# Co-Benefits of Bridges Construction in the Mekong Delta

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## ABSTRACT

This study analyzes the impact of bridge construction on air pollution in the Mekong Delta. This region relies on ferry systems to cross dense river networks. Millions of dollars have been invested in the region to build roads and bridges, replacing the existing ferry systems. As transportation is the biggest source of air pollution in the region and traffic volume is increasing yearly, the effect of these bridges on air pollution is unknown. Using remote sensing satellite-based data, OMI for $\mathrm{NO_2}$ and MODIS for Aerosol, and econometrics models, the operation of the bridges estimates a decrease in $\mathrm{NO_2}$ by $7.269 \times 10^{13}$ molecules/$\mathrm{cm}^3$, controlling for nearby powerplants, temperature, humidity, El Niño, and monthly fluctuations. Wider bridge width and larger bridge area estimates greater decrease in $\mathrm{NO_2}$ by $0.460 \times 10^{13}$ molecules/$\mathrm{cm}^3$ and $0.0002 \times 10^{13}$ molecules/$\mathrm{cm}^3$ with an additional meter of bridge width and meter squared of bridge area respectively. In contrast, there is little to no change in particulate matter. This effect is a result of the closure of ferry services, as ferries used bunker fuels, which emit more nitrogen oxides than gasolines of road vehicles. However, the replacement of ferries with bridges is not sustainable, as many discontinued ferry services are returning back to accommodate short distance commuting needs and rising traffic congestion at newly built bridges.

## KEYWORDS

air pollution, nitrogen dioxide, aerosol, remote sensing, transportation investment

# INTRODUCTION

Humans have always lived in proximity to rivers and deltas, as these regions are one of the most fertile regions for agriculture and a central hub for trading and transportation of goods (Edmonds et al. 2017). River deltas remain one of the most densely populated regions today, with deltas covering only 0.56% of total earth area, but containing approximately 4.1% of the world population (Edmonds et al. 2017). As major agricultural regions, these deltas are also significant to national and regional economies, with the Mekong Delta in the southernmost region of Vietnam as no exception. As the third-largest delta in the world, it is one of the most densely populated and is the most important agricultural region in Vietnam, contributing to 90% of Vietnam's total rice export and 50% of rice for domestic consumption ("Đồng..." 2017). The delta also has the highest traffic flow in the country with an estimated 213,000 tonnes of freight and 74,000 people traveling between the Mekong Delta and Ho Chi Minh City each day in 2008 (Japan International Cooperation Agency et al. 2010). However, its dense river networks create a challenging landscape for transportation connectivity with the rest of the country.

The Vietnamese government places a great emphasis on building a centralized transportation system across the country, to increase the efficiency of transportation, minimizing travel time and distance (Đoàn Đại biểu Quốc hội tỉnh Trà Vinh 2019, "Đầu…" 2019). However, transportation systems in the Mekong Delta are made of crisscrossed networks of land and waterways. Waterway transportation has relied on ferries to carry vehicles, people, and goods across rivers. However, the increase in traffic of private cars and freights exceeds current roads and ferries capacity, leading to serious traffic congestion and road deterioration (Japan International Cooperation Agency 2016). In the Mekong Delta, bridges have been built to replace existing waterways and integrate roadway transportation systems (Nguyen 2020). Similarly, rural infrastructural projects have been shown to generate positive socio-economic impacts with stronger development of the local market and greater mobility for rural regions (Mu and Van de Walle 2011).

The transportation sector is a significant contributor to air pollution in Vietnam. Major cities in Vietnam have become increasingly polluted, exceeding national and WHO's ambient air standards (Nguyen and Blume 2018). Other regions are on track to become as polluted (Nguyen and Blume 2018). A Study in Can Tho City, in the Mekong Delta found transportation contributes to 48% of total $NO_x$, 75% of total CO, and 50% of total $SO_2$ in 2015 (Ho et al. 2018). These air pollutants contribute to significant long-term health consequences (Kim et al. 2020). As transportation also contributes to greenhouse gases emissions, there are also long term climate implications. Although current investments in transportation focus primarily on potential economic growth and development, potential impact on local air quality must also be considered in transportation planning. It is uncertain if air pollution increases due to directed traffic to the bridge or air pollution decreases due less traffic congestion and waiting time at ferry stations.

