operate within broader contextual and environmental conditions, such as healthcare setting type, cultural and geographic context, healthcare system characteristics, and crisis situations.

This framework provides a comprehensive foundation for understanding the multifaceted nature of poor QWL in healthcare settings and supports the identification of targeted intervention points for policy and managerial action.

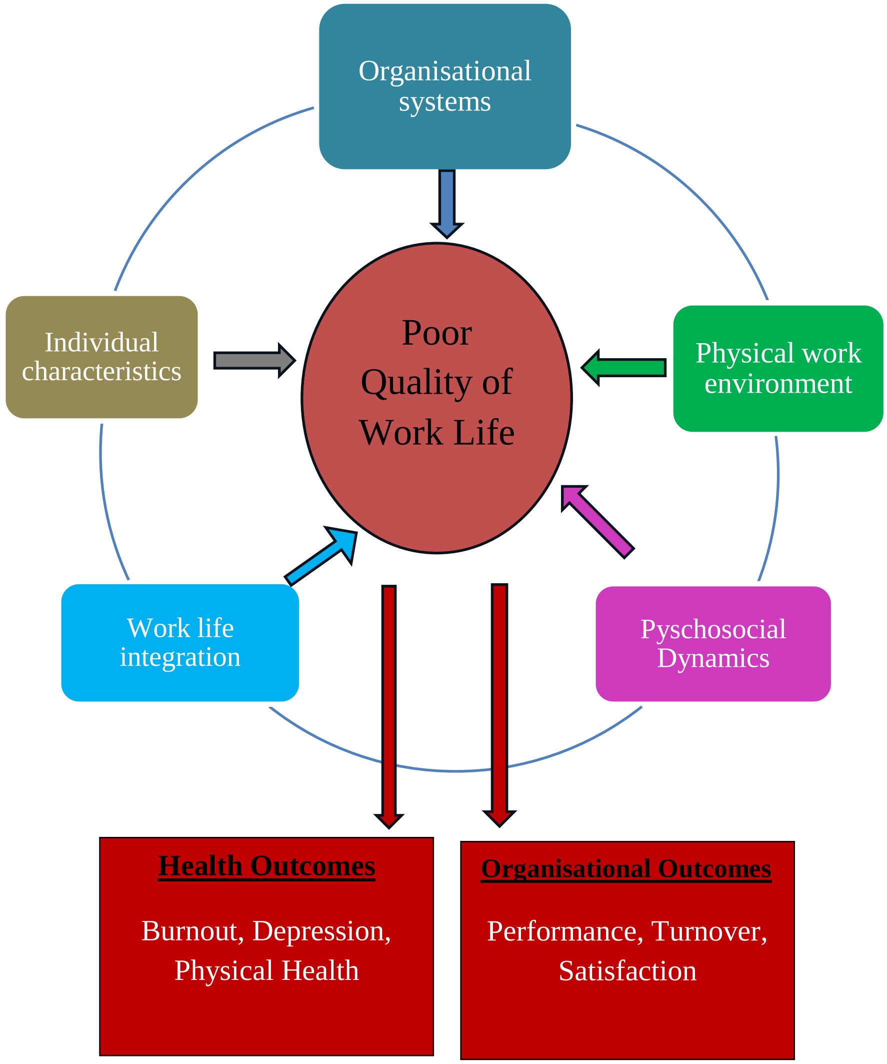

Figure 1: Integrated conceptual framework showing the five primary determinant categories and their relationships with Poor Quality of Work Life outcomes.

Source :(Compiled by author)

III. Framework Relationships and Interactions

a) Direct Relationships

Each determinant category exerts a direct influence on QWL outcomes. For instance, Bakhshi et al., (2018) demonstrated significant correlations between poor QWL and mental health outcomes, including stress, anxiety, and depression, alongside reduced job performance and satisfaction.

b) Moderating Relationships

Individual characteristics, such as age, gender, and education, moderate the effects of other determinants on QWL. Raeissi et al., (2019) found that demographic factors such as male gender, single status, older age, and lower education levels significantly predicted lower QWL, highlighting their moderating role.

c) Mediating Relationships

Psychosocial factors can mediate the relationship between organizational determinants and QWL outcomes. Poor management practices increase job demands and reduce available resources, which in turn generate psychosocial stress, ultimately contributing to poor QWL outcomes.

IV. Framework Outcomes and Consequences

The framework identifies two primary categories of outcomes resulting from poor QWL. Health and well-being outcomes include burnout (Joseph Obiri Asante et al., 2019)(Meltem Saygılı et al., 2020), depression, anxiety, and stress (E. Bakhshi et al., 2018), physical health problems (Mariza Alves Barbosa Teles et al., 2014), and musculoskeletal disorders (S. Neupane et al., 2016). Organizational outcomes encompass poor job performance (E. Bakhshi et al., 2019), intention to quit (Yeliz Mercan et al., 2023), job dissatisfaction (Ruthann Cunningham et al., 2022), and reduced organizational commitment.

To mitigate these adverse health and organizational consequences, the framework emphasizes the importance of strengthening Quality of Work Life through fair and transparent compensation systems, adequate staffing levels, supportive and participative leadership, and opportunities for professional growth. Interventions such as flexible work schedules, workload rationalization, employee assistance and mental health support programmes, ergonomically designed workplaces, and a positive organizational climate that values employee voice and recognition are critical in reducing stress, burnout, and turnover intentions. Enhancing worklife balance and ensuring safe, supportive working conditions can significantly improve employee well-being, job satisfaction, and organizational commitment, thereby transforming negative outcomes into sustainable workforce performance.

V. Framework Limitations

While this framework provides a comprehensive synthesis of current literature, it is important to acknowledge certain limitations. The framework is based on available published research, which may not capture all emerging determinants or cultural variations in QWL experiences. Additionally, the relative importance of different determinant categories may vary across specific healthcare contexts and require empirical validation through future research. The framework should be viewed as a dynamic model that may require refinement as new evidence emerges and healthcare environments continue to evolve.

