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Assessing the Dynamics of Fintech and Financial Inclusion in Reducing Inequality in Malaysia: a Bayesian-Wavelet approach

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Abstract:

This paper examines the impact of FinTech on financial inclusion and inequality reduction in Malaysia within the framework of SDG 10. Using a Bayesian VAR model and wavelet coherence analysis (2004–2022), the study analyzes dynamic links between FinTech, inclusion, inequality, and growth. A FinTech Adoption Index (PCA) and a novel Financial Inclusion Index are constructed. Results reveal bidirectional causality, with FinTech and inclusion jointly reducing disparities and fostering inclusive growth. Policy implications highlight the need for inclusive ecosystems, literacy programs, and adaptive regulation.

Key words: Fintech, Financial Inclusion, SDG 10, Inequality, Bayesian VAR, Wavelet, Malaysia
JEL Classification Codes: G20, G28, O16, I32, C32

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Introduction :

Recently, financial technology (Fintech) has emerged as a pivotal force in reshaping the financial landscape globally. Its rapid adoption and innovative applications have particularly profound implications for promoting financial inclusion and mitigating inequalities, especially within the framework of the Sustainable Development Goals (SDGs). The importance of Fintech in advancing financial inclusion is well-documented in literature. Studies such as those by (Demirgüç-Kunt et al., 2018) have highlighted how digital financial services significantly lower the barriers to financial access, providing affordable, fast, and secure financial services to individuals and businesses.

In Malaysia, the Fintech landscape has expanded rapidly over the past decade, supported by favorable regulatory reforms and public-sector initiatives such as the Malaysia Digital Economy Blueprint and the establishment of digital banks. Despite these efforts, substantial gaps in financial access persist, especially among low-income and rural populations. Financial exclusion remains a significant barrier to inclusive growth, limiting access to credit, insurance, and savings mechanisms that are essential for economic resilience. This context raises critical questions regarding the extent to which Fintech adoption has contributed to financial inclusion in Malaysia, and whether such advances have translated into measurable reductions in inequality.

Moreover, within the SDG framework, Fintech's capacity to contribute to targets such as SDG 1 (No Poverty), SDG 5 (Gender Equality), and SDG 10 (Reduced Inequalities) is critical. The intersection of Fintech with these goals underscores a strategic approach to leveraging technology in eradicating poverty, enhancing gender equality, and reducing economic disparities (UNDP, 2019). This paper highlights the link between financial inclusion and Sustainable Development Goal (SDG) 10 - Reduced Inequalities -. It is underscored by the capacity of inclusive financial systems to provide individuals with the tools needed for economic empowerment. Access to credit, savings, and insurance enables individuals to manage economic shocks, invest in educational and health services, and increase their overall economic stability, which are crucial components in reducing inequalities (Corrado & Corrado, 2017).

The objective of this study is to empirically assess the relationship between Fintech adoption, financial inclusion, and inequality reduction in Malaysia, within the context of SDG 10. Specifically, the research aims to (i) construct a composite Fintech Adoption Index using Principal Component Analysis, (ii) develop a Financial Inclusion Index

using a non-parametric approach, and (iii) examine the dynamic interactions between these indices and indicators of inequality and economic performance. The central hypothesis is that Fintech adoption positively influences financial inclusion and, in turn, contributes to reducing socioeconomic inequalities. We further hypothesize that these relationships are bidirectional and evolve over time.

Given the complexity of economic data and the nuanced impact of Fintech, this paper employs a Bayesian Vector Autoregression (VAR) methodology and a wavelet-based analysis to analyze the relationships between Fintech adoption, financial inclusion index and the SDG10. By incorporating Bayesian methods, we enhance the model's ability to handle uncertainties and infer causality in a multi-variable context, making it particularly suited to the analysis of policy interventions aimed at reducing inequalities.

This study makes a dual contribution: empirically, it sheds light on the mechanisms through which Fintech influences inclusion and inequality in a middle-income country; methodologically, it applies a Bayesian VAR framework that enhances the robustness of results in the presence of small sample sizes. The findings are expected to offer valuable insights for policymakers aiming to leverage Fintech to foster inclusive and sustainable economic development in Malaysia and similar contexts.

1. The theoretical framework of the study

1.1. literature review:

The role of financial technology (Fintech) in promoting financial inclusion and mitigating inequalities has been a subject of growing interest in academic and policy circles. Several studies have explored the potential of Fintech to address the challenges of financial exclusion and socioeconomic disparities, particularly in the context of developing countries like Malaysia.

One of the key aspects highlighted in the literature is the ability of Fintech to expand access to financial services for underserved populations. (Ozili, 2018) found that Fintech innovations, such as mobile banking, digital wallets, and peer-to-peer lending, can significantly improve financial inclusion by providing affordable and convenient financial solutions to individuals and small businesses that were previously excluded from the formal financial system. Similarly, (Demirgüç-Kunt et al., 2018) noted that the rise of Fintech has contributed to the "Fintech revolution," which has the potential to bridge the financial inclusion gap in many parts of the world.

The literature also emphasizes the role of Fintech in empowering marginalized communities and promoting more equitable economic development. (Klapper & Singer, 2017) argued that digital financial services can enable individuals to manage financial

