

ASYMMETRIC DIRECTIONAL INFORMATION FLOW BETWEEN OUTPUT AND LABOUR IN MALAYSIA: AN INFORMATION-THEORETIC ANALYSIS

*(Aliran Maklumat Berarah Asimetri antara Output dan Buruh di Malaysia: Analisis
Berasaskan Teori Maklumat)*

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ABSTRACT

Empirical studies of output-labour relationships typically rely on regression-based causality models that assume linearity within a specified parametric form. These methods may obscure variations in the direction and strength of causal influence in non-linear, heterogeneous adjustment processes. This paper examines the directional information flow between output and labour in Malaysia using an information-theoretic approach that operationalises causality as the reduction of directional uncertainty. Pairwise causal interactions are analysed using Shannon transfer entropy on quarterly data series from 2011 to 2022 for real gross domestic product (GDP) growth, employment growth, and unemployment growth. The findings reveal a structure of asymmetric and hierarchical information flow. Unemployment growth exerts the strongest directional influence on real GDP growth, while employment growth demonstrates a modest unidirectional information flow to output, significant at the ten per cent level. Within the labour market, employment growth unidirectionally influences unemployment growth with no statistically significant reverse flow. The interaction between unemployment and output is bidirectional but asymmetric, with unemployment playing the dominant role. These results suggest that output-labour dynamics in Malaysia are characterised by selective directional dominance rather than uniform bidirectional feedback. Such asymmetric causal structures are difficult to isolate using parametric causality methods due to their reliance on symmetry assumptions and model specification. This study demonstrates the value of information-theoretic inference in analysing complex macroeconomic systems with heterogeneous adjustment dynamics.

Keywords: directional information flow; information-theoretic inference; output-labour dynamics; employment and unemployment; transfer entropy; Malaysia; macroeconomic dynamics

ABSTRAK

Kajian empirik perhubungan output-buruh lazimnya bergantung kepada model sebab akibat berasaskan regresi yang mengandaikan kelinearan dalam bentuk berparameter tertentu. Pendekatan sebegini berpotensi menyembunyikan perbezaan dalam arah dan kekuatan pengaruh sebab akibat dalam persekitaran proses penyelarasan yang tak linear dan heterogen. Makalah ini meneliti aliran maklumat berarah antara output dengan buruh di Malaysia menggunakan pendekatan berasaskan teori maklumat yang mentafsirkan hubungan sebab akibat sebagai pengurangan ketidakpastian berarah. Interaksi aliran maklumat pasangan demi pasangan dianalisis menggunakan entropi pindahan Shannon terhadap siri masa suku tahunan dari 2011 hingga 2022 bagi pertumbuhan keluaran dalam negeri kasar (KDNK) benar, pertumbuhan guna tenaga, dan pertumbuhan pengangguran. Hasil kajian menunjukkan struktur aliran maklumat yang bersifat asimetri dan berhierarki. Pertumbuhan pengangguran memberikan pengaruh berarah yang paling kuat terhadap pertumbuhan KDNK benar, manakala pertumbuhan guna tenaga menunjukkan aliran maklumat sehalu yang sederhana kepada output pada aras keertian sepuluh peratus. Dalam pasaran buruh, pertumbuhan guna tenaga mempengaruhi pertumbuhan

pengangguran secara sehalu tanpa aliran songsang yang bererti secara statistik. Interaksi antara pengangguran dan output pula bersifat dua hala tetapi asimetri, dengan pengangguran memainkan peranan yang lebih dominan. Dapatan ini menunjukkan bahawa dinamik output-buruh di Malaysia dicirikan oleh dominasi berarah yang terpilih berbanding maklum balas dua hala yang seragam. Struktur sebab akibat yang asimetri sedemikian sukar diasingkan menggunakan kaedah sebab akibat berparameter kerana kebergantungannya terhadap andaian simetri dan spesifikasi model. Kajian ini menunjukkan kelebihan inferens berasaskan teori maklumat dalam menganalisis sistem makroekonomi kompleks yang mempunyai dinamik penyelarasan heterogen.

Kata kunci: aliran maklumat berarah; inferens berasaskan teori maklumat; dinamik output-buruh; guna tenaga dan pengangguran; entropi pindahan; Malaysia; dinamik makroekonomi

1. Introduction

A thorough understanding of the causal dynamics between the economy and the labour market is central to accurate macroeconomic analysis, which subsequently provides the basis for informed decision-making. Economic production is usually measured by the gross domestic product (GDP) indicator, while employment and unemployment are among the common indicators reflecting labour market conditions and utilisation. The interplay between the economy and the labour market is one of the focuses of the global policy framework through the eighth Sustainable Development Goal (SDG) that calls for sustained economic growth and productive employment (International Labour Organization 2023; Lee *et al.* 2020; United Nations Department of Economic and Social Affairs 2023). However, the complex interactions among these variables, especially in terms of direction and dominance of causal influence over time, remain disputed.

