
Climate & Gig Work: Is Heat Wave Reducing Gig Riders' Productivity in Greater Jakarta?

Yohanes Eki Apriliawan
Statistics Indonesia

Correspondence: yohanes.apriliawan@bps.go.id

Abstract

This study demonstrates that rising surface temperatures significantly reduce gig rider productivity in Greater Jakarta, primarily by decreasing their weekly working hours and monthly income. Using spatial panel analysis with socioeconomic and environmental data from 2021 to 2024, we find that heat impacts are most severe in densely built, low-vegetation areas, while green spaces offer mitigation. Vegetation buffers the negative effects of heat, whereas higher night-time economic intensity exacerbates them. Metropolitan-scale analysis reveals that increases in temperature in one area also depress productivity in neighboring areas, highlighting interconnected climate risks. Further, gig riders are especially vulnerable compared to non-gig informal workers due to their mobility, exposure, and limited protections. These findings directly support policy priorities on human capital, economic transformation, and climate adaptation, emphasizing the urgent need for urban heat-safety standards, cooling infrastructure, and adaptive social protection for gig workers.

Keywords: Gig economy, heatwaves, urban heat island, worker productivity, greater Jakarta.

1. Introduction

1.1. Background

Digital technology has transformed the global labor market, including Indonesia. A key aspect is the gig economy, a flexible, platform-based system in which workers and employers connect on demand. In Indonesia, more online workers are now joining transportation and delivery services through platforms like Gojek, Grab, and ShopeeFood. According to Permana et al. (2023), gig workers on Java account for 74% of Indonesia's gig workforce, a proportion higher than the island's 60% share of the national population. Behl et al. (2021) found that transportation-sector gig workers are concentrated in metropolitan cities, a point also noted by Kumar (2024) and Sutherland et al. (2020). Online motorcycle taxi drivers and couriers are described in these studies as operating with flexible systems, lacking long-term contracts, and relying on digitally facilitated demand. While these arrangements expand employment opportunities for individuals with limited access to formal work, the same studies highlight emerging concerns about welfare, job security, and working conditions.

According to data from the Meteorology, Climatology and Geophysics Agency (BMKG), as quoted by the BPS (2025), the average maximum temperature in the Jakarta area increased from 36.5 degrees Celsius in 2015 to 36.8 degrees Celsius in 2024. According to Ningrum (2018) and Poórová et al. (2020), this temperature increase is mainly due to global climate change and the Urban Heat Island (UHI) effect. They identify dense urban development, limited green spaces, and heat absorption by concrete and asphalt surfaces as key factors contributing to the UHI effect. Graff Zivin & Neidell (2014) report that each one degree Celsius rise in daily temperature can decrease outdoor workforce productivity by one to three percent, particularly in labor-intensive sectors without artificial cooling. Somanathan et al. (2021) found that during heat waves in India, informal workers lost up to 5% of their productive working hours and experienced a significant decline in income due to reduced physical capacity in extreme temperatures.

BPS (2024) reports that around 57.95 percent of Indonesia's workforce remains in the informal sector. Gig workers are growing fastest in this group. Most gig workers are informal and lack formal labor protections or social security. Their flexible but unstable work conditions, and their direct exposure to extreme environmental hazards, make them highly vulnerable to climate and economic risks. At the global level, research led by Burke et al. (2015) found that extreme temperature increases have nonlinear effects on economic production across countries. Heat stress negatively affects work capacity, especially among outdoor workers. However, Ioannou et al. (2022) note that most existing studies focus on agriculture or manufacturing. Little research examines these relationships in the context of the digital economy and platform-based work.

Liu et al. (2021) demonstrated that UHI intensity correlates strongly with settlement density, limited vegetation, and nighttime economic activity. Nightlights indicate this activity. This suggests that spatial, data-driven analyses are crucial for understanding workers' vulnerability to extreme heat in densely populated metropolitan areas like Greater Jakarta. To address this knowledge gap, this study analyzes how Land Surface Temperature (LST) affects gig worker productivity in Greater Jakarta from 2020 to 2024. The analysis uses spatial panel data. LST is measured with MODIS satellite imagery. Productivity data come from the National Labor Force Survey (Sakernas) managed by BPS, and are integrated with environmental indicators, including NDVI, nightlights, and population density.

This research directly supports Indonesia's national development vision and global climate adaptation commitment. In the 2024-2029 Presidential Ideal (Asta Cita), this research contributes to the 2nd, 3rd, 6th, and 8th Ideals. These focus on the digital economy, quality job growth, local economic equity, and sustainable development (Presidential Regulation Number 12, 2025). This research also aligns with the 2025-2045 National Long-Term Development Plan (RPJPN). The plan calls for a green and digital economic transformation for Golden Indonesia 2045. RPJPN requires inclusive, productive, and climate-adaptive economic development. This research provides evidence on climate risks for the digital economy and urban jobs (Law Number 59, 2024).