Discussion

• **Analysis of Key Determinants of Poor Quality of Work Life**

The synthesis of global literature indicates that poor quality of work life (QWL) among healthcare employees is predominantly shaped by organizational and managementrelated factors, which emerge as the most consistent and influential determinants across diverse healthcare systems. Studies conducted in different regions consistently report inadequate compensation, ineffective leadership practices, and insufficient organizational support as central contributors to diminished QWL. The recurrence of these determinants across both developed and developing healthcare systems suggests that organizational deficiencies represent structural and systemic challenges rather than contextspecific anomalies.

A particularly important insight from the reviewed studies is the dominant role of extrinsic factors, especially pay and benefits, in shaping QWL outcomes. Evidence indicates that fair compensation and job security exert a stronger influence on QWL satisfaction than intrinsic factors such as autonomy or professional growth (Lewis et al., 2001). This finding challenges traditional assumptions that healthcare professionals are primarily motivated by intrinsic rewards and highlights the necessity of addressing fundamental organizational inequities before implementing higherorder motivational strategies.

Psychosocial work factors also emerge as critical determinants of poor QWL, reflecting the emotionally demanding nature of healthcare work. The prevalence of effortreward imbalance ,excessive job demands relative to available resources (Dolan et al., 2008), and inadequate supervisory support suggests a weakened psychological contract between healthcare organizations and employees. These conditions generate sustained occupational stress, which not only undermines individual well-being but also contributes to reduced performance, absenteeism, and turnover intentions, thereby reinforcing organizational inefficiencies.

• **Geographic and Cultural Variations in QWL Determinants**

While organizational and management factors consistently dominate QWL outcomes globally, their manifestation varies across regions and healthcare systems. Evidence from lowand middle income contexts highlights persistent challenges related to resource shortages, inadequate infrastructure, and occupational safety concerns, whereas studies from high-income healthcare systems place greater emphasis on worklife balance, psychological well-being, and professional development opportunities (Van Laar et al., 2007).

In culturally distinct healthcare systems, particularly within Gulfregion contexts, job satisfaction and QWL are shaped by additional determinants such as interpersonal relations, patient interactions, leadership styles, and organizational hierarchy (Alkhateeb et al., 2025). These findings suggest that cultural norms surrounding authority, professional roles, and care delivery significantly influence how QWL determinants are experienced, reinforcing the need for contextsensitive intervention strategies rather than universally standardized solutions.

Across several rapidly expanding healthcare systems, high levels of QWL dissatisfaction have been reported, often linked to increasing service demand without proportional investment in workforce support. This imbalance results in heightened workloads, limited organizational backing, and insufficient coping mechanisms. Collectively, these findings underscore that while QWL challenges are globally prevalent, their underlying drivers and expressions remain strongly contextdependent.

• **Differences Across Healthcare Settings and Professional Groups**

QWL determinants vary substantially across healthcare settings and occupational roles. Primary healthcare environments frequently report lower QWL compared to tertiary or specialized facilities, reflecting disparities in resource allocation, professional support, and career advancement opportunities (Asante et al., 2019). Primary care professionals often operate in relatively isolated settings with limited institutional recognition, which exacerbates dissatisfaction despite their critical role in community health delivery.

Highintensity environments such as emergency and intensive care units present distinct challenges, particularly evident during public health crises. Workers in these settings experience compounded stress due to prolonged exposure to critical decisionmaking, emotional strain, and inadequate recovery time, leading to persistently low QWL across physical, psychological, and environmental domains.

Professional group disparities are especially pronounced among nursing personnel, who consistently report poorer QWL compared to other healthcare workers (Cunningham et al., 2022). This trend reflects nurses’ high patientcare responsibilities combined with relatively limited organizational authority and recognition, positioning them as a particularly vulnerable group within healthcare workforce structures.

• **Interconnections Between Determinants and Evolving QWL Challenges**

The reviewed evidence demonstrates that QWL determinants do not operate in isolation but are highly interrelated, producing cascading effects within healthcare organizations. Organizational and management shortcomings function as upstream determinants that intensify psychosocial stress, worsen physical work environments, and undermine worklife balance. Inadequate compensation and ineffective leadership amplify the negative impact of demanding workloads and insufficient staffing, accelerating dissatisfaction and emotional exhaustion.

Worklife balance factors illustrate this interdependence most clearly. Excessive workloads and irregular shift patterns not only directly impair QWL but also exacerbate psychosocial strain and limit employees’ capacity to cope with organizational pressures (Nena et al., 2018; Mercan et al., 2023). Evidence of widespread workfamily conflict among healthcare professionals (Zandian et al., 2020) suggests that imbalance between professional and personal roles has reached critical levels, potentially undermining the effectiveness of isolated organizational interventions.

Individual characteristics further moderate these relationships. Demographic variables such as age, gender, marital status, and educational level consistently influence QWL perceptions, shaping how healthcare workers experience organizational and psychosocial stressors (Kelbiso et al., 2017). These findings reinforce the need for differentiated and inclusive intervention strategies.

Over time, the nature of QWL challenges has evolved. Earlier studies emphasized tangible organizational conditions, whereas more recent research increasingly highlights psychosocial stress, burnout, and mental health outcomes. The growing recognition of burnout as both a determinant and consequence of poor QWL reflects heightened awareness of the psychological demands of contemporary healthcare work (Asante et al., 2019; Saygılı et al., 2020). This bidirectional relationship suggests that deteriorating QWL and burnout reinforce one another, creating self-perpetuating cycles of workforce distress.

• **Framework Implications and Applications**

The conceptual framework provides a comprehensive foundation for understanding the multifaceted nature of poor QWL in healthcare settings. It offers healthcare managers and policymakers a systematic approach to identifying intervention points and developing targeted strategies to improve healthcare worker QWL. The framework's multidimensional nature acknowledges that effective interventions must address multiple determinant categories simultaneously rather than focusing on isolated factors. Furthermore, the framework's recognition of contextual influences emphasizes the need for tailored approaches that consider specific healthcare environments and cultural contexts.

• Implications

a) For Healthcare Management and Practice

The findings indicate that healthcare managers possess significant leverage to improve QWL through organizational reforms. Priority actions include addressing compensation inequities through transparent pay structures and comprehensive reward systems, alongside strengthening leadership capacity through management training focused on supportive supervision and effective communication (Raeissi et al., 2019).