Vector autoregressive (VAR) and Granger-based methods are often used to examine the linkages between output and labour. These symmetric and model-oriented methods draw predictions of causal inferences through reliance on linearity and assumptions on the distributional functions (Granger 1969; 1980). While VAR and Granger-based methods are capable of detecting unidirectional causal relationships under appropriate specifications, these approaches may not adequately distinguish directional dominance in systems defined by non-linear adjustments, heterogeneous responses, and asymmetric information transmission. In these settings, causal influence is more appropriately interpreted as the reduction of uncertainty in one variable given the evolution of another, rather than as predictive association within a specified parametric structure (Schreiber 2000).

These inferential limitations are particularly evident in the context of heterogeneous output-labour dynamics where variables adjust through distinct channels, operate on different time scales, and often respond asymmetrically to shocks (Lechthaler & Tesfaselassie 2023; Steblik 2025). Even though changes in production can induce labour market responses by creating employment, dissolving jobs, and engagement choices, labour market variables need not have a direct or comparable impact on output. Such differences usually elude the symmetric causality models, hence resulting in false inferences of the bidirectional causality, which obscure the hierarchical nature of a complex system. Therefore, an inferential method that can detect information flow with non-restrictive modelling assumptions is necessary to establish the leading directional effects of such systems.

Malaysia provides a relevant empirical environment to observe the asymmetric output-labour relationship during the ongoing economic and labour market adaptation. The economy has, over the years, undergone a number of sectoral changes, in addition to being more exposed

to external shocks. The COVID-19 pandemic further demonstrated how major economic disruptions can affect household income and spending behaviour in Malaysia, highlighting the heterogeneous responses of economic agents to external shocks (Hisham *et al.* 2023). The desire to attain the high-income country status is rooted in the national development policies, which, among others, underline the fundamental place of human capital and the alignment of the labour market in the facilitation of sustainable economic growth. According to the previous research, the output alterations in Malaysia induced non-homogeneous and non-instantaneous labour market adjustments, with specific adjustment mechanisms in the employment and unemployment levels (Nasir *et al.* 2024). These dynamics imply that the correlation between output and the labour market variables is directional dominance rather than feedback. Asymmetric adjustments in the labour market to output have been similar in more macroeconomic environments, particularly in periods of economic contraction and recovery (Furceri *et al.* 2020). This strengthens the applicability of quantifying the association between output and labour in a flexible approach that is able to acquire non-linear and heterogeneous directional data.

To systematically examine these dynamics, this study addresses the following research question: To what extent do directional information flows between output and labour market variables in Malaysia exhibit asymmetric patterns that are not captured by conventional symmetric causality methods? Based on the institutional characteristics of the Malaysian labour market and previous empirical evidence, two directional hypotheses are proposed: (H1) Directional information flows between labour market variables and output are expected to exhibit asymmetric dominance rather than symmetric feedback; and (H2) Within the labour market, employment-to-unemployment information flow dominates the reverse direction, consistent with institutional adjustment mechanisms during economic contraction.

The association among output variables, labour market variables and the long-run relationships together with short-run adjustment mechanisms has been of main interest in the empirical studies on the relationship between output and labour market variables in Malaysia. The majority of the studies use parametric models like linear regression, cointegration, and vector error correction models or Granger causality to investigate the connections between employment, unemployment, and output (Aziz & Azmi 2017; Januri *et al.* 2022). These techniques are particularly suitable for the modeling of equilibrium dynamics at a given parametric framework. However, reliance on linear specifications and predefined model structures constrains their ability to determine whether observed relationships reflect reciprocal feedback mechanisms or dominant directional influences. This is particularly relevant in an economic system such as Malaysia, where adjustment mechanisms to irregular shocks are often non-linear and heterogeneous. As a result, there remains a gap in understanding the underlying causal structure between output and labour in Malaysia with respect to the direction and relative strength of these dynamics.

This study adopts an approach based on information theory, namely transfer entropy, to define causality as the reduction of directional uncertainty as opposed to symmetric predictive associations. This approach determines whether past information from the source variable has an influence over future changes of the target variable, conditional on the target's own history (Bossomaier *et al.* 2016; Schreiber 2000). Since transfer entropy is a non-parametric approach, this estimate can reveal asymmetric information flows directly from empirical data without restrictive assumptions about functional forms and population distributions. This is especially appealing for analysing time series with non-linear adjustments, heterogeneous responses and sporadic shocks.

Overall, this study contributes to the existing literature by presenting empirical insights into the underlying dynamics between output and labour using a flexible non-parametric approach. Malaysia is regarded as an empirical system for examining causality, where dominant and asymmetric information flows among real GDP, employment, and unemployment can be isolated using transfer entropy. The paper is organised into five sections, including this introductory section. The next section reviews the relevant literature, while the third section outlines the data and methodology in this study. Empirical results are presented and discussed in the fourth section, while the final section draws a conclusion on this study.

2. Literature Review

2.1. The Output-Employment Nexus

The relationship between output and employment has long been a central issue in macroeconomic analysis due to its implications for labour market adjustment, productivity, and economic development. Conventional economic theory generally posits that increases in output stimulate labour demand and subsequently raise employment levels. Nevertheless, the extent and direction of this relationship often differ across institutional settings, economic structures, and adjustment periods.