This study supports the 2025–2045 RPJPN's focus on green, digital transformation for Golden Indonesia 2045 and the 2020–2024 RPJMN's goals on digital economy growth, urban sustainability, and climate resilience (Law Number 59, 2024). Globally, this research helps achieve SDG 8 (Decent Work and Economic Growth) and SDG 13 (Climate Action). It also supports the Paris Agreement and

the ILO's Just Transition Framework for a fair transition to a sustainable economy. The framework provides protections for vulnerable workers (ILO, 2015; UN, 2015, 2025).

1.2. Problem Statement

Based on the background, this research asks:

1. What is the spatial distribution of gig workers in the Greater Jakarta area during the 2021-2024 period?
2. How does surface temperature (LST) affect the productivity of gig riders, as measured through hours worked and income?
3. How do environmental conditions, such as vegetation (NDVI), population density, and economic activity, affect the relationship between heat and productivity?
4. Are gig riders more susceptible to heat productivity decline than non-gig informal workers?
5. What are the recommendations for climate adaptation policies that can protect gig workers from the risk of extreme heat in urban areas?

1.3. Purpose of Study

This research aims to:

1. Analyzing the relationship between surface temperature (LST) and the productivity of gig riders in the Greater Jakarta area in 2021-2024.
2. Identify environmental and spatial factors that modify the impact of heat on productivity.
3. Comparing the level of vulnerability of gig riders to extreme heat with that of non-gig informal workers.
4. Provide recommendations for urban employment-based climate adaptation policies that support the implementation of the 2025-2045 RPJPN, 2025-2029 RPJMN, and SDGs 8 and 13.

1.4. Benefit of Study

1. Academic benefits:

Contribute new data on labor economics, climate change, and the digital economy by integrating socio-economic (Sakernas) and remote sensing (ESG, NDVI, nightlights) data.

2. Practical benefits:

Give scientific evidence to help governments create climate-adaptive employment policies and motivate digital platforms to protect gig workers.

3. Policy benefits:

Support national policies in the 2020-2024 RPJMN, the 2025-2045 RPJPN, and global goals in the SDGs and Paris Agreement.

2. Research method

2.1. Theoretical Framework

This research departs from a theoretical framework that connects the physical environment, digital labor market structure, and the city's spatial dynamics. The framework is based on three main dimensions. First, the theory of labor productivity under environmental pressure (heat-productivity nexus). Second, the theory of the gig economy and digital work flexibility. Third, the theory of spatial economics explains how regions interact in economic activities. These three form a conceptual basis to explain how extreme temperatures in urban areas like Greater Jakarta affect gig workers' productivity. This especially applies to those working outdoors, such as online transportation drivers or delivery couriers.

In classical labor productivity theory, productivity is a function of human capital, physical capital, and technological efficiency (Solow, 1956). Later, this approach included environmental factors, as research showed that climate conditions affect working capacity. Excessive heat exposure reduces physical and mental capacity through heat stress. Heat stress is physiological stress caused by elevated body temperature that affects metabolism and concentration. For outdoor work, a temperature rise of one degree Celsius above the optimal threshold (26-30 degrees Celsius) can reduce productivity by one to three percent. The reduction depends on the work type and adaptation level. This aligns with the theory of human capital depreciation under environmental stress. It states that exposure to extreme heat temporarily reduces labor capacity, increases rest time, and decreases output per hour worked (Kjellstrom et al., 2014).

In the digital economy, the emergence of a platform-based work system, or gig economy, has changed the traditional structure of the labor market. Gig work is defined as an economic activity mediated by digital platforms, in which the working relationship between workers and employers is temporary, task-based, and flexible in terms of time and location. This flexibility is one of the main attractions for urban workers, especially in developing countries, as it offers the freedom to set one's own hours and the opportunity to earn without the limitations of long-term contracts. However, gig economy theory also emphasizes the vulnerability side, including the lack of social protection, income instability, and direct exposure to market and environmental risks. In the Indonesian context, gig workers such as online motorcycle taxi drivers, food couriers, and digital logistics workers make up the largest share of the platform's workforce, where most work outdoors with long working hours and direct exposure to weather and pollution. Therefore, they are the most sensitive group to urban climate change, especially to increasing temperature extremes and the phenomenon of urban heat islands (De Stefano, 2015; Kässi & Lehdonvirta, 2018).

The relationship between ambient temperature and labor productivity is not only individual but also spatial. In regional and spatial economic theory, especially as explained by, there is an assumption that economic activities in one region are not independent, but rather affect each other between regions through spatial dependency mechanisms and spillover effects. Spatial dependence can arise from labor mobility, transportation network connectivity, or market proximity. In the context of this study, spatial interaction becomes relevant due to the high mobility of gig workers, especially gig riders, which

affects their productivity not only by the environmental conditions in their area of residence but also by the heat and density of the surrounding area. For example, rising surface temperatures in Central Jakarta have the potential to affect the workload and income of online drivers operating across regions, such as to Bekasi or Tangerang, so analyses that ignore spatial relationships risk biasing estimates of the effects of climate on productivity (Anselin, 2003; LeSage & Pace, 2009).