Improving work environments through ergonomic design, adequate staffing, and enhanced safety measures remains essential, as does the implementation of work-life integration initiatives such as flexible scheduling and employee support programs (Zandian et al., 2020). Collectively, these measures address both structural and psychosocial determinants of QWL.

b) For Policy Development

At the policy level, the global prevalence of poor QWL underscores the need to recognize healthcare worker well-being as a core component of health system sustainability. National policies should incorporate minimum QWL standards related to compensation, working conditions, and organizational support, while regulatory bodies can integrate QWL indicators into accreditation and quality assurance frameworks (Kelbiso et al., 2017).

Experiences during the COVID-19 pandemic highlight the importance of crisisresponsive workforce policies, including surge staffing, enhanced safety protocols, and accessible mental health support systems (Maqsood et al., 2021). International collaboration in developing adaptable QWL benchmarks can further support healthcare systems facing similar workforce challenges.

c) For Future Research

Future research should prioritize longitudinal and interventionbased designs to establish causal relationships and evaluate the effectiveness of QWL improvement strategies. Expanding research coverage to underrepresented regions and professional groups, alongside the development of standardized healthcarespecific QWL measurement tools, will enhance comparability and generalizability.

Further investigation into the economic costs of poor QWL and the return on investment of organizational interventions would strengthen the evidence base for policy action. Emerging areas such as technologyrelated stress, resilience mechanisms, and mental health pathways warrant systematic exploration to address the evolving realities of healthcare work.

CONCLUSION

This study synthesizes global evidence to demonstrate that poor quality of work life among healthcare employees is a multidimensional and systemic issue shaped by interacting organizational, psychosocial, environmental, and individual factors. Organizational and managementrelated deficiencies, particularly inadequate compensation, weak leadership, and insufficient support, emerge as the most consistent determinants across healthcare systems. These structural challenges interact with demanding work environments, psychosocial stress, and worklife imbalance, leading to adverse outcomes such as burnout, reduced performance, and increased turnover intentions.

The proposed conceptual framework advances understanding by integrating these determinants into a unified structure, emphasizing that QWL challenges cannot be effectively addressed through isolated interventions. Differences across healthcare settings and professional groups further highlight the need for context-sensitive and rolespecific strategies. While the study is limited by its reliance on secondary data, it provides a robust foundation for future longitudinal and intervention-based research.

Overall, improving healthcare employees' quality of work life is essential for workforce sustainability and health system performance. The findings underscore the need for comprehensive, multi-level strategies that address both structural and psychosocial dimensions of work life in healthcare settings.

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ANALYZING INDIA'S BILATERAL TRADE DYNAMICS WITHIN THE QUAD: A GRAVITY MODEL APPROACH

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ABSTRACT

This paper aims to analyze India's bilateral trade flows within QUAD concerning the Gravity Model of International Trade. The study includes distance and GDP as essential factors of trade relations and other quantitative variables. The results show the influence of importing nations' GDP and Population on India's exports, which underscores the significance of market size and demand in shaping trade relations. The presence of free trade agreements between India and its trading partners has also been found to facilitate trade activities. Contrary to conventional expectations, distance has been found to have a statistically insignificant impact on trade flows among the Quad countries. This suggests that advancements in communication and transportation technologies have mitigated the barriers posed by geographic distance, enabling countries to engage in trade relations irrespective of their physical proximity. The study suggests that policymakers are encouraged to bolster economic relations through initiatives like free trade agreements, recognizing the pivotal role of economic prowess in shaping bilateral trade within the QUAD. Additionally, investing in infrastructure and technology can help overcome geographic barriers, fostering smoother trade interactions among QUAD nations. Market access promotion, tariff reduction, and customs procedure streamlining are suggested measures to stimulate trade and enhance economic collaboration in the Indo-Pacific region.

KEYWORDS: *QUAD Countries, Panel Data, Gravity Model, Trade Potential.*

Declaration of Interest Statement

We, the authors of the manuscript **Analyzing India's Bilateral Trade Dynamics within the QUAD: A Gravity Model Approach** declare that we have no conflicts of interest to disclose.

We affirm that no financial, personal, or professional interests could be perceived as influencing the research findings or interpretations presented in this manuscript.

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1.1 INTRODUCTION

Trade is a foundation of the global economy, easing innovation, specialization, and the exchange of goods and services across borders. In an era of increasing globalization, trade has become integral to sustaining economic competitiveness and fostering growth. Grossman et al. (2015) emphasize how globalization fosters economic growth through information dissemination, market expansion, and technology transfer. Trade between nations fosters economic development and growth, bringing numerous benefits to the countries involved (Ijirshar, 2022). The determinants and explanations of export flows have been thoroughly analyzed and explored by policymakers and scholars since the beginning of globalization (Atif et al (2017). However, understanding the factors that influence bilateral trade dynamics within specific regional agreements is crucial for formulating effective trade policies and enhancing economic cooperation (Kumar & Ahmed, 2015). One such regional agreement is the QUAD, consisting of India, the United States, Japan, and Australia. The QUAD, also known as the Quadrilateral Security Dialogue, brings together four major democracies in the Indo-Pacific region and aims to promote cooperation on security and economic issues.

The basic logic behind the formation of the quad is to prevent China's influence across the Indo-Pacific region by uniting the countries around the Pacific region (Eisentraut, S., & Gaens, B. (2018),Hanada, R. (2019), Bayram, D. Ç. (2022), Deb and Wilson (2021)). Since the member countries cooperatehighly with defense and security issues, it is also argued that Quad needs to continue expanding its agenda beyond diplomacy and defense. Expanding its agenda in trade, finance, foreign investment, commercial technology, and information security would help to build the Pacific region stronger (Jaishankar, D., & Madan, T. (2021)). Motivated by China's efficient international trade practices, these strong economies work together to strengthen their trade relations (Agarwal, 2022).

Trade plays a crucial role in promoting economic growth and development, especially in developing countries like India (Kadir & Ozan, 2010). International trade, particularly within regional alliances like the QUAD, has the potential to generate significant economic benefits for India (GULNAZ & Manglani, 2022). While diplomatic relations and strategic alliances are important aspects of the QUAD, exploring the trade aspects within this alliance is equally essential. The role of India among the Quad countries is different as it is the only developing country in the Quad, which gives immense scope for the country to utilize the platform better in trade and finance within the Quad nation as the other three countries are technologically, financially, economically advanced (Panda, J. P. (2020). Apart from the diplomatic roles of Quad countries, the possible trade enhancement with other Quad members and India is underestimated. The comparative advantage of India will be high for many of the goods and services produced in India as it is unique and has a vast potential market in those developed nations (Goswami, B., & Nath, H. K. (2021). When discussing trade with India and other quad countries, the study looks towards the feasibility of trade between those countries. This thought has arisen because, considering the cooperation between the countries in defense and diplomacy, the countries have an advantage of trade liberalization among the nations, which can be good for exports.