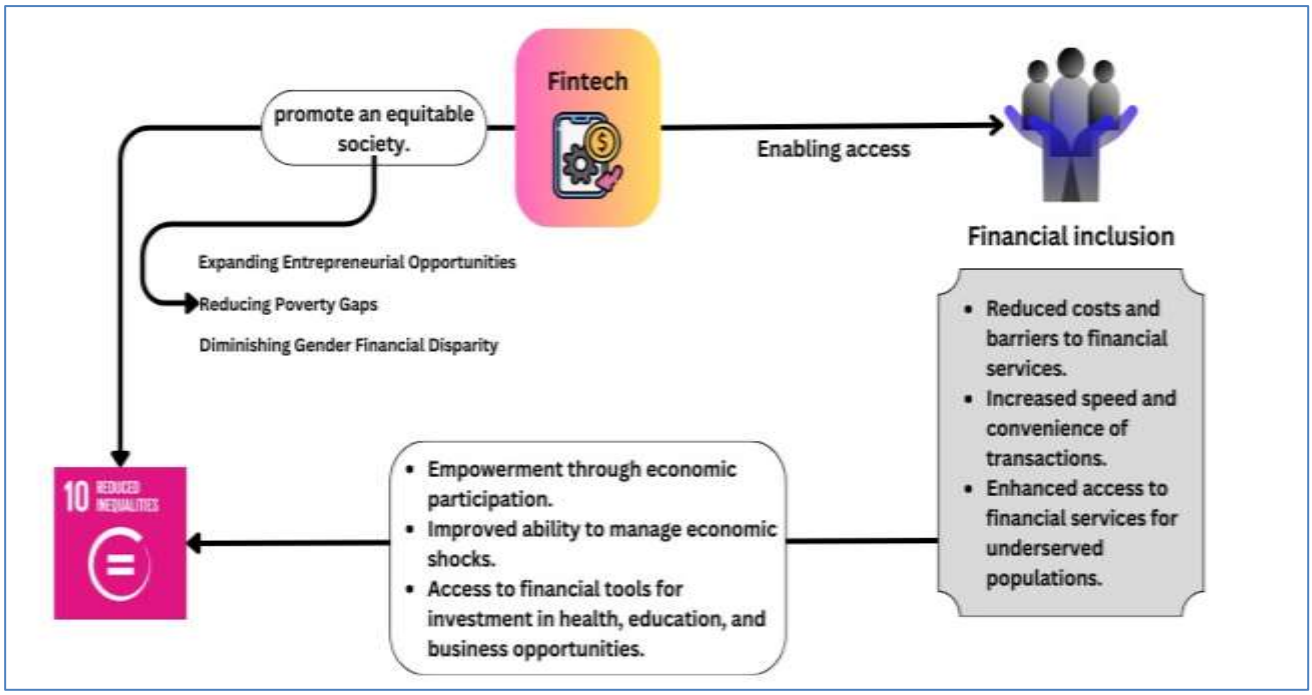
risks, invest in human capital, and participate more actively in the formal economy, thereby contributing to the reduction of income and wealth inequalities. Furthermore, studies have shown that Fintech-driven financial inclusion can have positive spillover effects on other development outcomes, such as improved health, education, and gender equality (Demirgüç-Kunt et al., 2018)

In the context of Malaysia, the government has recognized the importance of Fintech in driving financial inclusion and has implemented various initiatives to support its growth. The Malaysian Digital Economy Blueprint, for instance, outlines strategies to leverage digital technologies, including Fintech, to create a more inclusive and equitable society (Malaysia Digital Economy Corporation, 2021). Additionally, the Central Bank of Malaysia has introduced regulatory frameworks and sandbox environments to foster innovation and ensure the responsible development of Fintech (Bank Negara Malaysia, 2020).

However, the literature also highlights the challenges and limitations of Fintech in addressing financial exclusion and inequalities. (Ozili, 2018) noted that while Fintech can improve access to financial services, it may also lead to financial instability if not properly regulated. Additionally, (Klapper & Singer, 2017) cautioned that the benefits of Fintech-driven financial inclusion may not be evenly distributed, and certain segments of the population may still face barriers in accessing and utilizing digital financial services.

This paper addresses a significant research gap by providing a rigorous empirical analysis of how Fintech facilitates financial inclusion and contributes to achieving SDG 10 in the context of an emerging economy, specifically Malaysia. While existing literature has broadly acknowledged the positive correlation between Fintech and financial accessibility, there is a lack of detailed understanding of the mechanisms at play and their efficacy in reducing economic disparities. The added value of this research lies in its focused exploration of these mechanisms within Malaysia's dynamic economy and its use of a Bayesian Vector Autoregression (VAR) model to quantitatively assess the impact of Fintech on specific indicators of financial inclusion and inequality. This study not only contributes to the theoretical discourse on the role of Fintech in socio-economic development but also provides policy-relevant insights that can inform strategic decision-making within the financial sector.

Figure 01: conceptual framework for the relation between fintech, financial inclusion and reducing inequalities



Source: by the authors

Figure 01 presents a conceptual framework showing the theoritical relationship between financial technology (Fintech), financial inclusion, and Sustainable Development Goal 10 (SDG 10), which is aimed at reducing inequalities. Through this lens, the paper proposes a structured pathway by which Fintech's innovations are not merely enhancements to the financial sector but are instrumental in forging a path toward achieving global equity and inclusion goals set by the United Nations.

As the nexus of modern digital solutions and financial services, Fintech acts as a catalyst, smoothing access to financial products and services through innovative means. This encompasses a variety of technologies such as mobile banking, digital wallets, and peer-to-peer lending platforms, all characterized by their capacity to dismantle traditional barriers to financial access. In addition, this figure highlights financial inclusion as a vital intermediary, the bridge between the capabilities provided by Fintech and the principle aims of SDG 10. Through the lens of financial inclusion, Fintech's contributions become clear—reducing costs and barriers to financial services, expediting transactions, and broadening the reach of these services to historically underserved or marginalized groups. It is here that Fintech's offerings translate into tangible economic empowerment, allowing individuals and communities improved participation in economic life. Access to credit, savings, insurance, and payment

services equips them with the necessary tools to weather economic shocks, invest in health and education, and seize business opportunities that may have previously been out of reach.

Finally, regarding the impact on SDG 10, figure 01 draws a direct correlation between the adoption of Fintech-driven financial inclusion strategies and progress toward reduced inequalities. The figure outlines specific areas of impact—such as expanding entrepreneurial opportunities, reducing poverty gaps, and diminishing gender financial disparity—each representing a significant stride towards a more inclusive economy. These targeted areas exemplify the multifaceted ways in which Fintech contributes to levelling the economic playing field and fostering a society where prosperity is more equitably distributed.

1.2. Fintech in Malaysia:

The fintech landscape in Malaysia has evolved significantly, with a range of innovative companies offering financial services via technology platforms and mobile applications. The country's financial sector has now included fintech as one of its central areas of focus, given its potential for rapid expansion (Hatta & Alwi, 2021). Malaysian consumers and businesses are prepared to adopt fintech, especially with the country's increasing middle class, high mobile phone usage, and strong government assistance for economic modernization.