The interaction among productivity theory, gig economy theory, and spatial theory provides the conceptual framework for this research. Conceptually, the productivity of labor in the region i in the year t (Y_{it}) is influenced by surface temperature conditions (LST_{it}), digital job characteristics ($GigShare_{it}$), and environmental factors such as vegetation and intensity of the nocturnal economy ($NDVI_{it}$ dan NTL_{it}). The interaction between regions is represented by the influence of these variables in the surrounding area, which is spatially appropriate. This relationship can theoretically be inferred in the form of a general function:

$$Productivity_{it} = f(LST_{it}, GigShare_{it}, NDVI_{it}, NTL_{it}, Spillover_{it}) \quad (1)$$

which illustrates that the level of worker productivity in a region results from a complex interaction among environmental factors, the digital economy, and dynamics between urban areas.

2.2. Data

This study uses quantitative secondary data from various sources, compiled into regency/municipality spatial panels for the Greater Jakarta area, for the period 2021 to 2024. The main source of data is from Sakernas, organized by BPS. From Sakernas, a number of key variables are used to identify gig workers, including employment status, classification of industrial sectors based on two-digit KBLI, use of the internet in work, employment contract status, and work location. In addition, weekly working hours and monthly income are used to measure labor productivity. When this microdata is processed, normalization and cleanup are performed to eliminate duplicate records.

The operational definition of gig workers in this study follows the criteria: individuals who are self-employed, do not have a permanent employment contract, and use the internet to support work. The gig riders subgroup comprises gig workers in transportation and public sectors, as well as outdoor activities. Non-gig informal workers are individuals with a similar informal employment status who do not use the internet to work and do not work in the digital transportation sector. This approach allows for direct comparisons between groups of workers with relatively homogeneous socioeconomic characteristics who differ in their technology use and environmental exposure.

In addition to socioeconomic data, remote sensing data is used to describe the region's physical environmental conditions. Surface temperature (LST) data were obtained from MODIS imagery with a spatial resolution of 1 km and a temporal resolution of eight days. All satellite images for the 2021-2024 period are processed using zonal statistics at the regency/municipality administrative boundaries of the BPS, resulting in a series of surface temperature values for each region in a given year. These values are then converted to degrees Celsius and averaged to obtain the average annual LST for each regency/municipality, representing the region's baseline heat exposure level.

In addition to the average value, the study also calculated annual temperature variations to describe the degree of instability or temperature fluctuations in a region throughout the year. Variance is used as an indicator of the intensity of daily temperature changes and the frequency of heat-stress variability, which, in theory, affects the productivity of outdoor workers. Variance is calculated by the formula:

$$LST_{var,it} = \frac{1}{n} \sum_{d=1}^n (LST_{idt} - LST_{mean,it})^2 \quad (2)$$

By being the value of surface temperature on the day of observation in the region in the year, and is the average value of the annual temperature of the region.

In addition to LST, the vegetation index (NDVI) from MODIS is used to describe vegetation density, and the night lighting intensity (NTL) from the VIIRS satellite is used as a proxy for urban economic activity. Other supporting data, such as population density and road network length, are taken from BPS and OpenStreetMap.

The research analysis unit is a regency/municipality in Greater Jakarta, which consists of five areas of DKI Jakarta (Central Jakarta, North Jakarta, West Jakarta, East Jakarta, South Jakarta) and eight surrounding areas (Bogor, Depok, Bekasi, Tangerang, Bogor City, Bekasi City, Tangerang City, and South Tangerang City). This analysis unit was selected because Greater Jakarta is the region with the highest concentration of gig workers in Indonesia and has experienced a significant increase in urban temperatures over the last decade.

2.3. Methodology

The research process is carried out through a series of continuous analytical stages, starting from the micro data processing stage, spatial environmental data integration, spatial panel formation to econometric model estimation. The first stage is the processing and classification of Sakernas micro data. Individual data from Sakernas for 2021-2024 is combined, cleaned and categorized based on the criteria of gig workers, gig riders and informal non-gig workers as described in the previous subchapter. The aggregation process is carried out by taking into account the weight of the survey to produce an estimate that represents the regency/municipality population. The weighted average estimate for weekly working hours and monthly income is calculated using the formula:

$$Y_{ig} = \frac{\sum_{j=1}^{n_i} w_{ij} Y_{ijg}}{\sum_{j=1}^{n_i} w_{ij}} \quad (3)$$

where Y_{ig} is the weighted average estimate of the productivity variable for the worker group in the regency/municipality and is the weight of the individual survey. The estimated total worker population of each group is calculated through:

$$\hat{N}_{ig} = \sum_{j=1}^{n_i} w_{ij} \quad (4)$$

To calculate the standard deviation from the average estimate, the Taylor linearization method is used, which takes into account the variation between PSUs within the strata.