In this paper, I analyze the impact of bridges on two air pollutants $NO_2$ and Aerosol in the Mekong Delta, using remote sensing data and econometrics modeling. My main research question is if there are any changes in air pollution after the bridge is in operation.

## BACKGROUND

### Air Pollution in Vietnam

Poor air quality in Vietnam has been studied to impact human health, leading to 60,000 deaths each year and increased hospitalization due to cardiovascular diseases (Nguyen et al. 2020, Tran 2018). Traffic congestion in Vietnam leads to higher air pollution concentrations (Tang et al. 2020). As the majority of the population drive motorbikes and are exposed to ambient air pollution, roadside air quality is an important public health concern. Although the majority of ambient air pollutants like $\mathrm{NO_2}$, CO, $\mathrm{SO_2}$, come from transportation, other significant annual sources include factories, power plants, and the practice of burning of rice straw in rice cultivation (Ho et al. 2018, Ministry of Natural Resources and Environment 2014).

### Remote Sensing Air Pollution

Vietnam's air quality monitoring is still relatively poor. The only air quality monitoring sensors are run independently by the U.S consulates in the two biggest cities in Vietnam, Ho Chi Minh City and Ha Noi. Because the region does not have air quality sensors, I used remote sensing data instead. Studies have shown significant correlation between satellite estimates and ground air quality data (Lalitaporn et al. 2020, Nguyen et al. 2015). Growing bodies of air pollution research in Vietnam and other developing countries have successfully used remote sensing data (Jayachandran 2009, Kim et al. 2020, Le et al. 2014). For example, particulate matter is estimated from satellite measurements of aerosol optical index (Nguyen et al. 2015).

## Transportation Infrastructure Investments

Transportation infrastructure is critical to economic growth and development, providing easy access to markets and ensuring economic opportunities and mobility for all. In China, proximity to transportation networks has a positive effect on per capita GDP (Banerjee et al. 2012). In Vietnam, rural roads investments led to a significant positive impact on local market development (Mu and Van de Walle 2011). Transportation networks also moved people across different sectors, primarily with people moving out of agriculture into wage labor (Asher and Novosad 2020). Contrary to previous results, a study in India found that rural roads do not lead to significant changes in agricultural outcomes and incomes (Asher and Novosad 2020). Environmental impact analysis of transportation infrastructure is often only limited to environmental damages during construction, not its potential environmental impact on road usage in the future.

Although the intention of infrastructure investments is not traditionally for the environment, transportation planning should consider sustainability, considering transportation is the largest contributor to greenhouse gas emissions and air pollutants in Vietnam (Ho et al. 2018). For road transport, recommendations include better traffic management and routing systems, to reduce travel times and traffic congestion, while accommodating growing demands for transport (Intergovernmental Panel on Climate Chanel 2014). Past impact analysis of bridges in Vietnam only include travel times and economic mobility, but do not include potential analysis for air pollution reduction due to changes in transportation networks (Adam Smith International 2017, , Ingérosec Corporation 2014, The World Bank Group 2014).

## The Mekong Delta

The Mekong Delta in Vietnam is approximately 40,000 km2, shaped by the Mekong River, splitting into two major river branches, the Tien River and Hau river, which further split into 9 branches, emptying into the Pacific Ocean. It is home to 18 million people, living in 12 provinces and Can Tho city. The majority of the population works in agriculture. Past transportation systems consist of a mix of roadways and waterways, with ferries to transport goods and people across the rivers.

As of 2019, there are 8 bridges that cross over Mekong river branches. The first bridge to cross the Mekong in Vietnam was built in 2000. Since then, more bridges have been built to cross over all river branches (Table 1). The construction of these bridges is funded by either loans from development agencies or government fundings, which are later paid back by tolls.