The fintech sector has thrived greatly in 2020 and 2021, as the COVID-19 pandemic increased the demand for digital advancements to replace the physical interactions between businesses and consumers. The growth of fintech in Malaysia has been supported by initiatives such as the establishment of the Malaysia Digital Economy Corporation (MDEC), a government agency that aims to accelerate the growth of the digital economy in the country. This has included initiatives to promote fintech innovation, such as the establishment of the Malaysia Fintech Hub, which provides support and resources for fintech startups.

Figure 02: online banking in Malaysia (2021-2022)

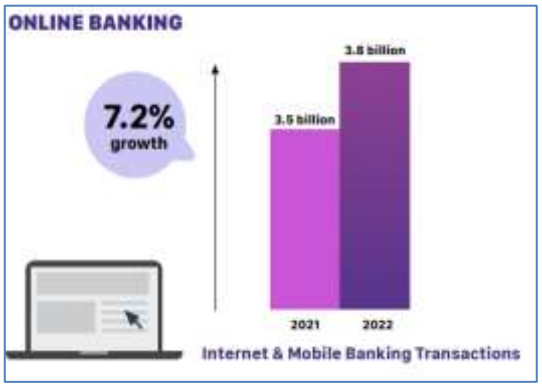
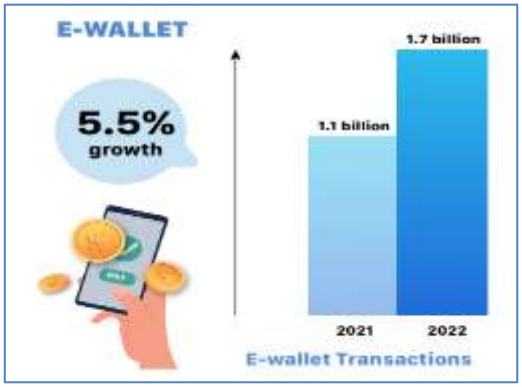
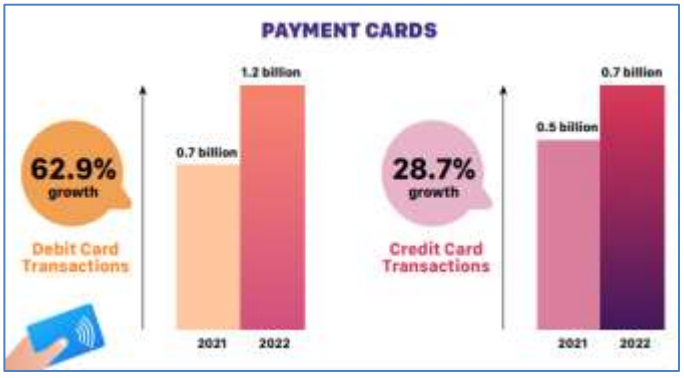


Figure 03: E-wallet transactions in Malaysia (2021-2022)



Source: Malaysia fintech report 2023

Figure 04: debit and credit cards transactions



Source: Malaysia fintech report 2023

Digital payments and e-wallets are paving the way in Malaysian fintech, bolstered by emerging trends and developments like artificial intelligence and machine learning, digital transfers, cryptocurrency, crowdfunding, and other kinds of financial

innovations. The emergence of fintech in Malaysia has been driven by government initiatives, a large market due to expanding population with high digital aptitude, a favorable regulatory environment for fintech companies and consumers, and increased demand for financial services (Malaysia fintech report, 2023).

2. Methodology:

2.1. Research design :

This study follows a quantitative, empirical, and econometric research design aimed at examining the dynamic relationships between FinTech adoption, financial inclusion, inequality reduction (SDG10), and economic growth in Malaysia. The design is longitudinal, relying on annual time-series data from 2004 to 2022, which enables the identification of both structural trends and cyclical fluctuations in the evolution of digital finance and inclusion.

The choice of Malaysia is justified: the country represents a middle-income economy where rapid digital financial adoption coexists with persistent inequality gaps, making it a relevant case study for the objectives of SDG 10. The study constructs composite indices (FinTech Adoption Index and Financial Inclusion Index) to capture the multidimensional aspects of digital finance and inclusion, ensuring that the design reflects both technological penetration and social accessibility.

Methodologically, the design integrates classical econometric tests (stationarity, cointegration) with Bayesian Vector Autoregression (BVAR) and wavelet coherence analysis, offering a multi-layered approach. While BVAR captures bidirectional, time-varying interactions in a small-sample setting, wavelet coherence complements this by identifying time–frequency co-movements that highlight how relationships evolve across short- and long-term horizons. Together, these methods enhance the validity and robustness of the results, allowing the research design to address both statistical rigor and policy relevance.

2.2. Variables selection and Data collection:

The impact of fintech on financial inclusion and the achievement of Sustainable Development Goal 10 (SDG10) in Malaysia is transformative. A detailed analysis of various key indices brings this to light. The Fintech Adoption Index, built using Principal Component Analysis (PCA), shows that fintech has effectively spread across different socioeconomic sectors, demonstrating its reach and effectiveness. At the same time, the Financial Inclusion Index highlights significant improvements in access to financial services, especially in underserved and rural areas, which reflects fintech's role

in expanding these services. The link between the SDG10 Index, fintech, and financial inclusion points to how the growth in fintech has encouraged broader economic participation and helped reduce income inequality. Additionally, GDP per capita is used as a control variable, with data covering the period from 2004 to 2022

Table (1): variables of the study

Variable	Description	Source
Fintech Adoption Index (FADi)	Financial technology usage including online payments using cards, E-wallets, Mobile banking	Developed using ACP based on data from eikon (Boulila et al., 2024)
Financial Inclusion Index (FINi)	Measures accessibility and use of financial services	Calculated using an innovative non-parametric approach
SDG10	Assesses progress towards reducing inequalities	Sustainable Development Report 2023
GDP per Capita(GDPc)	Used as a control variable to reflect overall economic conditions	World bank

Source: by the authors

To construct the Fintech Adoption Index (FADi), we applied Principal Component Analysis (PCA) [†] to a set of standardized indicators: mobile banking usage, e-wallet transaction volume, internet banking penetration, and debit/credit card usage. The first principal component, which captures the largest share of variance, was retained and scaled from 0 to 1. For the Financial Inclusion Index (FINi), a non-parametric approach[‡] was used, aggregating indicators such as the percentage of the adult population with formal financial accounts, access to credit, and use of digital financial services in rural areas. Each component was normalized using a min-max transformation and

[†] Principal Component Analysis (PCA) is a statistical methodology used to convert original variables into a new set of variables, termed principal components, which capture the maximum variance from the original variables while being orthogonal to each other Jolliffe, I. T. (2002). *Principal component analysis for special types of data*. Springer. , ibid..