The third stage is the formation of a regency/municipality spatial panel with a two-dimensional structure (i, t), i indicates the region and t indicates year. This spatial panel allows longitudinal analysis (changes over time) and spatial analysis (interactions between regions). The fourth stage is econometric analysis using panel and spatial panel models. The basic model used is the Fixed Effects Model (FE):

$$Y_{it} = \alpha_{it} + \lambda_t + \beta_1 LST_{it} + X_{it}\beta + \varepsilon_{it} \quad (5)$$

which controls for differences in fixed characteristics between regions through α_i and for variations between periods through the effects of time λ_t . To capture inter-regional dependencies, the model was developed into the Spatial Durbin Model (SDM):

$$Y_{it} = \rho WY_{it} + X_{it}\beta + WX_{it}\theta + \mu_i + \lambda_t + \varepsilon_{it} \quad (6)$$

W is spatial weight matrix based on geographical proximity between regencies/municipalities. ρ reflects the presence of spatial lag effects, as well as θ reflects the spillover effects of independent variables.

In addition, to test whether gig workers are more sensitive to heat than other informal workers, an interaction model was used:

$$Y_{it} = \alpha_{it} + \lambda_t + \beta_1 LST_{it} + \beta_2 (LST_{it} \times GigShare_{it}) + X_{it}\gamma + \varepsilon_{it} \quad (7)$$

The coefficient β_2 measures differences in the productivity sensitivity to heat across regions with a higher proportion of gig workers.

All stages are integrated to provide a comprehensive empirical picture of how increases in surface temperatures due to climate change and the urban heat island effect affect labor productivity in Indonesia's metropolitan areas. The results of the analysis are expected not only to contribute to the development of the scientific literature in labor economics and climate change but also to provide an empirical basis for formulating social protection and climate adaptation policies for informal workers in urban areas.

3. Results and Discussion

3.1. Overview

The Greater Jakarta area is the largest metropolitan area in Indonesia, which includes six administrative cities in DKI Jakarta and eight districts/buffer cities. This region is known as the center of digital economy activities and a home base for the highest number of gig riders in Indonesia. A descriptive analysis of the 2021-2024 panel dataset shows consistent spatial differences in surface temperature (LST), green space (NDVI), night-time lighting intensity (NTL), and population density, which together shape gig workers' vulnerability to extreme heat.

Table 1. Descriptive Statistics

Variable	Mean	Standard Error	Minimum	Median	Maximum
Gig Rider's work hour	52.3744	4.0215	43.0489	53.2962	58.9448
Gig Rider's income	2,616,177	522,869	1,329,675	2,651,506	4,097,270
Gig Rider's Productivity	199,750	36,736	108,029	201,129	304,743
Informal Non-Gig Worker's Productivity	205,910	55,934	127,393	191,126	365,206
LST_{mean}	35.5083	2.5038	29.1815	36.2018	38.3186
LST_{var}	11,478	2,910	6,835	10,919	19,415
NDVI	0.3806	0.1012	0.2325	0.3546	0.6261
NTL	19.3096	9.9474	2.7523	19.3924	48.3487
Population Density	11,349	6,277	1,845	10,933	23,001
Road Density	20.3948	7.5199	5.3262	22.8847	31.2112

The variable LST_{mean} consistently has the highest values in the Administrative Cities of North Jakarta, Central Jakarta, Tangerang, and Bekasi. These areas are urbanization pockets characterized by high building density, a lack of green open space, and the dominance of watertight surfaces. The high LST in the region aligns with the urban heat island mechanism, which states that residential density, intensive economic activity, and the lack of vegetation increase surface temperatures. In contrast, areas such as Bogor City and Bogor Regency show lower values LST_{mean} , supported by high NDVI and greener regional structures.

The temperature variance value (LST_{var}) shows more volatile temperature dynamics in metropolitan suburbs such as Bekasi Regency, Tangerang Regency, and Bogor Regency. This condition is common because urban-rural transition areas tend to exhibit land-cover heterogeneity, rapid spatial change, and intense development. This temperature variance is important to analyze because daily and seasonal temperature fluctuations are often the main triggers of heat stress in outdoor workers (Zander et al., 2015).

In terms of productivity, gig riders differ from informal non-gig groups. The cities of Bekasi, Depok, and South Tangerang show high average working hours for gig riders, in line with the dominant pattern of online transportation app use in suburban areas. Meanwhile, the highest monthly income of gig riders is found in areas with strong nocturnal economic activity, such as West Jakarta, South Jakarta, and Tangerang. The high intensity of NTL is a proxy for consumption centers that cause a

high demand for transportation and courier services, so it has the potential to increase the performance hours of gig riders.

Overall, the spatial description suggests that environmental factors such as vegetation, urban economic intensity, and surface temperature form a highly variable risk pattern between cities. Jabodetabek is not a homogeneous area; The combination of density, spatial structure, and the presence of road infrastructure creates complex patterns of gig worker vulnerability and needs to be analyzed through panel-based empirical models and spatial approaches.