A substantial body of empirical literature has examined the interaction between economic growth and employment. Kapsos (2006) highlighted the importance of employment responsiveness to growth in evaluating the inclusiveness of economic expansion. Empirical findings by Jo *et al.* (2023) indicated that increases in real GDP contribute to employment growth, while Jiun and Nga (2011) found that economic growth positively affects employment in Malaysia. Similar evidence was reported by Manh *et al.* (2014) for Vietnam, where output expansion exerted a significant influence on employment adjustment.

Despite the general expectation that output drives employment, existing evidence remains inconclusive regarding the direction and dominance of influence between these variables. Differences in findings are often associated with model specifications, sample characteristics, and methodological assumptions. Most existing studies rely on parametric frameworks such as linear regression, cointegration analysis, vector autoregressive models, and Granger causality approaches. While these methods are useful for modelling equilibrium dynamics and predictive relationships, they are typically constructed within symmetric linear specifications that may not adequately capture heterogeneous adjustment processes and dominant directional effects.

This limitation is particularly relevant in labour market systems characterised by asymmetric responses to shocks and uneven adjustment speeds across economic sectors. Consequently, the underlying directional structure between output and employment remains insufficiently understood, particularly in determining whether the observed interactions reflect reciprocal feedback mechanisms or asymmetric information transmission. This motivates the need for a more flexible inferential framework capable of identifying directional information flow under minimal distributional assumptions.

2.2. The Output-Unemployment Relationship

The relationship between unemployment and economic growth is frequently discussed within the framework of Okun's Law, which postulates an inverse relationship between unemployment and output (Okun 1962). In general, reductions in unemployment are expected to accompany periods of economic expansion, while economic contraction tends to increase

labour underutilisation. However, empirical evidence suggests that the strength, direction, and persistence of this relationship vary considerably across countries and periods.

Several studies have reported unidirectional causal relationships between unemployment and output. Gómez and Irewole (2024) identified causality running from economic growth to unemployment across African economies, while Soylu *et al.* (2018) reported similar findings for Eastern European countries. Meanwhile, Al-Sawaie (2020) documented a long-run bidirectional relationship between unemployment and output in Jordan using autoregressive distributed lag cointegration analysis. Chen (2022) further reported bidirectional causality between GDP growth and unemployment in several Asian economies, including Malaysia.

Other studies, however, reported no statistically significant causal relationship between unemployment and economic growth. Padder and Mathavan (2021) found no evidence of Granger causality between unemployment and GDP in India, while Agboola *et al.* (2019) similarly reported insignificant causal interaction between unemployment and output in Nigeria using the Fourier-Toda-Yamamoto approximation.

Collectively, these findings indicate that the relationship between unemployment and output is highly context-dependent and sensitive to methodological specifications. More importantly, the literature remains inconclusive regarding the presence of directional dominance within the interaction. Most existing studies continue to rely on symmetric parametric causality frameworks that infer causality through predictive improvements within predefined functional structures. As a result, existing evidence provides limited insight into whether unemployment-output dynamics are characterised by reciprocal feedback or hierarchical directional influence. This unresolved issue motivates the application of alternative inferential approaches capable of detecting asymmetric information flow directly from empirical observations.

2.3. Transfer Entropy as an Alternative Framework

Transfer entropy, introduced by Schreiber (2000), provides a non-parametric information-theoretic framework for quantifying directional information flow between dynamic systems. Unlike mutual information, which measures shared dependence without identifying directionality, transfer entropy evaluates whether past information from a source variable reduces uncertainty regarding the future state of a target variable beyond the target's own history (Bossomaier *et al.* 2016; Schreiber 2000).

One of the principal advantages of transfer entropy lies in its ability to capture both linear and non-linear dependencies without imposing restrictive assumptions regarding functional forms, normality, or symmetric interactions (Bossomaier *et al.* 2016; Vicente *et al.* 2011). Consequently, transfer entropy is particularly suitable for analysing complex macroeconomic systems characterised by heterogeneous adjustment mechanisms, asymmetric responses, and irregular shocks. In contrast to conventional Granger-type approaches that evaluate predictive association within parametric specifications, transfer entropy operationalises causality as directional uncertainty reduction and permits the identification of asymmetric information transmission.

The flexibility of transfer entropy has contributed to its increasing application across multiple disciplines. In macroeconomic research, Akadiri and Ajmi (2020) employed symbolic transfer entropy to investigate directional relationships among energy consumption, economic growth, foreign direct investment, and globalisation in Sub-Saharan Africa, demonstrating the usefulness of information-theoretic inference in identifying complex causal structures. Transfer entropy has also been applied in other domains involving dynamic and non-linear interactions, including neuroscience and industrial systems (Duan *et al.* 2013; Vicente *et al.* 2011).