[‡] non-parametric approach commonly used in research to construct composite indices by assigning equal weights to all variables involved. This technique is favored for its simplicity and objectivity, as it does not assume any underlying distribution for the data and avoids the complexity of determining individual weights for each variableYoon, J. (2015). Partial least squares and principal component analysis with non-metric variables for composite indices.

aggregated with equal weighting. These composite indices provide a consistent and interpretable measure of digital financial progress and access over time.

2.3. Analytical methods:

2.3.1. The Bayesian VAR approach:

To analyze the dynamic relationships between Fintech adoption, financial inclusion, and inequality reduction in Malaysia, this study employs a Bayesian Vector Autoregression (VAR) model. This framework is particularly suited for capturing temporal interactions among multiple interdependent variables while addressing limitations associated with small sample sizes. Unlike traditional VAR models, the Bayesian approach allows for the incorporation of prior distributions, improving estimation efficiency and reducing overfitting. (Tian et al., 2024).

This approach is particularly well-suited to the objectives of the study for several reasons. First, the nature of the research question demands a framework capable of capturing bidirectional, time-dependent relationships among multiple economic variables. Second, the relatively small sample size (annual data from 2004 to 2022) poses challenges for classical VAR estimation, such as parameter overfitting and unreliable inference. The Bayesian VAR addresses these limitations by incorporating prior distributions that shrink parameter estimates and improve stability, leading to more robust and interpretable results.

let the VAR model:

$$Y_t = X_t\beta + \varepsilon_t \dots (1)$$

Where:

- Y_t is a $n \times 1$ vector of endogenous variables which includes the Fintech Adoption Index (FADi), Financial Inclusion Index (FINi), SDG10 Index, and GDP per capita (GDPc). The general form of the Bayesian VAR model of order ppp is specified as:
- ε_t is a $n \times 1$ vector of error terms that explains the random disturbances, identically and normally distributed with variance - covariance matrix Σ, $\varepsilon_t \sim \text{IIN}(0, \Sigma)$.
- X_t is a matrix n $\times nk$ and represents the set of independent variables.
- β is $nk \times 1$ and represents the coefficients that assess the relationship between variables.

The Bayesian prior and posterior distribution rules of the parameters $p(\beta, \Sigma)$ are respectively as follows:

$$L\langle Y \mid \beta, \Sigma\rangle \emptyset |\Sigma|^{-\mathbb{T}_2} \exp\left\{-\frac{1}{2}\sum_t (Y_t - X_t\beta)'\Sigma^{-1}(Y_t - X_t\beta)\right\} \dots (2)$$

$$p\langle \beta, \Sigma \mid Y\rangle = \frac{p(\beta,\Sigma)LY|\beta,\Sigma\rangle}{p(Y)} \sigma p(\beta, \Sigma) L\langle Y \mid \beta, \Sigma\rangle \dots (3)$$

Given $p\langle\beta, \Sigma \mid Y\rangle$, the marginal posterior distributions conditional on the data, $p\langle\Sigma \mid Y\rangle$ and $p\langle\beta \mid Y\rangle$ can be obtained by integrating out β and Σ from $p\langle\beta, \Sigma \mid Y\rangle$ respectively.

In Bayesian analysis, incorporating prior distributions for model parameters is essential, as it combines existing knowledge with current data to form a posterior distribution, offering updated insights into parameter values.

2.3.2. Wavelet based analysis:

In addition to the Bayesian VAR framework, this study employs wavelet coherence analysis to investigate the time-frequency dynamics between FinTech adoption (FADi) and inequality reduction (SDG10). Unlike traditional econometric models that operate solely in the time domain, wavelet coherence simultaneously captures when and at what frequency two series co-move, thereby revealing both short-term fluctuations and long-term persistent relationships. Technically, the analysis is based on the **continuous wavelet transform (CWT)**, which decomposes each series into localized time–frequency space where two forms of results are generated: the **global coherence spectrum**, which summarizes average co-movements across scales, and the **time-frequency coherence plane with significance contours**, which highlights periods and frequencies where co-movements are statistically significant.

2.4. Results and discussion:

2.4.1. ADF stationarity test

The Augmented Dickey-Fuller (ADF) test is a widely utilized statistical method for detecting unit roots in time series data, thereby determining the stationarity of the series. An extension of the original Dickey-Fuller test, the ADF test accommodates more complex autoregressive models by incorporating lagged differences of the time series. This enhancement addresses potential issues of autocorrelation in the residuals, providing a more robust assessment of stationarity

Table (3): ADF unit root test results

Variables	**ADF without Constant & Trend**		
	Level	1st difference	Decision
FINi	*0.6844*	*0.0244*	I (1)
FADi	*0.5046*	*0.0149*	I (1)
SDG10	*0.6862*	*0.0000*	I (1)
GDPc	*0.3877*	*0.0072*	I (1)

Note: *significance level of 5%*

Source: data processing

The Augmented Dickey-Fuller (ADF) test results for the variables FINi, FADi, SDG10, and GDPc show that none are stationary at their levels, with ADF values of 0.6844, 0.5046, 0.6862, and 0.3877 respectively. However, their first differences, with ADF

values of 0.0244, 0.0149, 0.0000, and 0.0072, respectively, indicate a significant drop, allowing us to reject the unit root hypothesis at this level. Consequently, all variables are classified as I(1), meaning they achieve stationarity after one differencing.

2.4.2. Johansen cointegration test:

The Johansen cointegration test is a widely used method for analyzing cointegration in vector error-correction models. It has been extended to accommodate various types of innovations, including stable innovations (Chen, 2010). The test's consistency and asymptotic distribution have been confirmed, provided that certain parameter restrictions are met (Nielsen, 2009). However, it has been noted that the test can be overly powerful in certain situations, such as when variables are near-integrated, leading to size distortions and an increased risk of false conclusions (Hjalmarsson, 2010). Despite these limitations, the test remains a valuable tool for cointegration analysis.