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3.1. The Effect of Surface Temperature on Gig Riders' Productivity

Fixed-effects panel estimation is the core model for addressing the first research goal: the effect of heat on gig rider productivity. This model controls for the fixed characteristics of regencies/municipalities and the annual variations in the productivity of the digital workforce, so that the LST_{mean} and LST_{var} coefficients be interpreted as the effects of exogenous temperature changes on the productivity of gig riders.

The results of the estimation show that an increase in average surface temperature consistently decreases the productivity of gig riders. These findings support the global literature, which shows that extreme heat reduces human work capacity by increasing physiological heat load, affecting stamina, motor reactions, and the ability to perform physical work (Kjellstrom et al., 2014). In the context of gig riders, this relationship is even stronger because their work is done entirely outdoors, often without protection from direct heat radiation.

Table 2. Fixed Effects Panel Model on Gig Riders' Productivity

Variable	Coefficient		
	Productivity	Hours	Income
LST_{mean}	-0.0775	-0.6186	0.0614
LST_{var}	-0.0000	-0.0000	-0.0000
NDVI	-0.0707	-24.0890	-0.5773
NTL	-0.0033	-0.1012	-0.0055
Population	0.0008*	-0.0071	0.0007**
Density			
Road	-0.0316	1.2029	-0.0077
Density			
R ²	0.2487	0.0136	0.2242

Significance Level : (*) 10% (**) 5%

The LST_{var} coefficient also showed a negative influence. High year-to-year temperature variability indicates unstable environmental conditions, with extreme heat events and daily temperature changes often sharper. The results of the model show that an increase of one unit of temperature variance leads to a decrease in productivity. This effect illustrates that not only do high temperatures suppress productivity, but temperature fluctuations, which cause thermal discomfort, also reduce working hours or income, as found in Somanathan et al. (2021) study of informal workers in India.

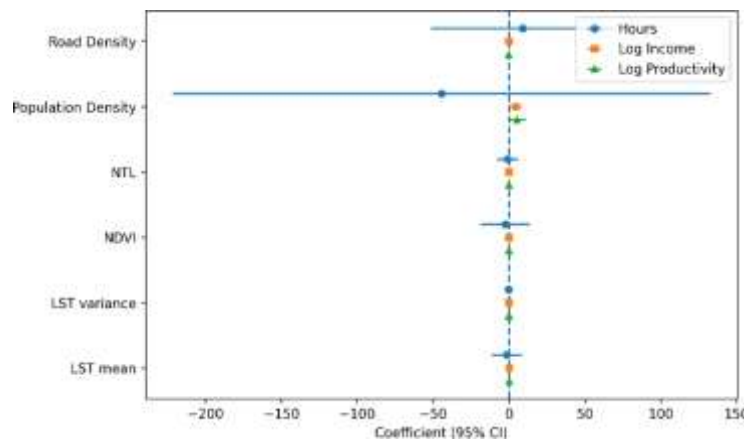


Figure 1. Coefficient Plot of Key Variables

When productivity is broken down into hours worked and monthly income, the same pattern appears consistently. Gig riders' weekly working hours tend to decrease as average temperatures rise. The reduction in working hours is not only due to heat-induced fatigue but also to worker adaptation strategies, such as avoiding very hot daytime shifts or working fewer hours to reduce health risks. Monthly revenue also declined as LST_{mean} rose, suggesting that the decline in working hours could not be fully offset by increased demand for services or platform incentives.

Overall, the fixed effects results provide strong evidence that extreme heat is a determinant of productivity for gig workers, in line with findings in the labor economics and climate change literature. Gig riders in Greater Jakarta have been empirically shown to be susceptible to consistent increases in surface temperatures in urban areas.

3.2. Interaction of Temperature with Vegetation and Economic Intensity

To address the second objective, environmental factors that strengthen or reduce the impact of heat on the productivity of gig riders, the interaction models of $LST \times NDVI$ and $NTL \times LST$ are used. The results show two patterns that are very important to understand in the context of space-based climate adaptation.

The interaction between LST_{mean} and NDVI resulted in a positive coefficient, suggesting that green space has a protective effect against heat degradation productivity. This means that even though surface temperatures are high, vegetation can reduce these impacts through shading, evapotranspiration, and reduced local surface temperatures. Theoretically, this relationship is consistent with the urban ecology literature, which suggests that vegetation reduces micro-

temperatures, thereby increasing human thermal comfort (Bowler et al., 2010). In the context of gig riders, this is especially relevant because most of their activities take place in street space that is often directly exposed to the sun. Urban green open spaces, road green lanes, and roadside trees function as a microclimate buffer, reducing the thermal load on workers' bodies.