Consequently, this paper seeks to enrich the current literature on trade flows by investigating the trade relations among the Quadrilateral Security Dialogue (Quad) countries—India, the United States, Japan, and Australia. The focus is on analyzing the research question of how distance, GDP differentials, and other quantitative variables impact trade relations between India and the developed nations of the Quadrilateral Security Dialogue (Quad), comprising the United States, Japan, and Australia.

In this context, a notable research gap exists for identifying the factors affecting the trade dynamics between India and other QUAD members. While the Quad aims to strengthen cooperation among its members, little research has delved into how factors affect trade flows, particularly between the developing country of India and the advanced economies within the Quad. By employing the Panel data Gravity model, this study aims to address this gap and provide crucial insights for policymakers aiming to foster economic cooperation and trade relations in the Indo-Pacific region.

The Gravity Model of International Trade is a widely used framework in economics that provides insights into the determinants of trade flows between countries. It considers factors such as the size of economies, the distance between countries, and other socio-economic variables that influence trade patterns. While geographic distance continues to influence trade patterns, advancements in communication and transportation technologies have mitigated its impact. The role of distance as a trade barrier has evolved in the context of modern trade dynamics, challenging traditional perceptions. This contrasts with the expectation that reduced communication costs diminish the significance of distance in trade. Karpiarz et al. (2014) prove that the gravity model shows an increasing distance coefficient over time. This suggests that distance plays a growing role in trade dynamics. However, the effects of distance on trade relations vary across countries and industries, highlighting the need to refineits role in shaping trade flows.

As mentioned, the Gravity Model by Shepherd et al. (2019) presents a valuable tool for comprehending and shaping global trade dynamics. Its application in policy research has reshaped the landscape, influencing the types of goods traded, the participating countries, and trade barriers. Supporting, Chaney (2018) emphasizes the role of economic scale and distance in bilateral trade flows through the empirical evidence supporting the panel data Gravity Model. This model of international trade has emerged as a fundamental framework for understanding the patterns and determinants of trade relations between countries. It posits that the volume of trade between two countries is inversely correlated with their economic mass and directly related to their geographic proximity (Anderson and Wincoop (2003)). However, the impact of various factors such as distance, transportation costs, and the nature of goods and services traded on trade relations remains a subject of ongoing research and debate.Despite the growing importance of the QUAD in the international arena, there is limited research on the specific impacts of bilateral trade flows within this alliance. This paper aims to analyze India's bilateral trade flows within the QUAD concerning the Gravity Model of International Trade.

1.2 Review of literature

The research papers reviewed span a wide range of topics within international trade, with a significant focus on applying and analyzing the Gravity Model. The studies highlight the differential effects of distance on trade flows, particularly between developing and developed countries, and the importance of considering internal trade costs alongside bilateral distance estimations. Additionally, the studies explore methodological aspects of the Gravity Equation, factors beyond distance that influence trade, such as trade policies, and the consequences of globalization on trade. The studies also examine the applicability of the Gravity Model to specific countries' trade relationships and the impact of globalization on manufacturing trade.

Ramos et al. (2007) and Yotov (2012) emphasize the differential effects of distance on trade flows, particularly between developing and developed countries, and suggest considerations of internal trade costs alongside bilateral distance estimations. Salvatici (2013) delves into the methodological aspects of the gravity equation, stressing factors beyond distance, such as trade policies, that influence trade. Greene (2013) and Costinot et al. (2014) investigate the consequences of globalization on trade, including the impact of trade policies and market liberalization gains. Karpiarz et al. (2014) and Malik et al. (2014) explore paradoxes in distance and geopolitical factors affecting trade dynamics. Sejdini (2014) and Stay et al. (2016) examine the applicability of the Gravity Model to specific countries' trade relationships, while Borchert et al. (2017) and Thai-Ha Le (2017) focus on the impact of globalization on manufacturing trade and the significance of economic factors in bilateral trade and FDI flows.

Other studies, such as Natale et al. (2015) and Maciejewski et al. (2019), analyze trade dynamics in specific sectors or regions using the Gravity Model, highlighting product characteristics and regional trade dynamics. Shahriar et al. (2019) and Baier et al. (2020) review the Gravity Model's theoretical foundations and estimation methodologies, stressing its continued relevance and the importance of methodological innovations. Zhang (2023) affirms the gravity model’s effectiveness in understanding bilateral trade relationships. Stevens et al. (2020) explore the economic geography of cities and workplace dynamics, offering insights into trade-related factors like gender and power dynamics. Bhatt (2019) indicates that India’s international trade is significantly influenced by trading partners, logistics performance index, and distance using the augmented gravity model. Lastly, Agarwal et al. (2022) examine the impact of political shocks on trade, focusing on India's relations with Quad countries and China's economic influence. These studies collectively contribute to a comprehensive understanding of international trade dynamics, emphasizing the multifaceted role of financial, geopolitical, and methodological factors in shaping trade patterns.

Itprovides a deeper understanding of the Gravity Model's applicability across various contexts. They emphasize the importance of considering multiple factors in understanding trade flows, including distance, trade policies, and internal trade costs. The studies also highlight the significance of methodological innovations and continued research on the Gravity Model to enhance our understanding of international bilateral trade dynamics.