Although transfer entropy has demonstrated considerable potential in analysing complex systems, its application in examining output-labour dynamics remains limited, particularly in the Malaysian context. Existing empirical studies on output, employment, and unemployment in Malaysia continue to rely predominantly on symmetric parametric approaches, offering limited evidence regarding asymmetric directional dominance and hierarchical information flow. Accordingly, this study addresses this gap by applying Shannon transfer entropy to examine the directional information flow between real GDP growth, employment growth, and unemployment growth in Malaysia under a flexible non-parametric framework.

3. Materials and Methods

3.1. Data Source and Description

The official quarterly macroeconomic data used in this study were sourced from the World Bank and the Department of Statistics Malaysia. World Bank's Global Economic Monitor (2023) provided real GDP data series at constant 2010 prices in Ringgit Malaysia. This variable represents the sum of value added from the production of goods and services within the country after adjusting for taxes and subsidies. Constant price eliminates the effects of inflation to ensure that changes are due to real economic activity. Meanwhile, the Department of Statistics Malaysia's official dissemination platform offered employment and unemployment data series. Employment refers to those who worked for an hour or more during a specific reference week, either for pay, profit, or family gain, while unemployment refers to persons not at work who are seeking and willing to take up available work (Department of Statistics Malaysia 2023).

All data series were first transformed into year-on-year percentage changes from the current quarter to the same quarter in the preceding year to minimise seasonal effects. Stationarity testing revealed that the unemployment growth series was stationary at the level, while employment growth and real GDP growth required first-order differencing to achieve stationarity. Transfer entropy was estimated using the stationary representations: UNE (year-on-year unemployment growth at level), EMP (first difference of year-on-year employment growth), and GDP (first difference of year-on-year real GDP growth). The resulting series covers the period from the first quarter of 2011 to the fourth quarter of 2022. Summary statistics for the year-on-year transformed variables are reported in Table 1.

Table 1: Summary statistics for employment, unemployment and real

Variables	EMP	UNE	GDP
Mean	2.3	4.7	4.4
Median	2.2	1.8	5.1
Maximum	5.9	52.1	16.2
Minimum	-1.3	-18.0	-16.9
Standard Deviation	1.6	15.1	4.5

Source: Author's calculation based on published statistics by the Department of Statistics Malaysia and the World Bank.

Notes: EMP, UNE and GDP are initially transformed into year-on-year percentage changes. GDP refers to real gross domestic product at 2010 constant prices. For transfer entropy estimation, UNE is used as year-on-year unemployment growth at the level, while EMP and GDP refer to the first differences of year-on-year employment growth and year-on-year real GDP growth, respectively.

It is important to acknowledge that the sample size of 48 quarterly observations is modest for transfer entropy estimation, which requires reliable estimation of joint and conditional probability distributions. While the year-on-year transformation and the effective transfer entropy correction mitigate some finite-sample concerns, the results should be interpreted with

appropriate caution. Future research could employ monthly data or rolling-window techniques to assess the robustness of these findings across larger samples.

3.2. Methodology

This paper uses Shannon transfer entropy to examine the directional information flow between employment and real GDP, unemployment and real GDP, and employment and unemployment. Transfer entropy was developed by Schreiber (2000) to provide a measure of information flow between a source variable and a target variable given the past states of the target. In particular, it assesses how much uncertainty about the future behaviour of a given variable is decreased by past values of another variable, over and above that which is explained by the history of the target itself (Bossomaier *et al.* 2016).

Transfer entropy as an information-theoretic framework does not make any assumptions of linearity, normality, or a specific parametric structure. This renders it especially appropriate to the analysis of complex macroeconomic systems that are nonlinear in their interactions and non-Gaussian in nature. Unlike the conventional Granger causality models, which often use symmetric predictive relationships under the specification of linear models, transfer entropy represents asymmetric information flows. It is possible to establish unidirectional causality and situations when feedback effects can be weak or restricted.

To analyse the data, a set of diagnostic tests has been carried out before starting the actual analysis to assess the data characteristics and their applicability in estimating transfer entropy. Although these preliminary analyses are not conclusive on the causality, they offer supportive evidence on important properties like linearity, dependence structure, and stationarity.

3.2.1. Linearity and dependence between variables

Pearson's product-moment correlation coefficient was employed to assess linear dependence between real GDP growth, employment growth, and unemployment growth. This coefficient measures the direction and strength of the pairwise linear relationship between variables as a baseline of linear co-movement. In addition, distance correlation is measured for each variable pair to evaluate the presence of non-linear relationships (Edelmann *et al.* 2021; Székely *et al.* 2007). Together, these measures provide a descriptive assessment of dependence structures without imposing restrictions on functional forms.

3.2.2. Stationarity of the variables

Transfer entropy estimation assumes that the underlying time series are stationary (Behrendt *et al.* 2019; Marschinski & Kantz 2002). Accordingly, stationarity is assessed for the quarterly growth series of employment, unemployment, and real GDP using unit root tests. The Augmented Dickey–Fuller (ADF) test is used to determine the presence of a unit root within an autoregressive framework, with lag lengths chosen automatically by Akaike criterion information to account for serial correlation. The results of these tests inform the suitability of the transformed series for entropy-based causal analysis. Where the growth series remained non-stationary, first-order differencing was applied to ensure stationarity prior to estimating transfer entropy. Transfer entropy was estimated using stationary representations of all variables.