Table (4): johansen cointegration test

Johansen test			
Hypothesized	**Eigenvalue**	**Trace statistics**	**Probabilities**
None	*0.913985*	*67.74580*	*0.0793*
At most one	*0.797715*	*50.58090*	*0.1281*
At most two	*0.724987*	*74.82987*	*0.1685*
At most three	*0.412580*	*39.20003*	*0.6530*

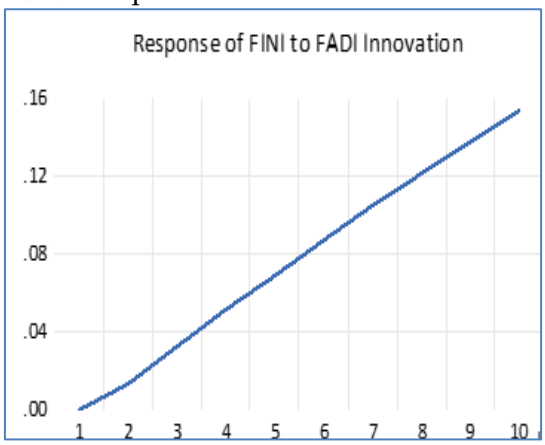
Source: data processing

Table (4) indicates that no-cointegration exists among variables which suggests that these variables do not exhibit a long-term relationship.

2.3.4. Bayesian Impulse response function:

Bayesian impulse response functions play a crucial role in time series analysis, especially within vector autoregression (VAR) frameworks. Inoue (2020) points out the drawbacks of traditional estimators like the posterior median and mean response functions, advocating instead for joint credible regions to improve estimation accuracy. Similarly, Plagborg-Møller (2019) recommends a Bayesian method for estimating structural impulse responses that accommodates noninvertible functions and incorporates prior information for a more robust analysis.

Figure (05): Response of financial inclusion to fintech



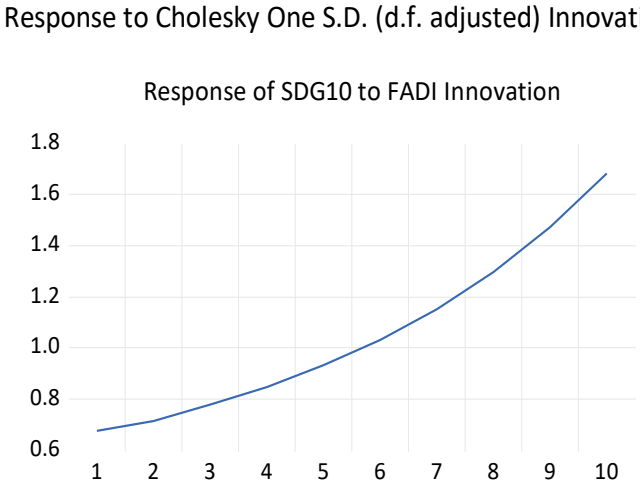
Source: data processing

- **Response of financial inclusion to fintech**

Figure (05) demonstrates a positive association between the Financial Inclusion Index (FINI) and innovations in the Fintech Adoption Index (FADI). The graph reveals that a one-standard-deviation increase in FADI triggers a gradual and sustained rise in FINI across a 10-period span. This initial positive response continues to gain strength, suggesting that fintech adoption significantly boosts financial inclusion. The upward trend implies that advances in fintech can play a crucial role in expanding access to financial services, thereby enhancing financial inclusion metrics. This scenario illustrates the effective integration of new financial technologies to bridge accessibility gaps, especially for underserved and underbanked communities. The steady increase over time also suggests the potential long-term advantages of ongoing fintech investments, emphasizing the value of developing fintech solutions that serve a wide demographic. This dynamic highlights the critical role of technological innovation in finance for broadening financial inclusion and promoting economic empowerment.

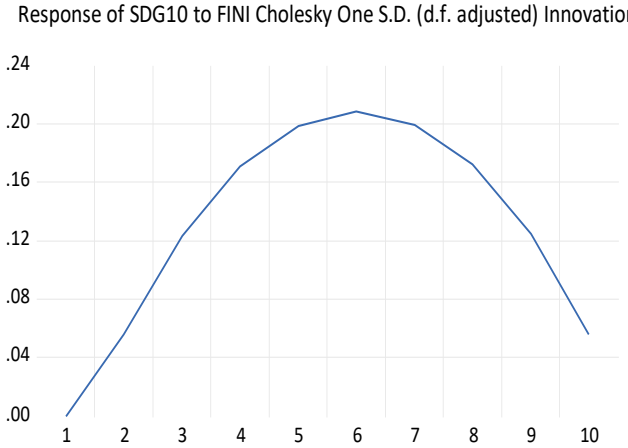
- **Response of SDG10 to fintech and financial inclusion**

Figure 06: response of SDG10 to fintech



Source : data processing

Figure (07) : response of SDG10 to financial inclusion



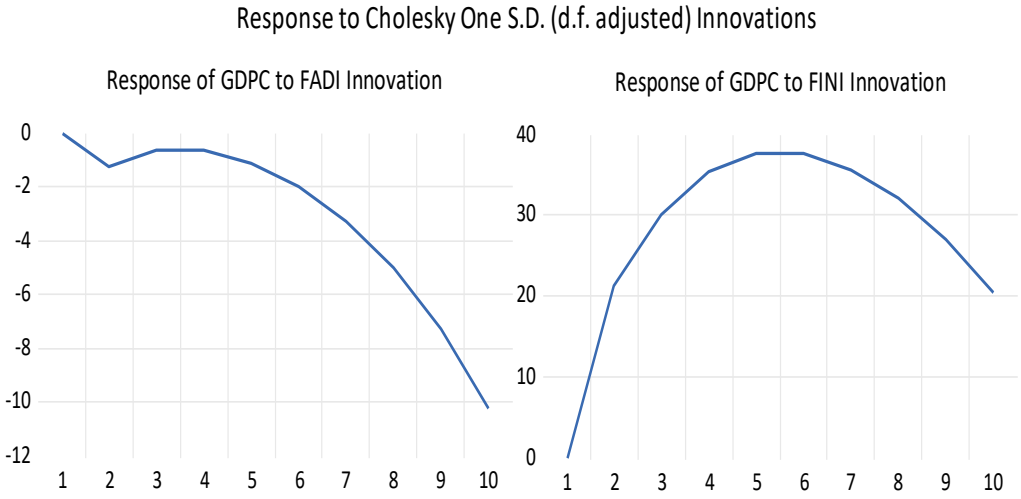
Source : data processing

Figure 06 shows that greater fintech adoption positively influences metrics related to reducing inequalities (SDG10). Initially positive, this effect continues to grow over time, indicating a reinforcing relationship between fintech advancements and inequality reduction efforts. This upward trend suggests that as fintech becomes more integrated and accessible, it may help reduce inequality by expanding access to financial services, particularly for underserved groups. This shift could democratize financial services, enabling previously excluded populations to access banking and other financial tools.