1.3 Econometric model, approach, and data sources

1.3.1 Econometric Model

The gravity model of trade is one of the empirical tools used to explain the international trade flows among economic partners. Gravity models are used in various fields, such as environment, migration, transportation, health and education, stock market behavior, and trade flow (Kabir et al., 2017). Although the model was initially used by E.G. Ravenstein in 1889 to know the impact of the country's size and migration lead, it was first introduced in the empirical studies of International Trade by Tinbergen (1962) and Poyhonen (1963). Its origin in 1687 arose through a Newtonian Physics belief, i.e., the two bodies' mutual attraction is determined by the product of their masses divided by the square of the separation between their gravity centers. It led to the following equation:

$$F = G\,\frac{m_1 \times m_2}{r^2}$$

The trade equation is comparable to the law, stating that the trade between two nations is inversely correlated with their distance from one another and directly proportional to the GDP of each nation. The gravity model can be written in its basic form as follows:

$$Trade_{ij} = \alpha\,\frac{GDP_i \times GDP_j}{Distance_{ij}}$$

Where $Trade_{ij}$ is represented as the Volume of Trade between i and j countries; GDP_i and GDP_j are indicated as the national income of i and j countries respectively, and $Distance_{ij}$ is the distance between the two countries (substituted for Trade Costs).

For the regression analysis, the equation is usually converted into the linear log form, written as:

$$log\ log\left(Trade_{ij}\right) = \alpha + \beta_1\ log\ log\left(GDP_i \times GDP_j\right) + \beta_2\ log\ log\left(Distance_{ij}\right) + \mu_{ij}$$
(1)

The given log-linear equation is the basic gravity model equation where trade is predicted to be a positive function of income and a negative function of distance from trading partners. Reducing trade barriers to maximize trade gains is one of the main goals of every trade deal. The variables that impede the smooth flow of commodities from exporters to importers, also known as transaction costs, include indirect barriers to trade and direct barriers, such as introducing tariffs. Trade costs are a category that includes trade barriers in the literature. The cost of transportation (including freight and time costs), border-related barriers (including linguistic, financial, informational, and security barriers), policy barriers (including tariffs and non-tariff), and the cost of retail and wholesale distribution are the main elements of trade cost, according to Anderson and Wincoop (2004). Distance can be used as a possible substitute for trade costs due to their broader impact on trade flows alone as proposed by Anderson and Wincoop (2004) and De (2007). In the model, distance is a substitute variable for transportation costs. This assumption posits that the transportation cost from the importer country to the exporter country is considered equivalent to the cost from the exporter country to the importer country, where the distance costs are the linear function of the distance. Ramos et al. (2007) explain that because of the tendency to be fixed for the demand and supply situation in the market and their doubtful representation of cultural proximity, information costs, and their perceived closeness, the transportation costs can only be assumed to be the distance in the model.

This basic model can be extended by incorporating other factors that can impact the bilateral trade between the countries (Frankel et al, 1997). The study also accounts for the following factors: Population, RFE, trade openness, and a dummy if the nations are a part of any common free trade agreement. Therefore, the gravity model used in this study can be given by:

$$Trade_{it} = \beta_0 \mathrm{GDP}_{it}^{\beta_1} \mathrm{GDP}_{jt}^{\beta_2} POP_{it}^{\beta_3} POP_{jt}^{\beta_4} \mathrm{Distance}_{ij}^{\beta_5} REF_{ij}^{\beta_6} TO_{it}^{\beta_7} FTA_{ij}^{\beta_8} \mathrm{quad}^{\beta_9} \quad (2)$$

Taking the natural logarithm of eq. (2), we get:

$$\ln(Trade_{it}) = \beta_0 + \beta_1 \mathrm{GDP}_{it} + \beta_2 \mathrm{GDP}_{jt} + \beta_3 POP_{it} + \beta_4 POP_{jt} + \beta_4 \mathrm{Distance}_{ij} + \beta_5 REF_{ij} + \beta_6 TO_{it} + \beta_7 FTA_{ij} + \beta_8 quad + \mu_{it} \quad (3)$$

Where, POP_{it} and POP_{jt} represent the population of *i* and *j* countries in *t* period, REF is the relative factor endowment that represents the difference in the sample countries in terms of the factor endowments, TO is a trade openness representing the openness of India with the world, FTA is a dummy taking value of 1 if India and trading partner are a part joint free trade agreement and 0 otherwise, and Quad is a dummy taking value 1 for the years after 2007 when Quadrilateral Security Dialogue (Quad) was formed between India, US, Australia, and Japan. μ_{it} is the error term and follows a normal distribution.

1.3.2 Econometric approach

Cross-sectional data is mainly used to estimate the trade effects and trade relationships for a particular period. However, the cross-sectional data over different periods, referred to as panel data, is more relevant for the estimation. This panel data methodology calculates the relatable relationship between the variables. According to Egger (2000), unraveling time-invariants and country-specific effects is the most appropriate. It also allows the reduction of bias prompted by heterogeneity across countries. Thus, this study uses panel data methods for the evidential gravity model of trade flows. To analyze the determinants of the trade flow (export and import flows), exports, imports, and total trade are acceptable as dependent variables.

The panel data gravity model can be estimated using OLS, fixed-effects, and random-effects panel data models. However, applying OLS to the gravity model can lead to biased estimates, mainly due to heteroscedasticity and omitted variable bias (Kalirajan, 2008; Silva and Tenreyro, 2006). Though the fixed-effects model helps to account for the unobserved heterogeneity (Nasrullah et al., 2020), it is unable to evaluate the presence of some of the time-invariant variables. The random effects model overcomes these issues of the fixed effects model. Thus, the Hausman Test is applied for the appropriate choice of random and fixed-effect, which assumes a null of no significant correlation between the explanatory variable and the error term. The statistically significant coefficient rejects the null hypothesis and produces evidence that the fixed effect model would be the best-fitted model.

Further, the Lagrange Multiplier test of Breusch and Pagan (1979) is used, which follows the Chi-square distribution with 1 degree of freedom. The test has a null hypothesis that the variance of individual-specific effects is zero. The null hypothesis is rejected in case of a statistically significant coefficient on the Lagrange test and indicates that random heterogeneity is present in the model.