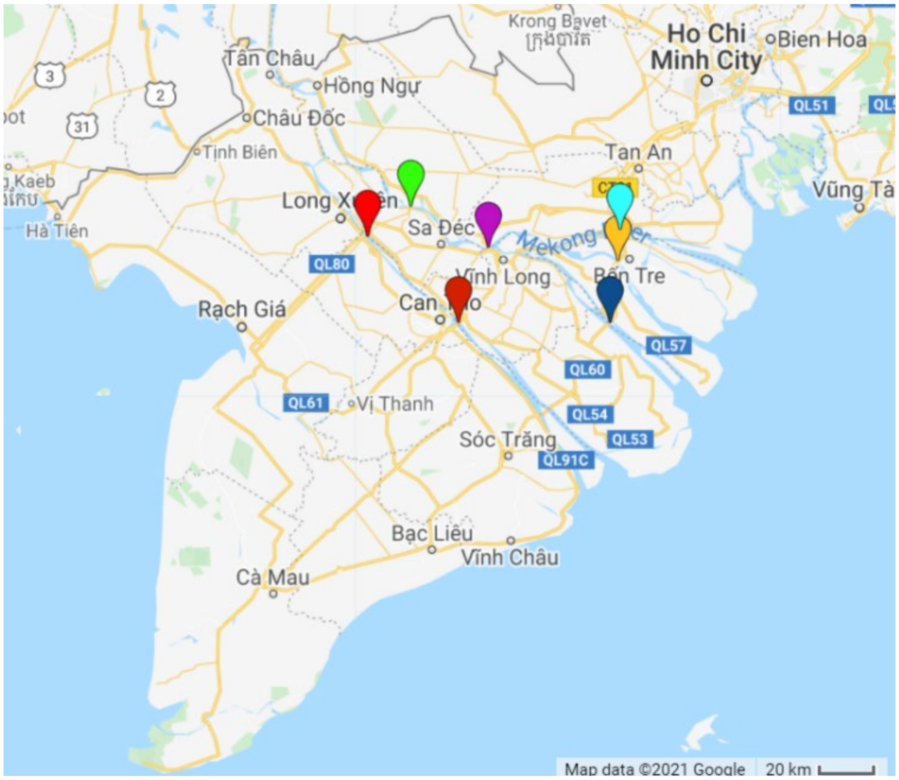

**Figure 1. Major Bridges in the Mekong Delta.** Bridges represented by pinpoints, mapped with Google Earth Engine.

# METHODS

## Data Collection

I compiled a list of bridges in the Mekong Delta that crosses through 7 major river branches, the year of operation, width, length, and geographical coordinates (Table 1). For each air pollutant, $NO_2$and Aerosol, I chose satellite datasets that range from 2007 to 2019, with the highest possible resolution, at most 0.125 arc degree (roughly 12 km). I chose the QA4ECV project for $NO_2$ air column density data (Boersma et al. 2017). For Aerosol, a proxy for particulate matter, I selected MODIS Terra and Aqua's Aerosol Optical Depth data measured at 0.47 µm and 0.55 0.47 µm (Lyapustin et al. 2018).

I, then, uploaded these datasets to Google Earth Engine and calculated the monthly means of each of these air pollutants. For $NO_2$, since the resolution is 0.125 arc degree, I extracted value from the pixel where the bridge is located at. For Aerosol, the resolution is roughly 1km, less than the length of the bridge, so I calculate the mean value over the area of the bridge. To better compare with $NO_2$, I also rescaled the AOD dataset to $NO_2$ resolution and extracted the bridge pixel value, similar to the method I used to extract $NO_2$ pixel value.