Table 3. Fixed Effects Panel Model with Interaction

Variable	Coefficient		
	Productivity	Hours	Income
LST_{mean}	-0.1683	-13.9300**	0.4280*
LST_{var}	0.0000	0.0016	0.0000
NDVI	-0.6551	1391.7**	26.209*
NTL	0.1352	2.5582	0.1797
Population Density	0.0008	0.0152	0.0010**
Road Density	-0.0926	1.7881	-0.0524
$LST_{mean} \times$ NDVI	0.0221	40.9520**	0.8110*
$LST_{mean} \times$ NTL	-0.0042	-0.0653	-0.0053
$LST_{var} \times$ NDVI	0.0001	-0.0011	0.0000
$LST_{var} \times$ NTL	0.0000	-0.0000	0.0000
R ²	0.2714	0.2326	0.3294

Significance Level : (*) 10% (**) 5%

In contrast, interactions between LST_{mean} with NTL showed negative coefficients. Areas with high economic intensity, indicated by night lighting, tend to experience a greater decline in gig rider productivity as temperatures rise. This indicates that highly densely populated and economically active areas are not only hotter but also more stressful for gig workers. Activity density increases travel time, congestion, and workload, which, when combined with high temperatures, results in a sharper drop in performance. These findings are consistent with the urban economics literature that suggests that economic density can create negative externalities in the form of pollution, heat, and mobility friction (Duranton & Puga, 2004).

Thus, NDVI becomes a mitigating factor that softens the impact of heat, while NTL becomes an amplifying factor that intensifies it. It provides a scientific basis for spatial planning and urban climate adaptation policies, especially in providing strategic green spaces for outdoor workers.

3.3. Vulnerability Comparison: Gig Riders vs Non-Gig Informal Workers

The estimates show a sharp difference between gig riders and non-gig informal workers. When the fixed-effects model was applied to informal non-gig groups, the impact of LST_{mean} on productivity

remained negative but smaller than that of gig riders. This confirms the third hypothesis that gig riders are more susceptible to extreme heat than other informal workers.

Table 4. Fixed Effects Panel Model on Non-Gig Informal Workers Productivity

Variable	Coefficient		
	Productivity	Hours	Income
LST_{mean}	-0.0283	-0.1781	-0.2946*
LST_{var}	-0.0000	-0.0003	0.0000
NDVI	3.9736	1.6607	4.1574
NTL	0.0122	0.7119	0.0328
Population Density	0.0014	-0.0059	0.0013
Road Density	-0.1129	0.6096	-0.1223
R ²	0.2416	0.1299	0.2217

Significance Level : (*) 10% (**) 5%

This higher vulnerability can be explained by the characteristics of gig riders' jobs that require high mobility, more frequent direct heat exposure, and an inability to regulate the work environment. Unlike some non-gig informal workers who may work in kiosks, small workshops, or other semi-indoor spots, gig riders operate in open spaces most of the time. Additionally, algorithm-based incentive systems on digital platforms can encourage users to spend more time on the road during high demand, thereby increasing heat exposure. These findings align with recent literature on gig labor vulnerability, which emphasizes weak job protections and high health risks for platform workers (ILO, 2015).

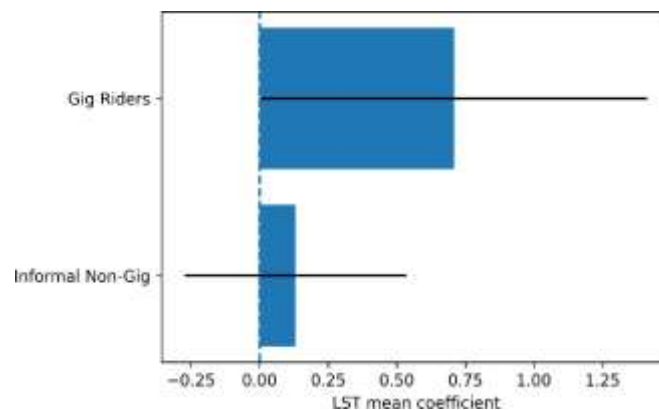


Figure 2. Sensitivity of Productivity to LST Comparison

The results of this study provide empirical evidence that the impact of extreme heat is uneven across the informal segment. Gig riders are a specialized subgroup in the urban workforce that bears the highest burden of climate risks.

3.4. Spillover Temperature and Productivity Between Metropolitan Cities

Using a quasi-SDM panel model, this study identified spatial spillovers between cities in Greater Jakarta. The spatial lag coefficient shows that rising temperatures in neighboring cities affect the productivity of gig riders in other cities. It describes the nature of urban heat that knows no administrative boundaries. When the core metropolitan areas, such as Central Jakarta and North Jakarta, experience higher temperatures, the heat can spread to surrounding areas, including Bekasi, Tangerang, and Depok. These findings align with the concept of "heat propagation" in urban climatology, which holds that metropolitan heat patterns move along with wind patterns, building density, and landscape thermal structures (Santamouris, 2015).