However, these techniques fail to consider the impact of "behind-the-border" restrictions on exporting nations, which results in inaccurately estimated coefficients. Kalirajan (2008) introduced the SFGA technique to address this problem by simulating the combined effect of all "behind-the-border" factors on bilateral between the nations. These characteristics may arise due to many socio-political-institutional elements that vary among countries and are within the power of exporting and importing countries. These "behind-the-border" factors create the disparity between the actual and potential trade of the two nations. These variables are accounted for in the single-sided error term (ε_t). . Thus, our model can be written as:

$$\ln(Trade_{it}) = \beta_0 + \beta_1 \text{GDP}_{it} + \beta_2 \text{GDP}_{jt} + \beta_3 POP_{it} + \beta_4 POP_{jt} + \beta_4 \text{Distance}_{ij} + \beta_5 REF_{ij} + \beta_6 TO_{it} + \beta_7 FTA_{ij} + \beta_8 quad + (\nu_t \text{-} \varepsilon_t)$$

(4)

If it ε_t takes a value other than 0, it shows that such restrictions would prevent actual exports from reaching their full potential (Kalirajan, 2007). Therefore, assessing the effects of such restrictions is crucial to reducing export restrictions. Additionally, the double-sided error term (ν_t) evaluates other variables, including measurement errors. The SFGA method shows significant improvements over the conventional methods of measuring the gravity model.

1.3.3 Data sources

The data on bilateral trade flows between India and other quad nations (Australia, the US, and Japan) for the period from 2000 to 2021 are collected from two sources: (i) the World Trade Integrated Solution (WTIS) tool of the United Nations Conference on Trade and Development (UNCTAD) and the World Bank; and (ii) Centre for Prospective Studies and International Information (CEPII) that provides data to estimate gravity equations. The Gross Domestic Product (GDP), Trade openness, and Population data are collected from the World Development Indicators database. Information on free trade agreements, relative factor endowments, and distance are collected from the CEPII database.

RFE has been calculated using the formula mentioned hereafter. RFE is used to calculate how much a pair of countries vary from one another in terms of relative factor endowment. A larger difference in RFE indicates the presence of a higher volume of inter-industry trade, and the opposite is also true. The natural logarithm of the capital-labor ratio's absolute difference is typically used to measure this variable. GDP is utilized in place of the capital-labor ratio due to the lack of statistics per capita. The presumed sign of the variable is positive. Therefore, the Relative Factor Endowment is extracted as:

$$RFE_{ij} = lnPGDP_i - lnPGDP$$

1.4 Empirical results

1.4.1 Pre-estimation analysis

Using the panel data models, we estimate the gravity model equations (cf. eq. 1, 2, and 3). The sensitivity analysis (cf. Table 1) suggests the inapplicability of the fixed effects model to our export's dataset as the F-statistic associated with the fixed effects model is statistically insignificant at the conventional significance levels. Therefore, we choose between pooled OLS and the random effects model based on the estimated coefficient of the *Lagrange Multiplier test of Breusch and Pagan (1979)*. We note a statistically insignificant coefficient with a p-value of

1.000; thereby, we do not reject the null hypothesis $Var(\nu_i) = \sigma_\nu^2 = 0,$, which indicates the absence of random heterogeneity in the model. Thus, pooled OLS is the most appropriate method for our export dataset. Likewise, we apply all three tests for our imports and total trade dataset, and it is noted that the fixed effects model turns out to be the most effective (cf. Table 1). The estimated results for exports (OLS), imports (fixed effects), and total trade (fixed effects) gravity equations are provided in Models 1 and 2 of Tables 3, 4, and 5, respectively.

Nevertheless, the fixed effects model does not provide the estimates of time-invariant variables like distance, foreign trade agreements, or dummy variables for free trade agreements and Quad. Furthermore, the pooled OLS or fixed effects model neglects the impact of the exporting country's "behind-the-border" constraints, resulting in unbiased estimators. As noted in Table 2, the value of gamma and ilgtgamma is statistically significant for the exports and total trade models, suggesting the role of "behind the border" factors in explaining the variations in the exports and total trade models. Moreover, the negative and statistically significant values of *eta* indicate that the degree of inefficiencies in the exports and total trade models increases over time. The significant value of *mu* also shows the applicability of the SFGA model as it depicts the truncated normal distribution. These sensitivity checks denote the applicability of the SFGA model.

Further, we also apply the pre-estimation tests for heteroscedasticity and autocorrelation to get efficient and unbiased estimates. The Bruesch-Pagan (1979) test is used to test heteroscedasticity, which is based on regressing the squared error term on explanatory variables (i.e., running auxiliary models). Estimating such auxiliary models will help to examine if any significant relationship exists between the squared error term and independent variables. The test assumes a null hypothesis of homoscedastic variance of the error term (i.e., $\mathrm{var}(\varepsilon_{it}) = \sigma_\varepsilon^2).$ The statistically significant coefficient on the *F*-statistic rejects the null hypothesis.

Furthermore, it is also crucial to check for serial correlation as estimates are inefficient, and standard errors are biased in the presence of autocorrelation. Drukker (2003) shows that the Wooldridge (2002) test of autocorrelation has good power and size properties and recommends testing if idiosyncratic error terms are serially correlated in the panel data model. This test is based on a null hypothesis of no first-order autocorrelation in residuals generated from the first-differenced regression. Specifically, it hypothesizes the correlation between residual from the first difference regression is equal to 0.5 (i.e., $corr(\Delta\varepsilon_{it}\Delta\varepsilon_{it-1}) = -0.5).$ This null hypothesis is rejected with the statistically significant coefficient on *F*-statistics. However, as the estimates show, none of our gravity models depict the presence of first-order autocorrelation, while heteroscedasticity is present in the variance of the error term of the export gravity model (cf. Table 3). Thus, we utilize White's heteroscedasticity-corrected robust standard errors for the export gravity model that allows for heteroscedasticity without affecting the magnitude of coefficients.

1.4.2 Main Findings

1.4.2.1 Export gravity model

The estimates of the export gravity model are provided in Table 4. We compute the model using both OLS and SFGA models for robustness purposes. Models 1 and 3 represent the basic gravity model, and Models 2 and 4 represent the augmented gravity models. The estimates of OLS and

SFGA are almost similar in terms of the magnitude and direction of the relationship. Thus, given the applicability and suitability of SFGA to our dataset, we explain our estimates using SFGA estimates. It is noted that the GDP and population of importing nations significantly influence India's exports. Specifically, the estimates show that the higher the income and population of the importing country, the higher the export value of India.

Regarding the influence of the domestic country, we note a positive influence of the Population of India on its exports; it implies that as the population increases by 1%, Indian exports increase by approx. 4.7% as it stimulates the development capacity. Likewise, the positive coefficient on the GDP of India indicates that a 1% increase in GDP leads to approx.—0.38% increase in India's exports.