**Table 1. Mekong Delta Bridge Information**

| Bridge | River | Provinces | Year | Width (m) | Length (m) |
|---|---|---|---|---|---|
| My Thuan | Tien | Tien Giang, Vinh Long | 2000 | 23.66 m | 1535.2 m |
| Rach Mieu | Tien | Tien Giang, Ben Tre | 2009 | 15 m | 2860 m |
| Ham Luong | Ham Luong | Ben Tre | 2010 | 16 m | 1277.2m |
| Can Tho | Hau | Vinh Long, Can Tho | 2010 | 23.1 m | 2750 m |
| Co Chien | Co Chien | Ben Tre, Tra Vinh | 2015 | 16 m | 1590 m |
| Cao Lanh | Tien | Dong Thap | 2018 | 24.5 m | 2010 m |
| Vam Cong | Hau | Dong Thap, Can Tho | 2019 | 24.5 m | 2970 m |

## Data Analysis

To estimate the impact of the bridge on air pollutants, I used econometrics frameworks and ran six regression models with different combinations of predictive variables and levels of complexity for each pollutant. Difference-in-differences econometrics models have been used to study the impact of transportation infrastructure, like greater deforestation in India (Asher et al 2020). The simple base model 1 includes a bridge dummy variable that is equal to 1 when the bridge is in operation and 0 otherwise, year variable, and months and locations fixed effects.

Coefficients of Beta 1 can be interpreted as the impact of bridges on air pollution. For model 3 and 5, I modified the bridge dummy variable to include information about bridge width and area when the bridge is operating.

$$\text{Pollutants} = \beta_0 + \beta_1\text{Bridge} + \beta_2\text{Year} + \text{Month} + \text{Location}\ (1)$$

$$\text{Pollutants} = \beta_0 + \beta_1\text{Bridge Width} + \beta_2\text{Year} + \text{Month} + \text{Location}\ (2)$$

$$\text{Pollutants} = \beta_0 + \beta_1\text{Bridge Area} + \beta_2\text{Year} + \text{Month} + \text{Location}\ (3)$$

$$\text{Pollutants} = \beta_0 + \beta_1\text{Bridge} + \beta_2\text{Year} + \beta_3\text{Power Plants} + \beta_4\text{El Nino} + \beta_5\text{Humidity} + \beta_6\text{Temperature} + \text{Month} + \text{Location}\ (4)$$

$$\text{Pollutants} = \beta_0 + \beta_1\text{Bridge Width} + \beta_2\text{Year} + \beta_3\text{Power Plants} + \beta_4\text{El Nino} + \beta_5\text{Humidity} + \beta_6\text{Temperature} + \text{Month} + \text{Location}\ (5)$$

$$\text{Pollutants} = \beta_0 + \beta_1\text{Bridge Area} + \beta_2\text{Year} + \beta_3\text{Power Plants} + \beta_4\text{El Nino} + \beta_5\text{Humidity} + \beta_6\text{Temperature} + \text{Month} + \text{Location}\ (6)$$

With the longer models 2, 4, and 6, I added additional control variables. The power plants variable documents the increase in the number of power plants in the region, as power plants are significant emission sources (Ho et al. 2018). El Niño is a dummy variable that is set to 1 when the weather event El Niño is happening, and 0 otherwise according to the Oceanic Niño Index (ONI) (NOAA Climate Prediction Center). I collected additional weather controls, region monthly mean temperature and humidity from the General Statistics Office, as temperature and humidity are important determinants of air quality (Hien et al. 2002).

## RESULTS

### Nitrogen Dioxide

#### *Bridge Pixel*

The operation of the bridge estimates a decrease in monthly mean tropospheric $\mathrm{NO_2}$ in areas containing the bridge across all the models (Table 1). The bridge effect is not significant in model 1, but becomes significant at 5% in model 2, estimating a decrease by $7.269 \times 10^{13}$ molecules/cm$^3$, after controlling for power plants and weather. Bridge width and area are negative at 5% and 1% respectively. An additional meter of bridge width estimates a decrease by $0.460 \times 10^{13}$ molecules/cm$^3$. An additional meter squared estimates a decrease by $0.0002 \times 10^{13}$ molecules/cm$^3$.

