

PFAS and Economic Development in Southeast Asia

WenCheng Hsiao¹, HuiChen Chiang^{*2}, Nguyen Cong Tuan Long³

^{1,2}Associate Professor, Department of Business Administration, Ming Chuan University, Taiwan

³Ming Chuan University, Taipei, Taiwan

ABSTRACT: Per- and polyfluoroalkyl substances (PFAS) are persistent industrial chemicals whose environmental and health risks are increasingly recognized, yet their economic implications in Southeast Asia remain poorly quantified. This study provides an exploratory cross-country assessment of associations between PFAS exposure and three development outcomes: GDP growth, human development, and export growth. Secondary country-level data were analyzed using descriptive statistics, Pearson correlations, multiple linear regression, and income-group mean comparisons. The available analytical samples were small ($N = 7-10$, depending on the model), reflecting substantial regional data limitations. PFAS was moderately negatively associated with GDP growth ($r = -0.521$), but the relationship was not statistically significant ($p = .426$). In the GDP model, PFAS had the largest standardized coefficient ($\beta = -0.478$, $p = .156$), while the overall model was not significant. For human development, the model explained 74.0% of observed variance, but PFAS was not significant ($\beta = .160$, $p = .583$); poverty rate showed the largest negative coefficient ($\beta = -.850$, $p = .085$). PFAS was essentially unrelated to export growth ($r = .042$, $p = .914$), and the export model showed severe overfitting (adjusted $R^2 = -.432$). Accordingly, the study does not establish a statistically robust economic effect of PFAS in Southeast Asia. Rather, it identifies suggestive patterns and, more importantly, a major regional evidence gap. The findings support investment in harmonized PFAS monitoring and larger longitudinal datasets before strong causal or policy claims are made.

KEYWORDS: PFAS; Southeast Asia; environmental economics; GDP growth; human development; exports; cross-country analysis

1. INTRODUCTION

Southeast Asia combines rapid industrialization, export-oriented manufacturing, and growing integration into global supply chains. These same features increase potential exposure to persistent industrial pollutants. Per- and polyfluoroalkyl substances (PFAS), often described as “forever chemicals,” are a large class of synthetic compounds valued for resistance to heat, water, and oil. Their persistence and mobility have raised concerns about contamination of water, soil, food systems, and human populations. Existing PFAS research is dominated by toxicology, epidemiology, and environmental monitoring. Economic research in Southeast Asia has more often examined carbon emissions, air pollution, waste, or climate-related risks. Consequently, the regional economic implications of PFAS remain difficult to quantify. This matters because contamination may affect economies through several channels, including healthcare costs, labor productivity, agricultural and aquaculture losses, remediation liabilities, regulatory compliance, and trade restrictions.

This study asks whether country-level PFAS exposure is empirically associated with three dimensions of development: GDP growth, human development, and export growth. The contribution is intentionally exploratory. Rather than claiming causal identification, the analysis evaluates whether the limited available cross-country evidence is consistent with the hypothesized negative externalities of PFAS and identifies the data constraints that currently prevent stronger inference. The study evaluates three hypotheses:

H1. Higher PFAS exposure is associated with lower GDP growth after accounting for industrial output and foreign investment.

H2. Higher PFAS exposure is associated with weaker human-development outcomes after accounting for NCD mortality and poverty.

H3. Higher PFAS exposure is associated with weaker export growth after accounting for exchange rates, total exports, and ODA for poverty reduction.

2. LITERATURE REVIEW

PFAS are highly persistent, mobile, and bioaccumulative. Major sources include fluorochemical production, metal plating, firefighting foams, landfills, sewage sludge, and wastewater. Human exposure occurs through contaminated water and food, while

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ecological exposure can affect aquatic systems, soil processes, and food chains (C8 Science Panel, 2012; Fenton et al., 2020; Tang et al., 2023).

From an environmental-economics perspective, PFAS pollution can be interpreted as a negative production externality: firms may receive private benefits from PFAS-enabled production while environmental, health, and remediation costs are shifted to households and governments. These costs can reduce social welfare even when measured industrial output rises.