Further, it was found that exports were higher if India had a free trade agreement with the trading partner. Furthermore, India's (an exporting country's) openness has a positive and statistically significant impact on its exports, which may be boosted because trade openness encourages technology transmission, efficient resource allocation, and knowledge spillovers (Wei, 2017). Though it is expected that a smaller distance reduces transportation costs and thus promotes trading activities (Bui, 2017), our SFGA and OLS estimates depict a statistically insignificant impact of distance between India and its trading partners on India's exports. This suggests that trade openness, free trade agreements, and other economic factors influence trading ties more than the distance between trading partners. Besides, the dummy for the origin of the Quad has no significant impact on the trading activities.

1.4.2.2 Import gravity model

Table 5 shows the estimates of the import gravity model. Both OLS and SFGA models have been used for the estimation to provide strong results. Models 1 and 3 represent the basic gravity model, whereas models 2 and 4 represent the augmented gravity model.

As found in the preliminary analysis, the fixed-effects model is the most appropriate for estimating the imports gravity model when compared to the SFGA estimated; therefore, we explain our estimates using the fixed-effects model. Regarding the influence of exporting nations, India's GDP and population significantly impact its imports. Specifically, it is noticed that a 1% increase in the population of trading partners leads to a 0.68% increase in their exports to India. Likewise, higher GDP also enhances the imports of the countries to India. Concerning the domestic factors, the GDP of India is noted to have a positive and statistically significant influence on its imports, while the population is noted to exert no significant impact.

In addition, it was found that if India had a free trade agreement with a trading partner, there would have been no imports among the countries. India's openness as an importing country is positive and statistically significant on its imports by approx. 0.07% to foster international relations based on technology and knowledge, but much less when compared to India as an exporting country (as explained in the export gravity model). Our fixed effects model shows no significant impact of distance on the volume of imports by our domestic country and the SFGA estimates further reiterate that distance does not hinder the trade relations among the countries. Furthermore, a dummy for the origin of the Quad has a negative but significant influence.

1.4.2.3 Total trade gravity model

The estimates of the total trade gravity model are provided in Table 6. The model is estimated using the fixed effects and SFGA models. However, given the applicability and superiority of the SFGA model over the fixed effects model (cf. Table 2), we focus on the estimated results of the SFGA model.

According to the findings, GDP and population significantly impact India's total trade. Notably, India's GDP and trading partners significantly impact the total trade between quad nations. For the population, consistent with our previous findings, only the population of trading partners significantly increases the volume of total trade, while the Indian Population has no significant impact. In addition, it is observed that India's Free Trade Agreement with other countries encourages total trade among the countries. India's openness as a total trade country is significant and positively justified by the impact of approximately 0.21% as it empowers the economies inside out.

Considering the distance to be the significant part according to theory, it is noted that it plays a statistically insignificant and positive relationship with SFGA estimates and does not put on any results with the fixed-effect model, this leads to the result of distance not obstructing the total trade among the countries. This concludes that other several important factors influence total trade among the countries, not just distance. This finding is consistent across all our gravity models. Also, a dummy for the origin of the Quad shows a negative but insignificant impact on the activity.

1.5 Conclusion and Policy Implications

The gravity model of international trade provides valuable insights into the factors influencing trade flows between India and other QUAD nations, highlighting the role of economic mass, geographic proximity, and other determinants (Anderson and Wincoop (2003)). Key findings from export, import, and total trade gravity models reveal several notable trends. First, the influence of importing nations' GDP and Population on India's exports underscores the significance of market size and demand in shaping trade relationships. Similarly, the GDP of India and its trading partners significantly affects imports, indicating the importance of economic strength in driving bilateral trade (Frankel and Romer (2017)). Free trade agreements between India and its trading partners have also been found to facilitate trade activities, emphasizing the role of trade policies in fostering economic cooperation. Contrary to conventional expectations, distance has been found to have a statistically insignificant impact on trade flows among Quad countries. This suggests that advancements in communication and transportation technologies have mitigated the barriers posed by geographic distance, enabling countries to engage in trade relations irrespective of their physical proximity.

Furthermore, the analysis highlights the role of India's openness as both an exporting and importing country in facilitating trade relations with the Quad nations. India's willingness to engage in international trade and embrace globalization has enhanced trade activities, fostering regional economic growth and cooperation. Overall, the findings underscore the multifaceted nature of international trade and the need for a comprehensive understanding of the factors that drive trade relations between countries (Helpman et al, 2008). By elucidating the determinants of trade flows between India and the Quad countries, this study contributes to the existing literature on international trade dynamics (Anderson, 2011). It informs policymakers about strategies to promote economic cooperation and prosperity in the Indo-Pacific region. This study was constrained to a static model within this econometric framework. While recognizing that the GDP of the previous year can influence the current year's GDP, this study, due to its static nature, exclusively considers the GDP for the current year. This limitation opens opportunities for future research to explore dynamic models encompassing the temporal impact of the previous year's GDP on the current year's economic indicators.

The following policy implications are derived from the study. Policymakers can focus on strengthening economic ties with these countries by pursuing free trade agreements and other economic partnerships, thereby leveraging the significant influence of economic strength in driving bilateral trade. the study also suggests that, invest in infrastructure development and technological advancements to enhance communication and transportation networks, which can mitigate the traditional barriers posed by geographic distance and facilitate trade relations among Quad countries. Policymakers can promote market access and trade facilitation measures, such as reducing tariffs and streamlining customs procedures, to encourage trade activities and foster economic cooperation in the Indo-Pacific region.

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1.7 Tables

Table 1: Specification tests for panel data models			
	Pooled	FE and	RE and

	OLS and FE	RE	OLS
	F-test	Hausman test	Breusch Pagan test
Exports	1.03 (0.365)	0.20 (0.905)	0.07 (1.00)
Imports	30.19*** (0.000)	23.07*** (0.000)	0.09 (1.00)
Total trade	16.05*** (0.000)	13.46*** (0.001)	0.010 (1.00)
Notes: OLS is ordinary least squares, FE is fixed effects mode, and RE is a random effects model; *** denotes the statistical significance at 1% level.			
Source: Authors' calculations.			