3.2.3. Transfer entropy

Directional information flow between variables is quantified using transfer entropy, defined as Equation (1) below:

$$TE_{X \rightarrow Y}(k, l) = \sum p(y_{t+1}, y_t^{(k)}, x_t^{(l)}) \log \frac{p(y_{t+1}|y_t^{(k)}, x_t^{(l)})}{p(y_{t+1}|y_t^{(k)})} \quad (1)$$

where y_{t+1} denotes the future value of the target variable, $y_t^{(k)}$ and $x_t^{(l)}$ represent the past histories of the target and source variables with embedding dimensions k and l , respectively, and $p(\cdot)$ denotes the relevant joint and conditional probability distributions. Transfer entropy is non-negative by construction, with values equal to zero indicating the absence of directional information flow. In contrast, positive values reflect the presence of informational influence whose numerical magnitude depends on the underlying joint distribution.

Statistical significance of empirical estimates was assessed using a bootstrap procedure that constructs the null distribution of transfer entropy under the hypothesis of no information flow. This is achieved by destroying interdependence between variables while preserving their individual dynamics (Dimpfl & Peter 2013). Repeated estimation under this null hypothesis provides an empirical basis for evaluating the statistical significance of observed transfer entropy values.

One of the limitations of transfer entropy is its tendency to compromise the significance of the analysis of a finite sample (Lungarella *et al.* 2007; Marschinski & Kantz 2002). This is especially relevant in empirical applications with limited observations. Marschinski and Kantz (2002) proposed effective transfer entropy to address this finite-sample bias. The source series was repeatedly randomised to create shuffled versions where dependencies within the source and between the source and the target are eliminated. Effective transfer entropy corrects the bias due to finite samples by subtracting the average transfer entropy of the shuffled source series from the observed transfer entropy, as in Equation (2). This adjustment ensures that the estimated information flow reflects genuine dynamics.

$$ETE_{X \rightarrow Y}(k, l) = TE_{X \rightarrow Y}(k, l) - TE_{X_{shuffled} \rightarrow Y}(k, l) \quad (2)$$

Following the approach of Dimpfl and Peter (2013) and Behrendt *et al.* (2019), embedding dimensions $k = l = 1$ were used for the transfer entropy estimation, consistent with the first-order Markov structure of the stationary series. All transfer entropy estimates were computed using the RTransferEntropy package (Behrendt *et al.* 2019), with the Shannon entropy estimator. Statistical significance was assessed using 1,000 bootstrap replications under the null hypothesis of no information flow. Effective transfer entropy was computed using 100 shuffles of the source series to correct for finite-sample bias (Marschinski & Kantz 2002).

Parametric approaches such as VAR or Granger models draw causal inferences through improvements in predictive ability, typically within a predefined linear structure. On the contrary, this study defines causality based on transfer entropy as a reduction in information uncertainty between variables. Specifically, causal influence from X to Y is inferred when past states of X reduce the uncertainty about the future state of Y beyond what is explained by the past of Y itself. Thus, the analysis focuses on identifying the presence and direction of information flow. The existence of directional information flow is determined based on the statistical significance of transfer entropy. In contrast, effective transfer entropy presents the bias-corrected estimate that accounts for finite-sample effects. Nevertheless, these magnitudes should be interpreted with careful consideration, as they depend on the joint distribution of the variables and are not directly comparable across variable pairs or causal direction. In this regard, the analysis emphasises the hierarchical causal structure rather than the numerical estimates.

It is important to note that pairwise transfer entropy identifies directional information flow between two variables conditional on their own histories, but does not account for potential

confounding by omitted variables. As such, the estimated information flows should be interpreted as measures of directional statistical dependence rather than structural causality (Lizier & Prokopenko 2010).

4. Results and Discussions

4.1. Findings of Preliminary Analyses

Figure 1 illustrates the pairwise relationship between real GDP growth, employment growth, and unemployment growth. Some dispersion of observations from trend lines indicates variability in the data. The scatter plots reveal a moderately positive linear relationship between real GDP growth and employment growth, and a moderately negative linear relationship between real GDP growth and unemployment. In addition, employment growth and unemployment growth display a moderately negative intra-labour relationship. These visual patterns provide a preliminary insight that motivates further quantitative analysis.

The results of statistical tests evaluating pairwise dependence among real GDP growth, employment growth, and unemployment growth are reported in Table 2. Pearson's product-moment correlation analysis reveals statistically significant linear relationships among the variables, which is consistent with prior graphical inspections. All three variable pairs yield t-statistics with corresponding p-values less than the 0.01 significance level, thereby providing strong evidence against the null hypothesis of no linear correlation. In terms of the magnitude of these linear relationships, as indicated by the correlation coefficient, r , real GDP growth and employment growth display a moderate positive correlation ($r = 0.4954$), a strong negative correlation is exhibited between real GDP growth and unemployment growth ($r = -0.7112$), and finally employment growth and unemployment growth demonstrate a moderate negative correlation ($r = -0.5377$).