Rapid manufacturing growth, dense urbanization, uneven wastewater infrastructure, and heterogeneous regulatory capacity may increase Southeast Asia's vulnerability to PFAS. Regional evidence documents PFAS occurrence in Asian groundwater, surface water, and coastal water, but systematic country-level monitoring remains uneven (Tang et al., 2023). This measurement gap complicates both regulatory design and economic evaluation.

Three channels motivate the empirical analysis. First, health and remediation costs may reduce productivity and economic growth. Second, environmental exposure may weaken human capital and therefore human-development outcomes. Third, stricter environmental requirements in destination markets may create non-tariff barriers or compliance costs for export-oriented sectors. These mechanisms motivate the three hypotheses but do not imply that simple cross-country associations establish causality.

3. DATA AND METHODS

3.1 Research Design and Data

The study uses secondary country-level data for Southeast Asian economies. Although the broader project assembled indicators for 2015–2024, PFAS availability is effectively cross-sectional for the empirical models; therefore, the reported regressions should be interpreted as exploratory cross-country analyses rather than longitudinal panel estimates. Effective sample sizes vary from 7 to 10 observations because of missing data.

Data sources identified in the source study include the World Bank, IMF, WTO, ASEAN Statistics, UNESCAP, UNEP, and related environmental datasets. Outcomes are GDP growth, Human Development Index (HDI), and export growth. PFAS exposure is the focal explanatory variable. Control variables differ by model and include industrial output, foreign investment, NCD mortality, poverty rate, exchange rate, total exports, and ODA for poverty reduction.

Three multiple linear regression specifications are estimated:

$$GDP\ Growth = \alpha + \beta_1 PFAS + \beta_2 Industrial\ Output + \beta_3 Foreign\ Investment + \varepsilon$$

$$HDI = \alpha + \beta_1 PFAS + \beta_2 NCD\ Mortality + \beta_3 Poverty\ Rate + \varepsilon$$

$$Export\ Growth = \alpha + \beta_1 PFAS + \beta_2 Exchange\ Rate + \beta_3 Total\ Exports + \beta_4 ODA + \varepsilon$$

Pearson correlations are used as bivariate diagnostics. Multiple regression estimates conditional associations, and independent-samples t-tests compare lower-middle-income economies with uppermiddle- and high-income economies. Statistical significance is evaluated at $p < .05$. Given the very small samples and high predictor-to-observation ratios, coefficient estimates and p-values are interpreted cautiously.

4. RESEARCH RESULTS

Table 1 summaries the statistical number for the variables of this research. **Table 1. Descriptive statistics reported in the source analysis.**

Model / variable	N	Mean	SD	Range
H1: GDP growth	10	4.21	2.917	—
H1: PFAS	10	8.96	3.097	—
H1: Industrial output	10	37.57	51.189	—
H1: Foreign investment	10	17.30	13.988	—
H2: HDI	7	0.72	0.080	reported min/max inconsistent in source table
H2: NCD mortality	7	71.18	9.186	53–81
H2: PFAS	7	9.23	3.026	5–15
H2: Poverty rate	7	3.15	2.995	0–7
H3: Export growth	9	3.73	6.392	–8–14
H3: PFAS	9	8.40	3.554	2–15
H3: Exchange rate	9	4910.76	8908.468	1–24165
H3: Total exports	8	307944.37	136639.960	26471–505658

Table 2. Selected Pearson correlations involving PFAS.

Outcome	PFAS correlation (r)	p	Interpretation
GDP growth	–0.521	.426	Moderate negative; not significant
HDI	.675	.096	Positive; not significant

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Export growth	.042	.914	Near zero; not significant
Total exports	-.379	.355	Moderate negative; not significant

From Table 2, it shows that none of the focal PFAS correlations reached conventional statistical significance. The negative GDP–PFAS coefficient is directionally consistent with H1, whereas the positive PFAS–HDI association is contrary to the expected direction. PFAS and export growth were essentially uncorrelated. With N values below 10 in several comparisons, these estimates are highly sensitive to individual country observations.