The steady upward movement over the 10 periods also emphasizes fintech's potential for long-term contributions to equality. This implies that sustained and inclusive fintech growth could be a pivotal factor in addressing economic and social disparities.

In contrast, Figure 07 shows the response of SDG10 to a shock in the Financial Inclusion Index (FINI), displaying a positive but curvilinear trend. Here, the initial positive effect peaks around the 6th period before gradually declining, though it remains positive throughout the 10 periods. This pattern suggests that while improvements in financial inclusion significantly impact inequality reduction, the effects may wane over time without ongoing enhancements in financial inclusion efforts. This peak and gradual decrease underscore the importance of consistent and progressive strategies in financial inclusion to maintain long-term social equity.

Figure (8): Response of GDPc to fintech and financial inclusion



Source : data processing

Figure 08 illustrates the response of GDP per capita to a shock in the Fintech Adoption Index, showing an initially downward trend. GDP per capita begins with a slight decrease, with the impact deepening over time to reach a notable low around the 10th period. This trend suggests that fintech advancements may initially disrupt existing economic structures, possibly displacing traditional financial services and leading to a short-term reduction in GDP per capita. Such a decline might represent a transitional adjustment phase as the economy adapts to the new technologies and business models introduced by fintech.

In contrast, GDP per capita's response to a shock in the Financial Inclusion Index reveals a markedly positive effect, peaking around the 5th period before gradually tapering off. This pattern suggests that initial enhancements in financial inclusion yield substantial economic gains, likely due to improved access to financial services, which stimulates economic activity and boosts productivity. The peak followed by a gradual decline indicates that the most significant benefits of financial inclusion occur in the mid-term. Beyond this period, the effects may level out or require additional policy support and innovation to sustain further economic growth

2.3.5. Granger causality test:

The Granger causality test is a popular tool for identifying causal relationships in time series data, with its reliability heavily dependent on data quality (Zanin, 2021). This test allows researchers to examine direct causal links between variables, where introducing an additional potential causal variable can enhance forecasting accuracy.

Table (5) : granger causality test

Null Hypothesis:	Obs	F-Statistic	Prob.
FINI does not Granger Cause FADI	18	1.62936	0.0212
FADI does not Granger Cause FINI		3.06610	0.0004
SDG10 does not Granger Cause FADI	18	2.32731	0.1479
FADI does not Granger Cause SDG10		0.66436	0.0278
GDPC does not Granger Cause FADI	18	0.77603	0.3923
FADI does not Granger Cause GDPC		1.38815	0.2571
SDG10 does not Granger Cause FINI	18	0.25197	0.6230
FINI does not Granger Cause SDG10		4.84144	0.0439
GDPC does not Granger Cause FINI	18	14.4751	0.0017
FINI does not Granger Cause GDPC		7.13052	0.0175
GDPC does not Granger Cause SDG10	18	4.88503	0.0430
SDG10 does not Granger Cause GDPC		0.03734	0.8494

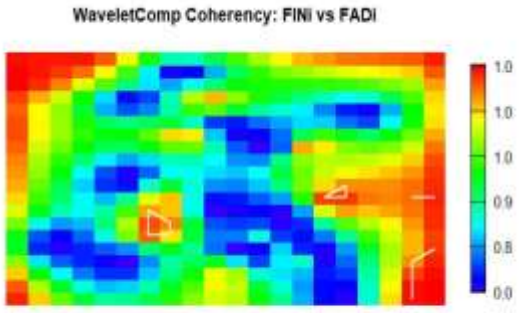
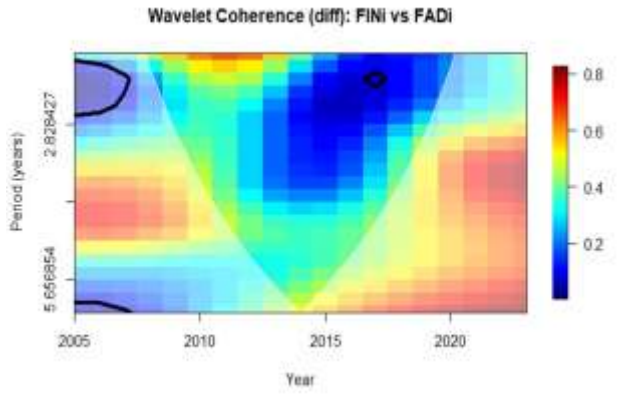
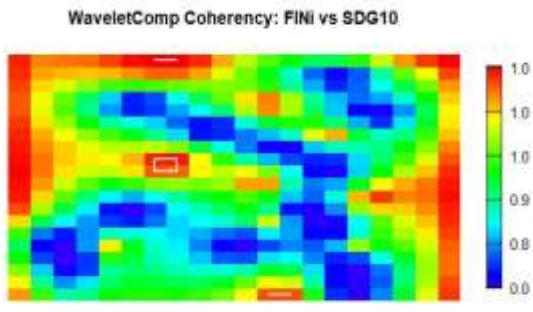
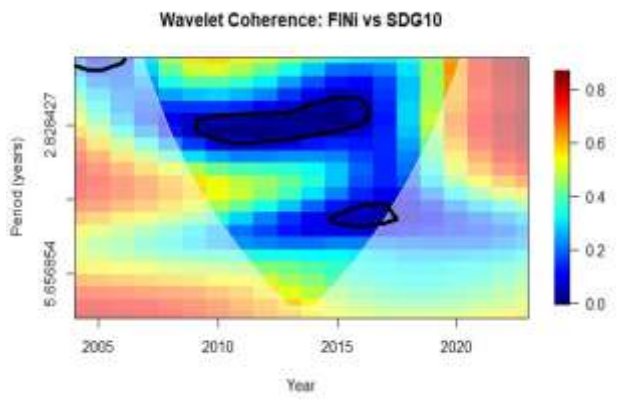
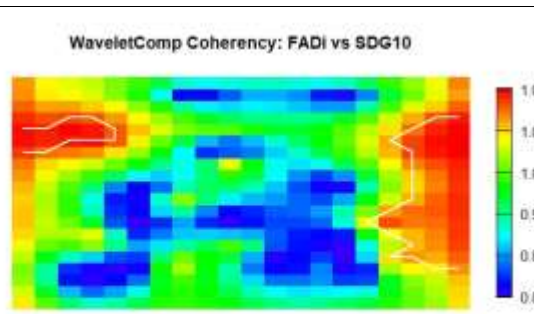
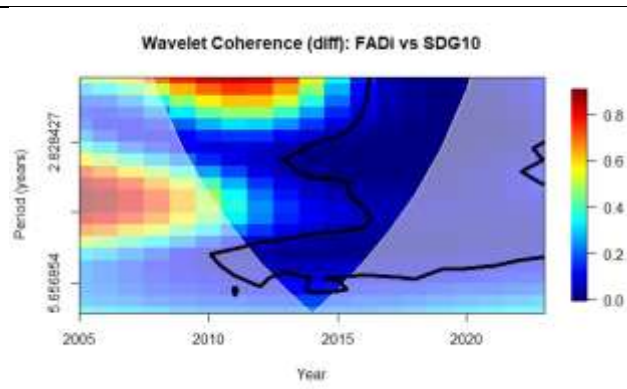
Source : data processing