Table 2: Sensitivity tests for the estimates of SFGA			
	Exports	Imports	Total trade
lnsigma2	-2.003*** (0.171)	-4.607*** (0.104)	-4.155*** (0.307)
ilgtgamma	-5.256*** (1.017)	-4.914 (8.957)	-7.695*** (0.180)
mu	-0.992*** (0.084)	-0.319 (2.231)	-0.081*** (0.0005)
eta	0.236*** (0.079)	0.185 (0.523)	0.028*** (0.006)
Sigma2	0.134 (0.060)	0.009 (0.001)	0.0156 (0.004)
Gamma	0.005 (0.005)	0.007 (0.064)	0.0004 (0.00008)
Sigma_u2	0.0006 (0.0009)	0.00007 (0.0006)	0.00007 (0.00009)
Sigma_v2	0.134 (0.059)	0.009 (0.001)	0.0156 (0.004)
log-likelihood	-30.56	56.82	42.85
Wald Chi-square (p-value)	737.59*** (0.000)	5906.56*** (0.000)	6955.90*** (0.000)
Notes: SFGA is a stochastic frontier gravity approach; *** denotes the statistical significance at 1% level.			
Source: Authors' calculations.			

Table 3: Test for heteroscedasticity and autocorrelation		
	BP HTS test	Wooldridge autocorrelation test
Exports model	13.16*** (0.0003)	0.154 (0.732)
Imports model	1.31 (0.251)	13.26 (0.167)
Total trade model	1.19 (0.274)	4.570 (0.166)
Notes: *** denotes the statistical significance at 1% level.		
Source: Authors' calculations.		

Table 4: Estimates of Exports Gravity Model for the period 2000-2021				
	OLS estimates		**SFGA estimates**	
Variable	Model 1: Base model	Model 2: Augmented model	Model 3: Base model	Model 4: Augmented model
lnGDP$_i$	1.236** (0.580)	-0.393 (0.480)	1.236** (0.580)	0.388*** (0.140)
lnGDP$_j$	0.270 (0.378)	0.459 (0.533)	0.270 (0.378)	0.481*** (0.033)
lnPOP$_i$	-2.489 (3.133)	5.066 (3.390)	-2.489 (3.133)	4.748*** (0.961)
lnPOP$_j$	0.444 (0.354)	1.249 (1.012)	0.444 (0.354)	1.244*** (0.367)
lnDIST	-2.698 (3.265)	4.761 (9.013)	-2.698 (3.265)	5.150 (5.753)
RFE	-	0.613* (0.319)	-	0.631* (0.329)
FTA	-	11.181* (5.917)	-	11.418*** (1.430)
Dummy(quad)	-	-0.037 (0.174)	-	-0.026 (0.144)
OPEN	-	0.765 (0.512)	-	0.702** (0.318)
Constant	78.341 (102.365)	-204.93** (92.471)	78.341 (102.365)	-199.735*** (27.883)
F-stat./Wald	2191.95***	1493.49***	2191.95***	1493.49***
R-squared	0.920	0.925		
Obs.	66	66		
Notes: *, **, and *** denote the statistical significance level at 10%, 5%, and 1% respectively.				
Source: Authors' calculations.				

Table 5: Estimates of Imports Gravity Model for the period 2000-2021				
	Fixed effects estimates		SFGA estimates	
Variable	Model 1: Base model	Model 2: Augmented model	Model 3: Base model	Model 4: Augmented model
lnGDP$_i$	0.392* (0.216)	-0.239 (0.283)	0.549*** (0.189)	-0.239 (0.352)
lnGDP$_j$	0.841*** (0.100)	1.335*** (0.108)	0.872*** (0.102)	1.335*** (0.134)
lnPOP$_i$	0.887 (1.439)	1.590 (1.629)	0.189 (1.416)	1.590 (2.121)
lnPOP$_j$	0.681** (0.388)	0.150 (0.301)	-0.119 (0.108)	0.150 (0.185)
lnDIST	-	-	2.432** (1.061)	17.518*** (3.070)
RFE	-	0.928***	-	0.927***

		(0.135)		(0.161)
FTA	-	-	-	11.754*** (2.402)
Dummy(quad)	-	-0.073 (0.077)	-	-0.088** (0.036)
OPEN	-	0.073 (0.112)	-	0.073 (0.106)
Constant	-41.598 (39.431)	-46.700 (42.970)	-30.275 (37.053)	-213.207*** (68.362)
F-stat./Wald	265.13***	266.68***	6950.00***	733.28***
R-squared	0.864	0.842		
Obs.	66	66		
Notes: *, **, and *** denote the statistical significance level at 10%, 5%, and 1% respectively.				
Source: Authors' calculations.				

Table 6: Estimates of total trade Gravity Model for the period 2000-2021				
	Fixed effects estimates		**SFGA estimates**	
Variable	Model 1: Base model	Model 2: Augmented model	Model 3: Base model	Model 4: Augmented model
$ln\text{GDP}_i$	0.519** (0.244)	-0.294 (0.351)	0.690*** (0.222)	-0.294 (0.267)
$ln\text{GDP}_j$	0.688*** (0.114)	1.125*** (0.134)	0.722*** (0.117)	1.125*** (0.090)
$ln\text{POP}_i$	0.603 (1.625)	2.631 (2.025)	-0.158 (1.568)	2.630 (1.811)
$ln\text{POP}_j$	0.893** (0.439)	0.395 (0.374)	0.018 (0.120)	0.395* (0.234)
$ln\text{DIST}$	-	-	1.190 (1.165)	14.630*** (3.403)
RFE	-	0.858*** (0.168)	-	0.858*** (0.174)
FTA	-	-	-	11.555*** (1.440)
Dummy(quad)	-	-0.053 (0.095)	-	-0.053 (0.046)
OPEN	-	0.219 (0.139)	-	0.219*** (0.057)
Constant	-36.941 (44.543)	-76.887 (53.404)	-11.304 (43.110)	-217.115*** (45.711)
F-stat./Wald	222.30***	183.96***	4133.55***	6955.90***
R-squared	0.827	0.717		
Obs.	66	66		
Notes: *, **, and *** denote the statistical significance level at 10%, 5%, and 1% respectively.				
Source: Authors' calculations.				

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