Table 2: Results of linearity and dependency tests

Statistics	EMP and GDP	UNE and GDP	EMP and UNE
Linearity - Pearson's product-moment correlation analysis			
t-statistics	3.8682***	-6.8607***	-4.3257***
Correlation coefficient	0.4954	-0.7112	-0.5377
Dependency - Distance correlation analysis			
Distance variance of X	1.0008	8.3076	1.0008
Distance variance of Y	1.9223	1.9223	8.3076
Distance covariance	0.7519	2.7757	1.8065
Distance correlation	0.5421***	0.6946***	0.6265***

Note: EMP, UNE and GDP are initially transformed into year-on-year percentage changes. GDP refers to real gross domestic product at 2010 constant prices. For transfer entropy estimation, UNE is used as year-on-year unemployment growth at the level, while EMP and GDP refer to the first differences of year-on-year employment growth and year-on-year real GDP growth, respectively. The null hypothesis assumes no association between the pair of variables. The hypothesis is rejected for test statistics with an associated p-value less than α . The notation *** denotes statistically significant results at $\alpha = 0.01$.

Furthermore, distance correlation also yields associated p-values below the 0.01 level of significance, with moderate values recorded for all variable pairs. This suggests statistically significant associations between the variables that may include non-linear dynamics. Consequently, these preliminary results justify the subsequent examination into the causal structure between output and labour using transfer entropy.

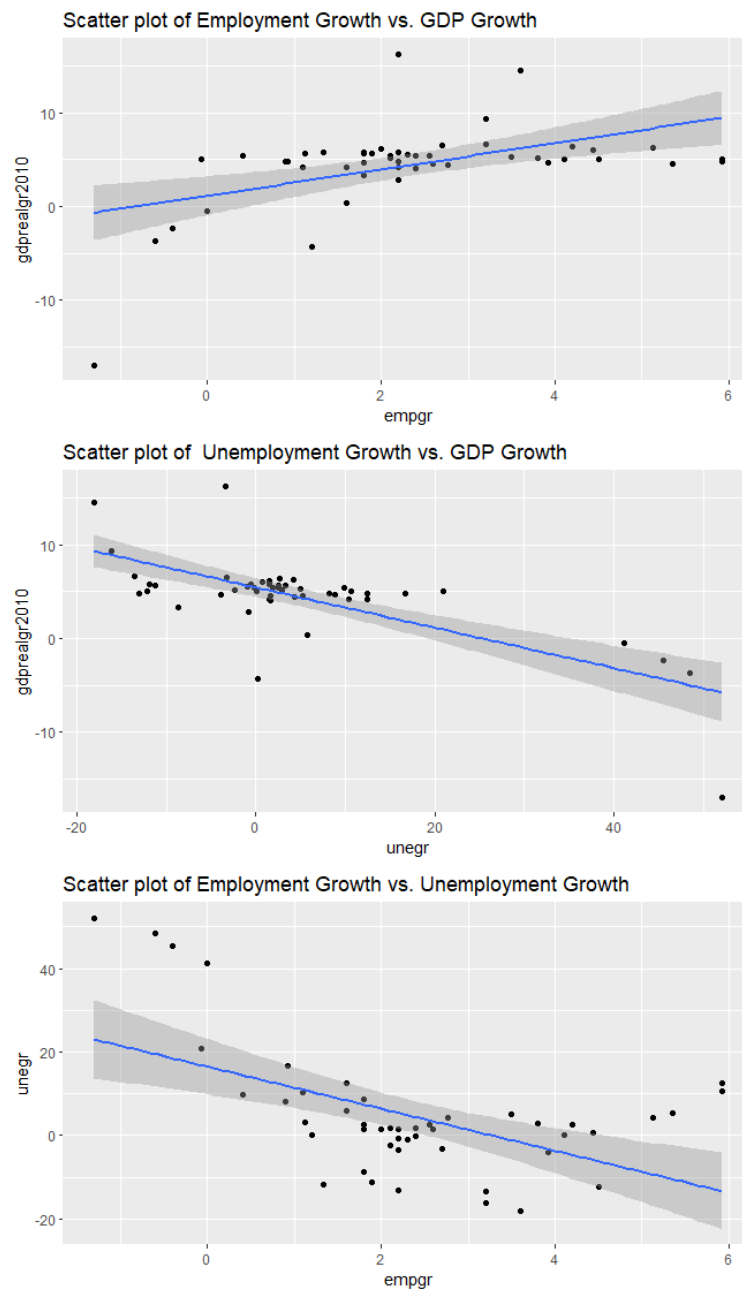


Figure 1: Scatter plot depicting a linear relationship between variables

The ADF test was conducted to assess the stationarity of the time series for employment growth, unemployment growth, and real GDP growth. Leveraging the tseries package in R, which allows automatic lag selection based on the Akaike information criterion, a lag length of three was determined for the analysis. The results of the unit root test are reported in Table 3. The statistics that yield a p-value below the significance level of 0.05 are used as the basis for rejecting the null hypothesis of non-stationarity. The time series for unemployment growth is integrated at the level where the associated p-value of the ADF statistic was 0.0221. Conversely, the series for employment growth and real GDP growth require first-order differencing to achieve stationarity, reflected by significant p-values of 0.0137 and 0.0100, respectively. It is

essential to ensure stationarity of the variables to avoid spurious results in the analysis of causality using transfer entropy.