**Table 1. Regression results on monthly mean $NO_2$ bridge pixel.** Notes: *p<0.10, **p<0.05, ***<p0.01

| | *Dependent variable: $NO_2$* | | | | | |
|---|---|---|---|---|---|---|
| | Bridge Short (1) | Bridge Full (2) | Bridge Width Short (3) | Bridge Width Full (4) | Bridge Area Short (5) | Bridge Area Full (6) |
| Bridge | -5.845 | $-7.269^{**}$ | | | | |
| | (3.630) | (3.620) | | | | |
| Bridge Width | | | $-0.403^{**}$ | $-0.460^{**}$ | | |
| | | | (0.186) | (0.185) | | |
| Bridge Area | | | | | $-0.0002^{**}$ | $-0.0002^{***}$ |
| | | | | | (0.0001) | (0.0001) |
| Year | $2.226^{***}$ | 0.629 | $2.329^{***}$ | 0.727 | $2.298^{***}$ | 0.696 |
| | (0.346) | (0.734) | (0.341) | (0.736) | (0.317) | (0.730) |
| Power Plants | | $7.119^{*}$ | | $7.052^{*}$ | | $6.870^{*}$ |
| | | (3.724) | | (3.712) | | (3.704) |
| El Niño | | $-7.425^{***}$ | | $-7.485^{***}$ | | $-7.399^{***}$ |
| | | (2.510) | | (2.508) | | (2.505) |
| Humidity | | -0.942 | | -0.934 | | -0.926 |
| | | (0.593) | | (0.592) | | (0.592) |
| Temperature | | $6.446^{***}$ | | $6.436^{***}$ | | $6.383^{***}$ |
| | | (2.478) | | (2.475) | | (2.473) |
| Month | Yes | Yes | Yes | Yes | Yes | Yes |
| Location | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 1,092 | 1,092 | 1,092 | 1,092 | 1,092 | 1,092 |
| $R^2$ | 0.276 | 0.292 | 0.278 | 0.293 | 0.279 | 0.294 |
| Adjusted $R^2$ | 0.263 | 0.276 | 0.265 | 0.278 | 0.266 | 0.279 |

The year variable is positively significant in the short model, but not the long model. Operation of power plants estimates a significant increase in monthly mean tropospheric $NO_2$. El Niño has a significant negative correlation with $NO_2$. Temperature has a significant positive correlation with $NO_2$, while humidity is not correlated with $NO_2$. Model 6 with bridge area, power plants, and weather controls has the best fit, with an adjusted R-squared value of 0.279.

### *Neighborhood Pixels*

From a 3x3 neighborhood around the bridge pixel, I selected the two neighborhood pixels with the highest monthly mean, averaged them with and without the bridge pixel, repeated the six regression models and found that the operation of the bridge is not statistically significant in neighboring pixels (Table 2). With the addition of the bridge pixel, bridge width and bridge area estimate a decrease in $NO_2$ at 5% significance level in the bridge and neighboring regions.

**Table 2. Regression results on monthly mean $NO_2$ neighborhood pixels.** Notes: *p<0.10, **p<0.05, ***<p0.01

| | *Dependent variable:* | | | | | |
|---|---|---|---|---|---|---|
| | Neighborhood and Bridge (1) | Neighborhood (2) | Neighborhood and Bridge (3) | Neighborhood (4) | Neighborhood and Bridge (5) | Neighborhood (6) |
| Bridge | -5.439 | -4.524 | | | | |
| | (3.487) | (3.683) | | | | |
| Bridge Width | | | $-0.359^{**}$ | -0.308 | | |
| | | | (0.178) | (0.188) | | |
| Bridge Area | | | | | $-0.0002^{**}$ | $-0.0002^{*}$ |
| | | | | | (0.0001) | (0.0001) |
| Year | 0.764 | 0.832 | 0.850 | 0.912 | 0.839 | 0.910 |
| | (0.708) | (0.747) | (0.709) | (0.749) | (0.704) | (0.744) |
| Power Plants | 5.687 | 4.971 | 5.658 | 4.961 | 5.533 | 4.865 |
| | (3.587) | (3.789) | (3.577) | (3.778) | (3.569) | (3.771) |
| El Niño | $-7.840^{***}$ | $-8.048^{***}$ | $-7.892^{***}$ | $-8.096^{***}$ | $-7.829^{***}$ | $-8.045^{***}$ |
| | (2.418) | (2.554) | (2.417) | (2.553) | (2.414) | (2.551) |
| Humidity | $-1.119^{*}$ | $-1.208^{**}$ | $-1.114^{*}$ | $-1.204^{**}$ | $-1.108^{*}$ | $-1.198^{**}$ |
| | (0.571) | (0.604) | (0.571) | (0.603) | (0.571) | (0.603) |
| Temperature | $8.603^{***}$ | $9.681^{***}$ | $8.598^{***}$ | $9.679^{***}$ | $8.558^{***}$ | $9.645^{***}$ |
| | (2.387) | (2.521) | (2.385) | (2.519) | (2.383) | (2.518) |
| Month | Yes | Yes | Yes | Yes | Yes | Yes |
| Location | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 1,092 | 1,092 | 1,092 | 1,092 | 1,092 | 1,092 |
| $R^2$ | 0.342 | 0.344 | 0.343 | 0.344 | 0.344 | 0.345 |
| Adjusted $R^2$ | 0.328 | 0.329 | 0.329 | 0.330 | 0.330 | 0.331 |