Table 5. Spatial Durbin Panel Model on Gig Riders' Productivity

Variable	Coefficient		
	Productivity	Hours	Income
LST_{mean}	-0.0726	-0.5953	0.0660
LST_{var}	-0.0000	-0.0003	-0.0000*
NDVI	-0.7004	18.2850	-0.8999
NTL	0.0012	0.2624	0.0061
Population Density	0.0007	-0.0079	0.0005
Road Density	-0.0483	7.0809	0.0625
$W_{LST_{mean}}$	-0.1013	1.3066	-0.1007*
$W_{LST_{var}}$	-0.0000	0.0006	0.0000
W_{NDVI}	0.2172	-25.9560	-0.2688
W_{NTL}	-0.0012	-0.7736	-0.0198**
$W_{Population\ Density}$	-0.0000	0.0014	-0.0000
$W_{Road\ Density}$	0.0588*	-0.8408	0.0564*
W_y	0.0159	-0.6764*	0.1567
R^2	0.3870	0.3293	0.4028

Significance Level : (*) 10% (**) 5%

The spatial lag of the dependent variable is also significant in some models, suggesting that the productivity of gig workers in a region is influenced by productivity dynamics in neighboring regions. This can be explained by the economic and spatial integration of Greater Jakarta, where gig workers often move between cities in a single day, following the demand and incentives of applications. Thus, productivity spillover can be interpreted as the impact of cross-border worker mobility or cross-regional consumer effects that affect service demand patterns.

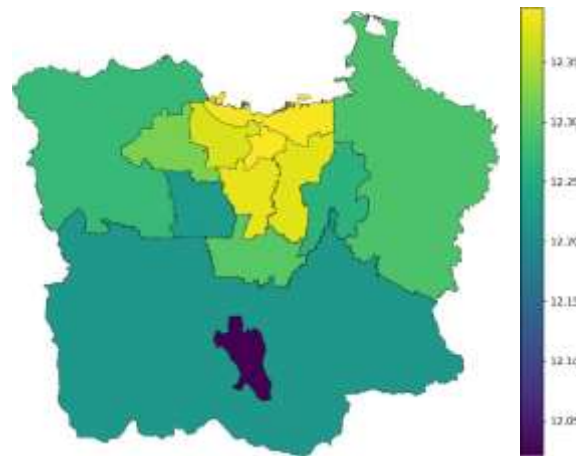


Figure 3. Gig Rider's Productivity Spatial Spillover Map

Overall, the spatial model confirms that analyzing the gig economy in metropolitan areas cannot be done without accounting for spatial dependencies between cities. These results reinforce the fixed-effects analysis and show that climate adaptation in urban areas should be designed at the metropolitan scale rather than at the city level.

3.5. Integration of Research Findings with the National Development Agenda

The empirical findings of this study regarding the impact of surface temperature on the productivity of gig workers, especially gig riders in the Greater Jakarta area, produce a number of strategic implications that have direct relevance to the direction of national development policies as stated in the 2025–2029 RPJMN and the long-term vision in the 2025–2045 RPJPN. The current Indonesian government carries a development paradigm that emphasizes economic transformation, improving the quality of human resources, and strengthening resilience to climate change, all of which have a strong common ground with the issue of urban workers' vulnerability to extreme heat.

In general, the 2025–2029 RPJMN marks the initial stage of development towards the Golden Indonesia Vision 2045, which is supported by eight *Asta Cita* as national priorities. This research is most strongly intersected with three main pillars: (1) improving the quality of human resources and workforce productivity; (2) economic transformation towards high-value-added and competitive activities; and (3) adaptive environmental development, especially facing the risk of climate change that worsens working conditions in the informal sector and the gig economy. This relevance is strengthened by the RPJMN's emphasis on decent work, protection for vulnerable workers, and the development of metropolitan areas as the center of the national economy.

In this context, the results of this study show that increased heat exposure, as reflected in average LST and annual temperature variance, has an impact on the productivity of gig riders, especially through reductions in working hours and weekly income. These empirical findings reinforce the scientific argument that workers with KBLI code 8 (transportation and warehousing) who work outdoors, have low contractual protections, and rely on digital platforms are among the most vulnerable groups to climate change risks. The international literature such as Somanathan et al. (2021), LoPalo (2020), and Intergovernmental Panel on Climate Change (2022) show similar and

consistent pattern: extreme heat lowers physical and cognitive work capacity, increases fatigue, and reduces effective working hours, mechanisms that were also found to be strong in the study.

In Asta Cita, the President emphasized the importance of improving the quality of life of the Indonesian people through health, education, and adaptive social protection. The study's findings fill an important gap in the agenda by showing that platform workers, most of whom lack formal employment protections, experience a decline in productivity as temperatures rise, potentially exacerbating income inequality.

In the context of the RPJMN, this aligns with the agenda of increasing the Human Capital Index and protecting vulnerable groups, given that gig riders are part of a large segment of urban informal workers in Indonesia. Evidence that extreme heat reduces productivity can be an important basis for adaptive social protection policies, such as heat-related health subsidies, adaptive income assistance, or occupational safety improvement programs for outdoor work.

The 2025–2029 RPJMN places Jabodetabek as a national strategic area in the economic transformation agenda. As centers of logistics, consumption, and mobility, gig riders play a crucial role in maintaining the smooth functioning of urban economic activities. Their decreased productivity due to rising temperatures will lead to higher micro-logistics costs, distribution delays, and potential shocks to platform-based services.