Table 3: Results of the ADF unit root test

Variables	ADF statistics	p-value
GDP	-3.3948	0.0680
EMP	-2.3769	0.4236
UNE	-3.8881	0.0221
Δ EMP	-4.0963	0.0137
Δ GDP	-6.2526	0.0100

Note: EMP represents the annual percentage change of employment; UNE represents the annual percentage change of unemployment; GDP represents the annual percentage change of real GDP at 2010 constant price. The null hypothesis assumed that the time series has a unit root (non-stationary). This hypothesis is rejected for a p-value less than $\alpha = 0.05$.

4.2. Results of Transfer Entropy Analysis

Table 4 reports the results of the pairwise transfer entropy analysis examining directional information flow between employment growth, unemployment growth, and real GDP growth. For each variable pair, the estimates identify whether past realisations of one variable reduce uncertainty about the future evolution of another beyond its own history, thereby revealing the presence and direction of causal influence.

A statistically significant information flow is observed from employment growth to real GDP growth at a ten per cent significance level ($p = 0.053$). This indicates that information from the history of employment growth reduces uncertainty about future real GDP growth beyond the information in GDP's own past. The effective transfer entropy value of 0.0541, after correcting for finite-sample bias, reflects a modest directional influence from employment to output. On the other hand, there is no statistically significant information flow from real GDP growth to employment growth, marking the absence of reciprocal feedback in the output-employment dynamics during the observation period.

The interaction between real GDP growth and unemployment growth exhibits a noticeably different pattern than the previous variable pair. The history of unemployment growth markedly decreases the uncertainty about future real GDP growth beyond GDP's own history, at a one per cent significance level ($p = 0.0033$). The effective transfer entropy value in this direction (0.1587) indicates a substantial influence of unemployment over output, even after adjusting for bias. The information flow from the opposite direction is also statistically significant, albeit at a lower level of significance of five per cent. This corresponds to a weaker effective transfer entropy value of 0.0388. Thus, the relationship is characterised by an asymmetric information flow structure, with unemployment exerting a stronger directional influence on output than the reverse feedback.

In the meantime, a statistically significant information flow is detected from employment growth to unemployment growth at a five per cent level of significance ($p = 0.0233$). After correcting for finite sample bias, the effective transfer entropy estimate of 0.0372 confirms the presence of a modest but statistically significant causal influence in this direction. In contrast, no statistically significant information flow is detected from unemployment growth to employment growth ($p = 0.1533$), indicating the absence of a reverse causal influence within labour market dynamics over the sample period.

Table 4: Pairwise transfer entropy between real GDP growth, employment growth and unemployment growth

Direction of Information Flow	Transfer entropy	Effective transfer entropy	p-value
GDP → EMP	0.0064	0.0000	0.8167
EMP → GDP	0.0901*	0.0541	0.0533
GDP → UNE	0.0651**	0.0388	0.0167
UNE → GDP	0.1925***	0.1587	0.0033
EMP → UNE	0.0668**	0.0372	0.0233
UNE → EMP	0.0661	0.0365	0.1533

Note: UNE denotes year-on-year unemployment growth at the level, while EMP and GDP denote the first differences of year-on-year employment growth and year-on-year real GDP growth, respectively. GDP refers to real gross domestic product at 2010 constant prices. Statistical significance is assessed using a bootstrap procedure based on the empirical distribution of the transfer entropy statistic under the null hypothesis of no information flow. Therefore, significance indicates the presence of directional dynamic causal information flow. The magnitudes of transfer entropy and effective transfer entropy are not directly comparable across variable pairs and should not be interpreted as effect sizes. *, **, *** denote significance at the ten per cent, five per cent, and one per cent levels, respectively.

4.3. Discussion

The transfer entropy results reveal that the dynamic relationship between output and labour in Malaysia is characterised by a fundamentally asymmetric and hierarchical causal structure as opposed to uniform bidirectional interaction. Noticeably, only the interaction between real GDP and unemployment exhibits reciprocal feedback among the three variable pairs. In particular, the influence of unemployment growth on real GDP growth dominates in comparison to weaker feedback from the reverse direction. This occurrence shows that unemployment variability provides more information about the prospects for future real GDP. In contrast, changes in real GDP make a relatively lesser contribution to unemployment dynamics. Meanwhile, employment exerts a unidirectional causal influence over the future changes in real GDP and unemployment, respectively. Lack of reverse information flow from both variables may indicate other adjustment processes within the time frame influencing these dynamics to shape subsequent change in employment. These results refine previous empirical findings on bidirectional relationships by revealing their asymmetric character. Where earlier studies using symmetric methods identified bidirectional causality between output and unemployment (Al-Sawaie 2020; Chen 2022), the transfer entropy results show that this bidirectional flow is unequal: the information flow from unemployment to output is substantially stronger than the reverse.