## Aerosol

For both AOD at 0.47 µm and at 0.55 µm, the operation of the bridge does not have a significant effect on aerosol across any of the models (Table 3 and Table 4). With AOD rescaled to $NO_2$ resolution, the operation of the bridge has an even weaker effect (Table 5). The year variable is positively correlated with AOD with varying significance between different models. El Niño is not correlated with monthly mean AOD. Humidity and temperature are negatively correlated with AOD at 1% significance level. The best model is the full bridge width model with the highest adjusted R-squared.

**Table 3. Regression results on monthly mean AOD at 0.47 micrometer.** Notes: *p<0.10, **p<0.05, ***<p0.01

| | *Dependent variable:* | | | | | |
|---|---|---|---|---|---|---|
| | Bridge Short (1) | Bridge Full (2) | Bridge Width Short (3) | Bridge Width Full (4) | Bridge Area Short (5) | Bridge Area Full (6) |
| Bridge | 20.046 | 22.931 | | | | |
| | (15.405) | (15.142) | | | | |
| Bridge Width | | | 1.225 | $1.349^{*}$ | | |
| | | | (0.788) | (0.774) | | |
| Bridge Area | | | | | 0.0004 | 0.0004 |
| | | | | | (0.0003) | (0.0003) |
| Year | 1.851 | $3.039^{*}$ | 1.668 | $2.872^{*}$ | 2.145 | $3.426^{**}$ |
| | (1.483) | (1.638) | (1.463) | (1.627) | (1.362) | (1.542) |
| El Niño | | 12.986 | | 13.132 | | 12.678 |
| | | (10.441) | | (10.438) | | (10.436) |
| Humidity | | $-9.922^{***}$ | | $-9.948^{***}$ | | $-9.944^{***}$ |
| | | (2.487) | | (2.486) | | (2.488) |
| Temperature | | $-59.369^{***}$ | | $-59.276^{***}$ | | $-58.996^{***}$ |
| | | (10.175) | | (10.168) | | (10.171) |
| Month | Yes | Yes | Yes | Yes | Yes | Yes |
| Location | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 1,018 | 1,018 | 1,018 | 1,018 | 1,018 | 1,018 |
| $R^2$ | 0.189 | 0.221 | 0.189 | 0.221 | 0.189 | 0.221 |
| Adjusted $R^2$ | 0.173 | 0.204 | 0.174 | 0.204 | 0.173 | 0.203 |