Table (5) reveals significant interconnections among fintech adoption (FADI), financial inclusion (FINI), and efforts to reduce inequalities (SDG10). Specifically, it provides strong evidence that historical values of financial inclusion Granger cause future fintech adoption, suggesting that improvements in financial inclusion may encourage further fintech adoption. Conversely, there is also evidence that past fintech adoption values Granger cause future financial inclusion, highlighting a reciprocal relationship between these variables. Additionally, while some causality from SDG10 to both FADI and FINI is detected, the effect is less pronounced than the reverse, implying that enhancements in financial inclusion and fintech adoption may have a more substantial impact on reducing inequalities. These findings emphasize the importance of promoting inclusive fintech innovations to boost financial inclusion and support efforts to reduce socioeconomic disparities, aligning with broader sustainable development goals.

2.3.6. Wavelet coherence results:

To complement the Bayesian VAR and Granger causality analysis, wavelet coherence was applied to examine the time–frequency dynamics among financial inclusion (FINi), FinTech adoption (FADi), and inequality reduction (SDG10). Table 6 present the global and time–frequency coherence plots for the three key relationships.

Table 06: Wavelet global and time–frequency coherence

The relation between Financial Inclusion and fintech adoption	
	
The relation between Financial Inclusion and SDG10	
	
The relation between fintech adoption and SDG10	
	

Source : data processing

– **Financial Inclusion and FinTech Adoption**

The wavelet coherence results between FINi and FADi reveal strong and persistent co-movements, particularly during 2010–2016, at both short- and medium-term frequencies (1–3 years). This confirms the existence of a bidirectional feedback loop:

greater financial inclusion stimulates the adoption of FinTech solutions, while FinTech innovations expand access and usage of financial services, reinforcing inclusion.

After 2018, the coherence plot appears to weaken. However, this is mainly due to **statistical boundary effects** at the end of the sample. In reality, FinTech adoption in Malaysia experienced a historic acceleration during the COVID-19 pandemic (2019–2021), driven by mobility restrictions, government cash transfer programs delivered through e-wallets, and the shift to contactless transactions (MDEC, 2021; World Bank, 2022).

- **Financial Inclusion and Inequality Reduction (SDG10):**

The coherence between financial inclusion and inequality reduction (SDG10) shows significant long-term bands (>4 years), with strong coherence around 2009–2014 and renewed significance in the post-2016 period. This pattern demonstrates that the inequality-reducing effects of financial inclusion are structural and persistent, materializing progressively as more individuals and businesses gain access to formal financial services.

Importantly, the coherence during 2020–2021 reflects the role of inclusive financial mechanisms in cushioning inequality during the COVID-19 crisis. Digital banking and mobile payments enabled low-income households and SMEs to maintain economic participation when physical access to financial institutions was restricted. This supports the idea that financial inclusion is not only a long-run driver of equity, but also a short-term shock absorber during crises.

- **Fintech and Inequality Reduction (SDG10):**

The relationship between FADi and SDG10 exhibits medium-term coherence (2–4 years), with strong significance during the 2008–2012 global financial crisis and again after 2018. The first peak corresponds to the regulatory reforms and FinTech acceleration following the crisis, while the second reflects the role of FinTech in mitigating inequality during the COVID-19 shock.

Although short-term coherence is weaker, the medium-term dynamics suggest that FinTech adoption requires a gestation period before its effects on inequality become visible. For example, new digital tools often take time to reach vulnerable populations, but once adopted, they expand access to credit, savings, and remittances, thereby reducing economic disparities. This is consistent with the observed acceleration of mobile banking and e-wallets in Malaysia after 2019, which supported low-income users in accessing financial services remotely

2.4. Discussion and results summary:

To facilitate a comprehensive understanding of the empirical analysis, this section presents a synthesis of the key findings derived from the Bayesian VAR estimations, impulse response functions, and Granger causality tests.