Table 3. Regression Analysis for this Research

Outcome / predictor	B	β	p
GDP growth: PFAS	–0.690	–.478	.156
GDP growth: Industrial output	.017	.198	.651
GDP growth: Foreign investment	–.038	–.146	.744
HDI: PFAS	.004	.160	.583
HDI: NCD mortality	–.002	–.140	.622
HDI: Poverty rate	–.018	–.850	.085
Export growth: PFAS	.222	.125	.828
Export growth: Exchange rate	.000	.607	.312
Export growth: Total exports	1.038E–5	.211	.699

Table 4. Testing Results

Model	R ²	Adjusted R ²	F	p	Decision
H1: GDP growth	.411	.117	1.462	.312	Not supported
H2: HDI	.740	.610	4.246	.097	PFAS hypothesis not supported
H3: Export growth	.386	–.432	.472	.759	Not supported

For GDP growth, the model explained 41.1% of the observed variance, but the adjusted R² fell to .117 and the model was not statistically significant, $F(3,6) = 1.462$, $p = .312$. PFAS had the largest standardized coefficient ($\beta = -.478$), but its effect was not significant ($p = .156$). H1 is therefore not supported.

For HDI, R² was .740 and adjusted R² was .610; however, the overall model did not reach $p < .05$, $F(3,3) = 4.246$, $p = .097$. Poverty rate had the largest coefficient ($\beta = -.850$, $p = .085$), while PFAS was small and nonsignificant ($\beta = .160$, $p = .583$). Because H2 concerns PFAS, the evidence does not support H2. The original manuscript's description of H2 as “partially supported” is not retained because significance of a control variable does not constitute support for the focal PFAS hypothesis.

For export growth, the model was not significant, $F(4,3) = .472$, $p = .759$, and adjusted R² was negative (–.432), indicating that the specification performs poorly after accounting for model complexity. PFAS was nonsignificant ($\beta = .125$, $p = .828$). H3 is not supported.

On the other hand, the independent-samples t-tests reported in the source analysis found no statistically significant differences between lower-middle-income and upper-middle-/high-income groups for PFAS concentration, GDP growth, industrial output, or foreign investment. Given the group sizes ($n = 6$ and $n = 4$), the comparisons have very low statistical power and should be viewed as descriptive.

5. CONCLUSION

The empirical results do not provide statistically robust evidence that PFAS exposure predicts GDP growth, HDI, or export growth across the countries in the available sample. This conclusion is narrower than the theoretical argument that PFAS can impose economic costs. The absence of statistical significance in these models cannot distinguish between a genuinely small regional effect and an effect obscured by measurement error, omitted variables, cross-country heterogeneity, and very low power.

The GDP results are the most suggestive: PFAS is negatively correlated with growth and has the largest standardized coefficient in the multivariate model. However, neither estimate is significant. The HDI results further illustrate the danger of causal interpretation: PFAS is positively correlated with HDI, likely reflecting cross-country structure or confounding rather than a beneficial PFAS effect. More industrialized or higher-income economies may simultaneously exhibit higher measured PFAS exposure and higher human development.

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The export model provides little evidence of a direct relationship. Its negative adjusted R^2 and four predictors with only a handful of complete observations make inference especially fragile. Future work should therefore prioritize data construction and identification strategy over adding further predictors to the present specification.

The findings do not justify claims that PFAS has already been shown to reduce Southeast Asian GDP or exports. They do, however, highlight a policy-relevant information deficit. Harmonized monitoring of PFAS in water, soil, food, industrial discharge, and human biomonitoring would make subsequent economic evaluation substantially more credible. Regional coordination could also improve comparability of definitions, reporting thresholds, and exposure measures.

This exploratory study evaluates whether PFAS exposure is associated with economic growth, human development, and export performance in Southeast Asia. Across correlation and regression analyses, the focal PFAS effects are not statistically significant. H1 and H3 are not supported, and the PFAS component of H2 is also not supported. The strongest pattern is a negative, but nonsignificant, PFAS coefficient in the GDP model.

The principal contribution is therefore not evidence of a confirmed macroeconomic PFAS effect, but evidence of how difficult such an effect is to estimate with current regional data. A publishable research agenda should move from small cross-sectional comparisons toward harmonized longitudinal exposure data, stronger measurement, and designs that can support causal inference. Until then, policy arguments should be grounded primarily in established environmental and health evidence rather than overstating the economic estimates reported here.

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