**Table 4. Regression results on monthly mean AOD at 0.55 micrometer.** Notes: *p<0.10, **p<0.05, ***<p0.01

| | *Dependent variable:* | | | | | |
|---|---|---|---|---|---|---|
| | Bridge Short (1) | Bridge Full (2) | Bridge Width Short (3) | Bridge Width Full (4) | Bridge Area Short (5) | Bridge Area Full (6) |
| Bridge | 14.309 | 16.433 | | | | |
| | (11.252) | (11.060) | | | | |
| Bridge Width | | | 0.875 | 0.966$^{*}$ | | |
| | | | (0.575) | (0.566) | | |
| Bridge Area | | | | | 0.0003 | 0.0003 |
| | | | | | (0.0002) | (0.0002) |
| Year | 1.360 | 2.218$^{*}$ | 1.228 | 2.099$^{*}$ | 1.564 | 2.493$^{**}$ |
| | (1.083) | (1.197) | (1.068) | (1.188) | (0.995) | (1.126) |
| El Niño | | 9.770 | | 9.874 | | 9.551 |
| | | (7.626) | | (7.624) | | (7.622) |
| Humidity | | -7.231$^{***}$ | | -7.250$^{***}$ | | -7.247$^{***}$ |
| | | (1.817) | | (1.816) | | (1.817) |
| Temperature | | -43.320$^{***}$ | | -43.253$^{***}$ | | -43.053$^{***}$ |
| | | (7.432) | | (7.427) | | (7.429) |
| Month | Yes | Yes | Yes | Yes | Yes | Yes |
| Location | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 1,018 | 1,018 | 1,018 | 1,018 | 1,018 | 1,018 |
| R$^2$ | 0.188 | 0.220 | 0.188 | 0.220 | 0.188 | 0.219 |
| Adjusted R$^2$ | 0.172 | 0.203 | 0.173 | 0.203 | 0.172 | 0.202 |

**Table 5. Regression results on monthly mean AOD at 0.47 micron rescaled at $NO_2$ resolution.** Notes: *p<0.10, **p<0.05, ***<p0.01

| | *Dependent variable:* | | | | | |
|---|---|---|---|---|---|---|
| | Bridge Short (1) | Bridge Full (2) | Bridge Width Short (3) | Bridge Width Full (4) | Bridge Area Short (5) | Bridge Area Full (6) |
| Bridge | 6.117 | 7.934 | | | | |
| | (8.997) | (8.664) | | | | |
| Bridge Width | | | 0.417 | 0.484 | | |
| | | | (0.461) | (0.444) | | |
| Bridge Area | | | | | 0.0002 | 0.0002 |
| | | | | | (0.0002) | (0.0002) |
| Year | $2.712^{***}$ | $4.480^{***}$ | $2.610^{***}$ | $4.405^{***}$ | $2.725^{***}$ | $4.563^{***}$ |
| | (0.858) | (0.920) | (0.847) | (0.914) | (0.788) | (0.864) |
| El Niño | | 2.934 | | 2.983 | | 2.845 |
| | | (6.002) | | (6.001) | | (5.998) |
| Humidity | | $-7.024^{***}$ | | $-7.032^{***}$ | | $-7.037^{***}$ |
| | | (1.425) | | (1.424) | | (1.424) |
| Temperature | | $-53.599^{***}$ | | $-53.577^{***}$ | | $-53.490^{***}$ |
| | | (5.910) | | (5.908) | | (5.907) |
| Month | Yes | Yes | Yes | Yes | Yes | Yes |
| Location | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 1,092 | 1,092 | 1,092 | 1,092 | 1,092 | 1,092 |
| $R^2$ | 0.282 | 0.338 | 0.282 | 0.338 | 0.282 | 0.338 |
| Adjusted $R^2$ | 0.269 | 0.324 | 0.269 | 0.324 | 0.269 | 0.324 |

# DISCUSSION

The operation of the bridge estimates a decrease in ambient nitrogen dioxide concentration, due to the replacement of the ferry systems, highlighting the significance of local air pollution around ferry stations. However, this effect is not observed for aerosol. For aerosols, the operation of the bridge estimates a non-significant increase in ambient aerosol. Other factors like power plants are positively correlated with air pollution, consistent with regional emission inventory. The difference in $NO_2$ and aerosol is due to the ferry used marine bunker fuel which emits significantly more nitrogen dioxide than road vehicles gasoline's emissions. As the region still relies on ferries, additional air quality regulation should be considered for ferry engines and fuels.