This study shows that road density and NTL (a proxy for economic activity) partially moderate the impact of heat, underscoring the importance of urban infrastructure in maintaining the work capacity of gig workers. This is in accordance with the RPJMN, which emphasizes improving the quality of urban infrastructure, especially transportation, public space, and climate-adaptive spatial planning.

Thus, the findings of this study provide empirical evidence that the development of climate-resilient cities is not only an environmental issue but also directly affects the productivity of the informal sector that supports the urban economy.

The RPJPN Law explicitly states that the state must build a long-term development system that is sustainable, inclusive, and adaptive to climate change, including through socio-economic transformation in the next 20 years. One of the strategic areas is decent work and increased labor productivity, which are considered key to achieving a per capita income equivalent to that of developed countries by 2045.

This research, with a focus on the climate vulnerability of the gig economy sector, contributes directly to the strategic agenda of the RPJPN, in particular:

- the realization of social resilience, because vulnerable workers need to be protected from environmental risks;
- transformation of the job market towards decent and adaptive work;
- urban development that is environmentally friendly and minimizes health risks; and
- control of climate change through a data- and evidence-based adaptation system.

By identifying that annual LST variance strongly influences gig workers' productivity, the study suggests that adaptation policies should consider climate variability rather than just annual average temperatures. The findings of this study can be translated into recommendations that are in line with the national development framework, including:

1. The implementation of heat work safety standards for outdoor workers in the logistics and transportation sectors is platform-based, supporting Asta Cita 2 and 3.
2. The provision of urban cooling infrastructure (cooling shelters, water stations) in areas with high gig activity aligns with the RPJMN's development of climate-adaptive cities.
3. Integration of LST data and the climate vulnerability of informal workers in metropolitan area planning, in accordance with the evidence-based planning mandate in Law 59/2024.
4. Preparation of adaptive social protection schemes targeting heat-vulnerable informal workers.
5. Strengthening digital platform regulations to support heat safety training, risk tracking, and mitigation protocols aligns with national priorities for digital transformation.

Thus, the results of this study not only address the study's academic objectives but also provide a strong scientific basis for the government to design more adaptive labor, climate, and urban policies, in line with Indonesia's transformation path towards 2045.

4. Conclusions

4.1. Policy Recommendations

Based on empirical findings and their relation to national policies, a number of strategic recommendations can be developed for various levels of actors, ranging from the central government and local governments to digital platforms and workers themselves. All of these recommendations depart from the premise that gig workers are an essential part of the modern urban economy, so their protection from the risk of extreme heat is an essential element in economic and social development.

The recommendations for the central government focus on drafting heat-safety standards for outdoor workers that integrate surface-temperature data, the heat index, and temperature variability. The central government also needs to integrate heat risk into national employment policies and expand coverage of adaptive social protection for informal workers through heat-wave cash assistance mechanisms and climate risk insurance. In addition, strengthening urban planning systems based on climate and occupational health data requires using research results such as these.

For local governments, especially the provinces of DKI Jakarta, West Java, and Banten, the recommendations focus on providing adaptive infrastructure, such as refrigerated restrooms, hydration stations, and green corridors, at high-gig activity points. Local governments need to improve spatial governance by considering LST when determining development zones, especially in areas that serve as mobility and logistics centers. The implementation of urban heat island mitigation, including increasing vegetation cover and using high-reflectivity materials, should also be prioritized.

Digital platforms such as Gojek, Grab, and ShopeeFood have an important responsibility in protecting their workers. Recommendations for the platform include developing heat-aware algorithmic management that limits orders to hours with extreme temperatures, provides heat alerts and safety education, and offers rest and cooling facilities through partnerships with public or private spaces. Additionally, platforms need to provide adaptive incentives, such as cooling-time credits or cool-night/night-night shift bonuses, to reduce heat exposure.

Meanwhile, for gig workers themselves, education related to heat risks is crucial. Workers need to understand the importance of hydration, adequate rest, the use of heat protection, such as cooling towels or arm sleeves, and adapting working hours to avoid peak hours. Thus, protecting gig riders is a collective responsibility that involves all stakeholders.

4.2. Conclusion

Overall, this study makes a significant contribution to understanding the relationship among climate change, urban environmental conditions, and labor productivity in Indonesia's gig economy. By using a spatial panel and integrating socioeconomic and remote sensing data, the study highlights the vulnerability of gig workers, particularly gig riders, to extreme heat. These findings not only enrich the academic literature on labor economics and urban climate but also have direct relevance for national policy formulation towards green and digital economic transformation as mandated in the RPJMN and RPJPN. By strengthening urban governance, implementing adaptive social protection, and restructuring urban infrastructure to be more climate-resilient, the productivity and well-being of gig workers can be improved, in line with Indonesia's vision of an inclusive, adaptive, and sustainable Indonesia.

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