Supplementary Information 1
for
Climate Change and Income Inequality: Panel Evidence from 34 Indonesian Provinces, 2009–2024

1. Lagged Effects of Climate Change on Income Inequality

There is a possibility that past temperatures and precipitation can influence current income inequality levels, as climate change affects income inequality through various channels, and these impacts may take time to be felt. The study would then have a lagged model that observes the effect of past temperatures and precipitation on income inequality in each province. To see this, Equation 1 is modified to include lagged variables of temperature and precipitation, and the following regression model is then estimated:

$$\text{Inequality}_{pt} = \beta_0 + \beta_1\text{Climate}_{pt\text{-}l} + \beta_k X_{k,pt} + r_p + y_t + \epsilon_{vt}$$

where every variable is the same as Equation 1, except that $\text{Climate}_{pt\text{-}l}$ represents the measures of climate change, annual average temperatures, and monthly precipitation of province *p* at time *t-l*. Here, *l* is the lag and will take on a value of 1 to 5, indicating that the annual average temperatures and monthly precipitation values are from one to five years prior. The estimate of interest would then be β_1, as it reveals the potential association between average temperatures and precipitation from one to five years ago and current income inequality levels.

1.1 Temperature

Results from the lagged model found a positive and significant association between temperatures from the previous year and the Gini index. However, there is no other associations between past values of climate indicators and income inequality indicators. From Table S1.1, we see that an increase of 1 degree Celsius in average annual temperatures in the previous year is associated with a 0.822-point increase in the Gini index of provinces, a similar figure to the baseline model results shown in Table 4.1. This figure only amounts to 2.3 percent of the average national Gini index, but again, in relative terms, this is a 20.7 percent reduction from the 3.96-point decrease in the Gini index over the period from 2012 to 2024. This suggests that rising temperatures have a short and quick pathway towards affecting the Gini index levels of Indonesian provinces. The regression on income deciles is more mixed and convoluted. From Table S1.2, it can be seen that the temperature increase two years ago has a negative association with the income share of the 10th decile. Temperature increases from three years ago are positively associated with the income share of the 3rd decile, while temperature increase from four years ago is positively associated with the income shares of the 9th decile. Lastly, the temperature increase from five years ago is positively associated with the income shares of the 1st, 2nd, and 3rd decile. The distribution of the estimates suggests that the bottom three income deciles adapts three to five years after an increase in average temperatures. On the other hand, there are conflicting associations for the top income deciles, for the very top decile, the results suggest that the adverse effects are delayed and are felt two years after the event, while for the 9th decile the estimate suggests adaptation four years after the rise in average temperatures.

Table S1.1 Lagged effect of temperature on income inequality indicators.

Dependent Variable:	Gini Index	Theil Index	90:10 Ratio
Variable			
1-yr Lagged Temperature	0.822***	0.0159	-0.0135
	(0.29)	(1.044)	(0.303)
2-yr Lagged Temperature	-0.201	-1.449	-0.223
	(0.302)	(0.893)	(0.477)
3-yr Lagged Temperature	0.22	-0.698	-0.224
	(0.246)	(1.012)	(0.423)
4-yr Lagged Temperature	0.0862	-1.019	0.0998
	(0.245)	(1.15)	(0.275)
5-yr Lagged Temperature	0.00929	-1.221	-0.259
	(0.238)	(0.787)	(0.209)
Controls			
Control variables	Yes	Yes	Yes
Fixed-effects	Yes	Yes	Yes
R-squared	0.468	0.428	0.270
Obs	373	372	372

Control variables: per capita and squared per capita provincial GDP, employment share in agriculture, manufacturing, and services, unemployment rate, electrification ratio, internet penetration, average years of schooling. Fixed-effects variable: province and year.
Standard errors in parentheses
$^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$

Table S1.2 Lagged effect of temperature on the share of income per decile.