## Nitrogen Dioxide

At the bridge pixel level, the operation of the bridge estimates a significant decrease in ambient nitrogen dioxide concentration at 5% significance level. The decrease becomes more significant as the bridge is wider and larger at 1% significance level. This effect is not observed for neighboring pixels. Therefore, the decrease is likely not due to volume of vehicles, but closure of the ferry system, when the bridge is in operation. Since ferries are fuel intensive and high concentrations of air pollution have been found near ports and ferries stations, the decrease in nitrogen dioxide could be attributed to the closing of ferry stations (Onat et al. 2019).

The power plants variable is positive and significant, consistent with literature documenting sources of local air pollution in the region (Ho et al. 2018, Huy et al. 2016). Weather controls, like El Niño and temperature, show up as significant in the model, while humidity is not significant.

## Aerosol

The operation of the bridge was not significant for ambient aerosol, a proxy for particulate matter. Weather controls, like humidity and temperature, show up as significant in the model, while El Niño is not significant. This result is different from the results for nitrogen dioxide. A possible explanation is that transportation accounts for a small percentage of total suspended particulates, according to the emission inventory of Can Tho City (Ho et. al. 2019). Another explanation is the difference in fuel and engine of ferries and road vehicles. Bunker marine fuels used by ferries and marine vehicles emit more nitrogen oxides than gasolines of road vehicles (WestStart-CALSTART 2001). A Bay Area study modeled and found that the expansion of the local ferry services increased nitrogen oxides, while reducing other air pollutants like particulate matter, despite using cleaner engines and running at full capacity (Farrell et. al. 2003). The substitution between ferries and road vehicles depends on fuel and engine pollution profile.

## Modeling Approach and Limitations

My modeling approach simplified the operation of the bridge to dummy variables of 0 and 1, but traffic volume differs between each bridge and changes daily and annually. The model does not consider air pollution trends before or after the bridge is built. The difference-in-difference methodology rests on the assumption that the timing of when the bridge is built is random, thus the old bridge can be used as a control for the newly-built bridge. However, the selection of where to build bridges is endogenous within the model, as certain transportation routes are prioritized to be built sooner due to economic importance or geographical feasibility.

Remote sensing also has many limitations. Satellite-based estimates contain instruments' measurement errors and cloudy weather conditions (Lorente et al. 2018, Ma et al. 2019, Nguyen et al. 2015). Additionally, MODIS captures only a snapshot of the region's air column at 10:30 AM and 1:30 PM, which is usually not peak traffic hour. On the ground air quality sensor will better reflect local air quality hourly. The diffusion of air pollutants is also dependent on meteorological factors like wind speed and directions which are not controlled for in this study (Ho et al. 2018). The power plant variable is just the number of power plants in the region, without controlling for the proximity of each bridge or pixel to the power plants. Other economic and human activities like rice cultivation and factories are not included in the model due to lack of data, but these activities are important contributors to local air pollution (Ho et al. 2018). Future research can capture traffic and air quality conditions on the ground of each bridge.

## Implications

There exists a trade off between nitrogen dioxide and other air pollutants when substituting between road vehicles and ferry systems. Additional fuel regulation is potentially needed to reduce air pollution in general (Farrell et al. 2003). As the region still plans to build more bridges, the substitution effect between ferries and bridges needs to be better understood. Even though these bridges are intended to accommodate higher traffic flow, many are already at full capacity, leading to discontinued ferry services returning to divert traffic from bridges (Trưởng 2021). Many local residents also demanded ferries to return because they are a convenient and affordable public transportation system for short distance commuters, students, and low income residents (Thông tấn xã Việt Nam 2019). The reduction of nitrogen dioxide from the closure of ferry services is eliminated as ferries returned.

Transportation system in the Mekong Delta is rapidly changing, as it grows economically. However, the return of the ferry due to newly built bridges at full capacity shows that bridge constructions are not sufficient to meet the rising demand for transportation in the region. Future investment in transportation infrastructure should also focus on public transportation to decrease reliance on personal vehicles and potentially reduce air pollution.

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