Table (7): Results summary

Causal Relationship	Empirical Method	Key Findings	Economic Implication
Fintech → Financial Inclusion	Impulse Response Function	Positive, cumulative impact over time	Fintech acts as a long-term driver of financial access
	Granger Causality Test	Significant bidirectional causality	Feedback loop: greater access encourages digital service adoption
	Wavelet	Strong coherence 2010–2016 (short & medium-term); reinforced during COVID-19 despite edge effects	Digital adoption and inclusion are mutually reinforcing, especially during shocks
Financial inclusion → SDG 10 (Inequality Reduction)	Impulse Response Function	Positive but diminishing effect after mid-term	Inclusion reduces inequality but requires continuous reinforcement
	Granger	FINi causes SDG10	Financial inclusion is a structural driver of equity
	Wavelet	Long-term coherence in 2009–2014 and post-2016; visible role during COVID-19	Inclusion helps reduce inequality in both normal times and crises
Fintech → SDG 10 (Inequality Reduction)	Impulse Response Function	Strong and persistent effect on reducing inequality	Fintech supports inclusive growth and social equity
	Granger	Positive but diminishing effect after mid-term	Financial inclusion helps reduce inequality, but requires continuous reinforcement
	Wavelet	Medium-term coherence, especially in 2008–2012 and after 2018	FinTech is a **cyclical accelerator**, effective during crises (e.g., COVID-19)
Financial Inclusion → GDP per capita	Granger Causality Test	Significant and positive impact	Inclusion stimulates economic growth and productivity
Fintech → GDP per capita	Impulse Response Function	Initial negative effect, stabilizing in the long run	Transition costs from digital disruption; short-term friction in adapting to new technologies

Source: by the authors

The results highlight a consistent pattern: FinTech adoption and financial inclusion move together and jointly contribute to reducing inequalities in Malaysia. The Bayesian VAR and Granger causality tests confirm a feedback loop where FinTech adoption stimulates greater access to financial services while improved inclusion drives further digital innovation. Wavelet coherence adds depth by showing that this relationship is strongest in specific periods—particularly during 2010–2016 and in the COVID-19 years.

These findings resonate with the broader literature that underscores the structural role of financial inclusion in fostering equity and sustainable growth. Demirgüç-Kunt, Klapper, Singer, Ansar, and Hess (2018) demonstrated, using the Global Findex database, that access to formal accounts and digital payments reduces barriers to participation in the financial system, thereby enabling vulnerable groups to mitigate shocks and invest in human capital. Similarly, Klapper and Singer (2017) stressed that financial inclusion contributes to narrowing income disparities by expanding access to credit, savings, and risk-management instruments. Our results align closely with these contributions, as financial inclusion shows the most persistent long-term coherence with inequality reduction (SDG10), reinforcing its role as a structural driver of equity.

The cyclical role of FinTech adoption in reducing inequality complements, rather than contradicts, these structural dynamics. Our results show that FinTech's impact on inequality is particularly pronounced in medium-term cycles and in times of disruption, such as the global financial crisis and the COVID-19 pandemic. This is consistent with Ozili (2018), who argued that FinTech can expand access to financial services but also noted its short-term instability if regulatory frameworks are weak. More recent applications of wavelet coherence also support these findings. For example, Vacha and Barunik (2012) showed that financial and commodity markets exhibit frequency-dependent co-movements, particularly in turbulent times. Similarly, Tran and Dinh (2024) found that digital financial inclusion in Vietnam had heterogeneous effects on sustainability outcomes across frequencies, confirming that the benefits of digital finance emerge differently over short- and long-term horizons. These studies lend weight to our conclusion that FinTech acts as a cyclical accelerator whose contribution to inequality reduction becomes most visible in times of crisis.

At the same time, the analysis has limitations. The reliance on national-level annual data masks heterogeneity across income groups, genders, and regions, which is increasingly highlighted in micro-level studies of financial inclusion. The composite indices (FADi and FINi) are constructed from multiple indicators and thus rely on assumptions that may introduce measurement error. Furthermore, the edge effects of wavelet analysis constrain the interpretation of results in the final years of the sample.

Despite these caveats, the triangulation of BVAR, Granger causality, and wavelet coherence provides a robust multi-method view of the FinTech–inclusion–inequality nexus.

The implications are clear. Theoretically, the results support a two-channel mechanism: financial inclusion provides the structural foundation for reducing inequality, while FinTech accelerates this process, particularly in times of disruption, once digital innovations are translated into inclusive access. Practically, this means that FinTech policy should not be pursued in isolation but embedded in strategies to expand financial inclusion, such as affordable accounts, rural outreach, and digital literacy programs. It also underlines the importance of consumer protection and adaptive regulation to ensure that rapid digital adoption contributes to equity rather than exacerbating disparities.

Conclusion:

This study investigated the dynamic relationships between FinTech adoption, financial inclusion, inequality reduction (SDG10), and economic growth in Malaysia using Bayesian VAR, Granger causality, and wavelet coherence. The results confirm that FinTech and inclusion are mutually reinforcing, with their interaction intensifying during periods of disruption such as the global financial crisis and the COVID-19 pandemic. This interplay underscores a feedback loop in which digital innovation expands access, while greater inclusion drives further FinTech uptake.

The evidence shows that financial inclusion is the most persistent structural driver of equity, with long-term coherence with SDG10 and a stronger link to growth than FinTech alone. By contrast, FinTech acts as a medium-term accelerator, with its inequality-reducing effects most visible during crises. These findings suggest that FinTech can amplify inclusion but is insufficient on its own to ensure sustained reductions in inequality unless it is embedded within inclusive finance strategies.

From a policy perspective, the results point to several recommendations. First, governments should embed FinTech expansion within broader national financial inclusion strategies, ensuring that innovations in mobile payments, e-wallets, and digital credit directly reach underserved populations. Second, investments in digital literacy and financial education are essential to empower users, particularly women, rural households, and micro-enterprises, to benefit from digital financial tools. Third, strong consumer protection and cybersecurity frameworks are needed to safeguard

vulnerable users from fraud, over-indebtedness, and digital risks. Fourth, regulators should adopt adaptive and innovation-friendly policies—such as sandbox environments and digital bank licenses—that encourage responsible FinTech growth while maintaining financial stability. Finally, governments and central banks can leverage FinTech platforms to deliver targeted social transfers and emergency support, as demonstrated during COVID-19, where digital payments helped maintain economic participation among vulnerable groups.

While this study provides robust evidence, it is not without limitations. The reliance on national-level data and constructed indices may obscure heterogeneity across groups and regions. Future research should use household- and firm-level data, explore cross-country comparisons, and apply advanced methods such as panel wavelet coherence to capture evolving dynamics under different regulatory regimes..

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