Dependent Variable:	1st Decile	2nd Decile	3rd Decile	4th Decile	5th Decile	6th Decile	7th Decile	8th Decile	9th Decile	10th Decile
Variable										
1-yr Lagged Temperature	0.0228 (0.0305)	-0.0259 (0.0428)	-0.0399 (0.0441)	-0.0496 (0.0515)	-0.0529 (0.0637)	0.0565 (0.0581)	0.0212 (0.0642)	-0.0233 (0.106)	-0.119 (0.0929)	0.21 (0.384)
2-yr Lagged Temperature	0.0132 (0.0317)	0.0609 (0.0495)	0.0654 (0.0535)	0.0884 (0.0601)	0.0645 (0.0829)	0.0516 (0.0936)	0.0924 (0.0743)	0.0968 (0.0773)	0.12 (0.148)	-0.653*** (0.316)
3-yr Lagged Temperature	0.0389 (0.0501)	0.0704 (0.0643)	0.132* (0.0748)	0.11 (0.0759)	0.0106 (0.0675)	-0.0437 (0.0625)	0.0103 (0.0746)	-0.0318 (0.124)	0.022 (0.122)	-0.318 (0.355)
4-yr Lagged Temperature	0.0123 (0.0323)	0.0344 (0.0396)	-0.00904 (0.0557)	-0.0862 (0.057)	-0.00851 (0.0621)	-0.09 (0.0676)	-0.0656 (0.0718)	0.141 (0.0866)	0.229** (0.103)	-0.158 (0.374)
5-yr Lagged Temperature	0.0699*** (0.0308)	0.101* (0.0576)	0.119** (0.0525)	0.0552 (0.0587)	-0.00476 (0.0718)	-0.0405 (0.0978)	-0.095 (0.0652)	0.0288 (0.0559)	0.0542 (0.0791)	-0.288 (0.334)
Controls										
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fixed-effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.420	0.340	0.392	0.439	0.456	0.434	0.439	0.366	0.498	0.449
Obs	372	372	372	372	372	372	372	372	372	372

Control variables: per capita and squared per capita provincial GDP, employment share in agriculture, manufacturing, and services, unemployment rate, electrification ratio, internet penetration, average years of schooling. Fixed-effects variable: province and year.

Standard errors in parentheses

$^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$

1.2 Precipitation

In the case of precipitation, as seen in Table S1.3, there is no statistically significant associations between past values of average monthly precipitation and income inequality indicators of Indonesian provinces. However, looking at the results for income deciles, as seen in Table S1.4, there is an indication that there is associations between past levels of precipitation and decile income shares. Estimates from the lagged model on income deciles show that rising precipitation has negative associations with the income shares of the middle deciles and positive associations for the upper deciles. First-year lag of monthly average precipitation is positively associated with the income share of the 9th decile. Second-year lag show a negative association with the income shares of the 6th and 7th deciles but a positive association with the income share of the 10th decile. While the third-year lag is negatively associated with the income shares of the 5th and 7th deciles. This suggests that precipitation has a longer pathway relative to temperature on affecting income inequality levels and its effects are more felt by the middle deciles. However, it must be noted that the coefficients are small and in terms of economic significance it would require precipitation to change by a large amount for income shares to be affected in a noticeable manner.

Table S1.3 Lagged effect of precipitation on income inequality indicators.

Dependent Variable:	Gini Index	Theil Index	90:10 Ratio
Variable			
1-yr Lagged Precipitation	0.00281	-0.0238	0.0135
	(0.0285)	(0.0701)	(0.0232)
2-yr Lagged Precipitation	-0.0265	0.0479	0.02
	(0.0246)	(0.0707)	(0.0228)
3-yr Lagged Precipitation	-0.0186	0.128	0.0295
	(0.0244)	(0.0763)	(0.0237)
4-yr Lagged Precipitation	0.0156	-0.0124	-0.0141
	(0.0329)	(0.0825)	(0.0209)
5-yr Lagged Precipitation	-0.0365	-0.00299	0.0113
	(0.0224)	(0.0892)	(0.0206)
Controls			
Control variables	Yes	Yes	Yes
Fixed-effects	Yes	Yes	Yes
R-squared	0.470	0.434	0.295
Obs	368	367	367

Control variables: per capita and squared per capita provincial GDP, employment share in agriculture, manufacturing, and services, unemployment rate, electrification ratio, internet penetration, average years of schooling. Fixed-effects variable: province and year.
Standard errors in parentheses
$^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$

Table S1.4 Lagged effect of precipitation on the share of income per decile.