In this context, transfer entropy presents the advantage of strengthening causal inference by explicitly quantifying how much information the past values of one variable contribute to explaining the future changes of another, conditional on the target variable's own past. In other words, transfer entropy measures whether knowledge of the historical behaviour of one variable provides additional information about future outcomes beyond what is already contained in the variable's own dynamics (Bossomaier *et al.* 2016; Schreiber 2000). This allows causal influence to be interpreted directly in terms of directional uncertainty reduction, rather than symmetric predictive association. As a result, transfer entropy distinguishes dominant information flow from weaker feedback effects, providing a more granular characterisation of causal structure in systems where adjustment processes are non-linear, heterogeneous, or operate at different speeds.

One possible interpretation of these asymmetric causal structures relates to the institutional labour market adjustments in Malaysia during economic contraction, particularly during the COVID-19 pandemic period of 2020 to 2021. While the transfer entropy framework does not formally identify structural breaks, the observed unidirectional patterns are consistent with

policy interventions under the National Economic Recovery Plan, particularly the Wage Subsidy Programme, which focused on protecting existing employment rather than generating new ones (Lim 2022; Tang 2021). Such interventions align with the unidirectional causal influence of employment on unemployment and the absence of a reverse feedback effect observed in the empirical results. Germany has adopted a similar model where active labour market policies facilitate employment retention without creating sustainable employment growth (Klein & Schiman 2023). The Mexican experience also shows that wage subsidy programmes can lower unemployment without a corresponding gain in employment (Bruhn 2020). It is important to emphasise that this policy linkage is presented as a speculative interpretation consistent with the observed information flow patterns, rather than a formally tested model output.

As a whole, the findings emphasise the critical role of labour market variables operating through asymmetric and non-uniform channels in defining Malaysia's economic dynamics. Employment and unemployment affect output fluctuations in different ways and do not respond symmetrically to changing economic conditions. The results also suggest that labour market adjustment is not uniform. Information appears to flow more strongly in certain directions, particularly from employment to unemployment, while the interaction between unemployment and output is bidirectional. This indicates that the relationship between output and labour is structured rather than evenly balanced across variables. Overall, the results point to distinct transmission processes within the labour market that shape future economic outcomes.

5. Conclusion

This paper analysed the dynamic relationship between employment growth, unemployment growth and real GDP growth in Malaysia using a non-parametric information theoretic framework. Causality is interpreted as the reduction of directional uncertainty, enabling the analysis to shift beyond symmetric predictive relationships to assess how labour market variables and output transmit information over time. Shannon transfer entropy was employed to determine whether past information from one variable improves the prediction of another variable beyond the information contained in the target variable's own history, under minimal modelling assumptions.

The empirical findings indicate that the output-labour relationship in Malaysia is more of an asymmetric and hierarchical information flow rather than uniform bidirectional feedback. The information flow from employment growth to real GDP growth is unidirectional and modest. At the same time, employment growth also exhibits a unidirectional influence on unemployment growth, with no statistically significant reverse flow. In contrast, unemployment growth and real GDP growth exhibit a bidirectional but asymmetric interaction, with unemployment growth providing the stronger forward-looking signal. These findings suggest that labour market variables do not contribute equally to output dynamics and do not respond uniformly to changes in economic conditions.

This study extends existing empirical evidence that has largely relied on symmetric parametric causality methods by distinguishing dominant directional influence from weaker feedback effects. Rather than contradicting previous studies that identify interactions between labour market conditions and output, the information-theoretic approach shows that these interactions may be uneven in strength and direction. In the Malaysian context, the output-labour system appears to reflect selective directional dominance and differentiated transmission channels that may be difficult to isolate using conventional parametric approaches.

Several limitations should be acknowledged. First, the study relies on 48 quarterly observations, which is modest for transfer entropy estimation because the method depends on

estimating joint and conditional distributions. Future studies could use monthly data or entropy estimators that are better suited to small samples. Second, the pairwise transfer entropy framework does not account for omitted variables or simultaneous multivariate interactions. This could be addressed using multivariate transfer entropy. Third, the choice of embedding parameters and discretisation may affect the estimates. Sensitivity analysis across alternative parameter settings would therefore strengthen the robustness of the findings. Fourth, as structural breaks are not formally modelled, any regime-specific patterns, such as those associated with the COVID-19 period, are inferred rather than explicitly tested. Future research could apply rolling-window or regime-switching transfer entropy to examine time-varying information flow. Finally, the analysis is limited to Malaysia. Cross-country comparison would help determine whether the observed asymmetric patterns also apply to other emerging economies.

Overall, this paper contributes to the literature by providing empirical evidence of asymmetric directional information flow in the output-labour relationship under weak distributional and functional assumptions. Malaysia provides a relevant empirical context for observing such dynamics, particularly given the heterogeneous adjustment of employment and unemployment to macroeconomic changes. The findings demonstrate the value of information-theoretic inference for analysing complex macroeconomic systems in which conventional causality frameworks may not adequately capture directional dominance, non-linear adjustment and heterogeneous behaviour.

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