Dependent Variable:	1st Decile	2nd Decile	3rd Decile	4th Decile	5th Decile	6th Decile	7th Decile	8th Decile	9th Decile	10th Decile
Variable										
1-yr Lagged	-0.0025	-0.00267	-0.00491	-0.00705	-0.00633	-0.00276	-0.000309	0.00918	0.0153^{*}	0.00201
Precipitation	(0.00315)	(0.00442)	(0.00456)	(0.00486)	(0.00494)	(0.00508)	(0.00558)	(0.00675)	(0.00864)	(0.0281)
2-yr Lagged	0.00123	0.000183	-0.0053	-0.00627	-0.00973	-0.0114^{**}	-0.0154^{**}	-0.0122	0.00481	0.0542^{*}
Precipitation	(0.00254)	(0.00373)	(0.00488)	(0.00538)	(0.0066)	(0.00525)	(0.00612)	(0.00724)	(0.00778)	(0.0279)
3-yr Lagged	-0.0013	-0.000611	-0.00296	-0.00171	-0.0104^{*}	-0.00681	-0.0121^{**}	-0.00716	-0.00521	0.0483
Precipitation	(0.00384)	(0.00523)	(0.00606)	(0.00676)	(0.00549)	(0.00536)	(0.00542)	(0.00702)	(0.00895)	(0.029)
4-yr Lagged	0.00348	0.00508	0.0028	0.0029	-0.0000304	-0.00609	-0.00275	-0.00717	-0.00874	0.0105
Precipitation	(0.00281)	(0.00403)	(0.00384)	(0.00459)	(0.00546)	(0.00588)	(0.00511)	(0.0059)	(0.00714)	(0.0282)
5-yr Lagged	-0.0000371	0.00138	-0.00218	-0.000321	0.000694	0.00167	0.00636	-0.000473	0.0028	-0.00988
Precipitation	(0.0031)	(0.00466)	(0.00624)	(0.0065)	(0.00614)	(0.00623)	(0.00648)	(0.00797)	(0.00881)	(0.0331)
Controls										
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fixed-effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.450	0.336	0.380	0.436	0.483	0.445	0.449	0.379	0.497	0.462
Obs	367	367	367	367	367	367	367	367	367	367

Control variables: per capita and squared per capita provincial GDP, employment share in agriculture, manufacturing, and services, unemployment rate, electrification ratio, internet penetration, average years of schooling. Fixed-effects variable: province and year.

Standard errors in parentheses

$^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$

1.3 Discussion

These estimates significantly differ from most literature that generally found long-term effects, where the influence of rising temperatures and precipitation persists in the long-term up to more than 10 years after (Chisadza et al., 2023; Castells-Quintana and McDermott, 2023). Other studies also find medium-term impacts, with temperature and precipitation shocks leading to positive effects on the Gini index for 3-4 years after (Hong and Kim, 2024). The estimate for lagged temperature and the Gini index aligns with one study that found the effect of extreme heat persists for one year before dissipating completely (Callahan and Mankin, 2022). But most studies mainly found that rising temperatures and precipitation have a detrimental effect on income inequality measures that persists in the medium to long run, different from the estimates in this study, which found both positive and negative associations between rising temperatures and precipitation towards income inequality measures.

Estimates derived from the lagged model partially confirms that there is a positive association between past values of climate variables and income inequality indicators. Past temperature increases are correlated with higher levels of income inequality one year after the temperature rise. The income decile estimates also suggest that the positive lags for the 3rd, 4th, and 5th year lags may be because of adaptation measures, as higher past temperatures cause low-income deciles to be reactive and adapt as several studies have noted that in Indonesia and other countries these groups adapt by diversifying their crops, labor diversification, altering farming practices, adapting alternate irrigation techniques, and local government may also enact regulations in response to rising climate-related impacts (Rahman et al., 2021; Simpson et al., 2023). The negative lags of the top 10 percent of income earners may result from the delayed impacts, as they have socioeconomic characteristics that partly shield them from climate-related impacts early on. For precipitation, the income decile estimates suggest that these precipitation lags shifted income distribution from the middle decile to the top. Earlier models in the main paper indicate that precipitation has a temporary, short-term effect that reduces income inequality, but this is followed by a later negative impact, as suggested by the estimates of the lagged models shown here. Overall, the mixed signs of the estimates for the income shares can be attributed to the differences in how temperature and precipitation affect the income source of each income decile, the socioeconomic characteristics of each decile, and how those characteristics alter the vulnerability and resilience of each income decile.

References

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