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The long-term causal effect of U.S. bombing missions on economic development: Evidence from the Ho Chi Minh Trail and Xieng Khouang Province in Lao P.D.R.

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ABSTRACT

This study investigates the long-term causal effect of heavy U.S. bombing missions during the Vietnam War on later economic development in Lao P.D.R. The empirical strategy relies on an instrumental variables approach. We exploit the distance between the centroid of village-level administrative boundaries and heavily bombed targets—the Ho Chi Minh Trail in the case of southern Laos and Xieng Khouang province in the case of northern Laos—as an instrument for the intensity of U.S. bombing missions. We use the three rounds of average nightlight strength data (1992, 2005, and 2013), and two rounds of population density data (1990 and 2005) as the outcome variables. The estimation results show no robust effect of U.S. bombing missions on economic development in the long term. Meanwhile, we find that the results do not necessarily support the conditional convergence hypothesis within a country, although this result could be Lao-specific.

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1. INTRODUCTION

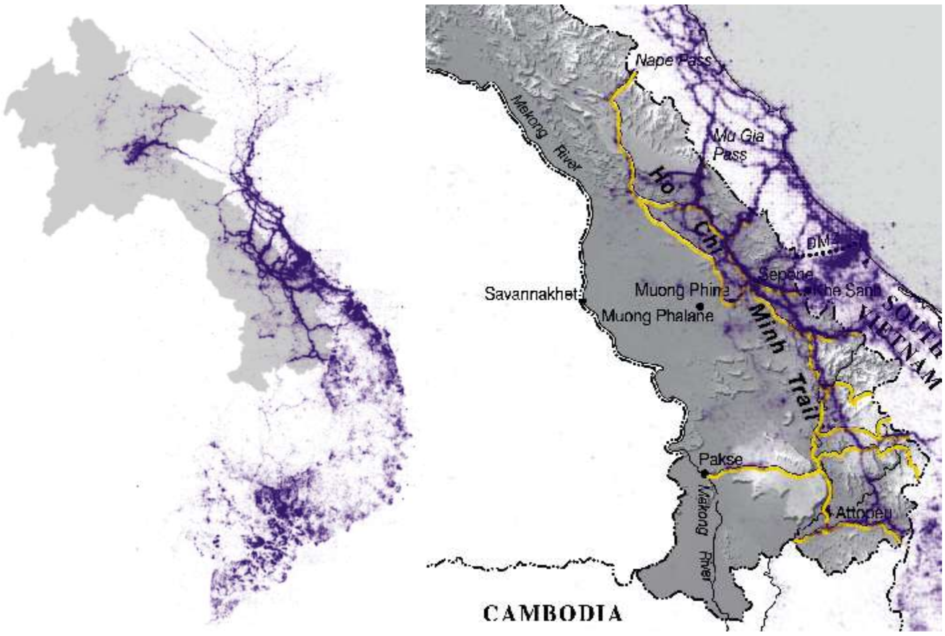
As the first American President in service, U.S. President Barack Obama acknowledged America's secret war in Laos on September 6th, 2016 during a visit for a summit of Southeast Asian countries. At the time of the Vietnam War, the U.S. did not officially acknowledge its CIA operations against communist North Vietnam. Laos is one of the most intensely bombed countries per capita in history; during the midst of the Vietnam War, 1964–1973, more than two million tons of ordnance, equivalent to 580,000 bombs, was dropped on Laos, exceeding the amounts used in Germany and Japan in World War II combined (Kurlanzick, 2017; NRA, 2015; The White House, 2016; Woodruff and Yiu, 2016). Compared to the importance of this historical fact, this tragedy in Laos may not be well known globally. However, the hideous results tell the truth; more than 50,000 people have been killed or injured since 1964, including victims of unexploded bombs remaining in Laos after the war (NRA, 2015). War provokes multiple catastrophic losses, including human casualties, and mass destruction of infrastructures and ecosystems.

This study first asks if the bombing missions during the secret war affected later economic growth in Laos. Three theories have attempted to explain the relationship between external shocks, including bombings during wars, and subsequent long-term economic growth: the neoclassical growth, creative destruction, and conflict trap theories. First, the traditional neoclassical growth theory argues that the economic growth of an affected area converges to its steady state in the long run (Barro, 2015; Barro and Sala-i-Martin, 1992a; Baumol, 1986; Blattman and Miguel, 2010). In other words, traditional neoclassical growth theory predicts that the partial destruction of war leads to a loss of both physical and human capital, but does not affect the rate of technological progress. That is, the economy experiences accumulation of capital in the affected areas (a short-term increase in investment results in a higher growth rate) and converges back to balanced growth steady states. Some empirical research supports the validity of the neoclassical growth model (Brakman et al., 2004; Cavallo et al., 2013; Davis and Weinstein, 2002; Miguel and Roland, 2011; Organski and Kugler, 1977, 1980; Przeworski et al., 2000). Second, Schumpeter's creative destruction theory regards external shocks as an opportunity for greater growth than in the precondition (Aghion and Howitt, 1992). This is because destruction may provide the opportunity for the affected area to introduce quality physical capital, leading to greater technological progress; this is supported by the empirical findings of Hornbeck and Keniston (2017), among others. Third, the conflict trap theory, induced by the concept of the poverty trap developed by Azariadis and Drazen (1990) and widely used by the World Bank (2003) and Sachs (2005), predicts the long run negative effect of external shocks relative to the ex-ante condition, which is consistent with the empirical result of Abadie and Gardeazabal (2003). While there is some empirical support for these three different theoretical explanations of the post-shock growth trajectory of an affected economy, there is no unified answer. Thus, the question of whether external shocks affect long-run economic growth is ultimately an empirical one (Cavallo et al., 2013).

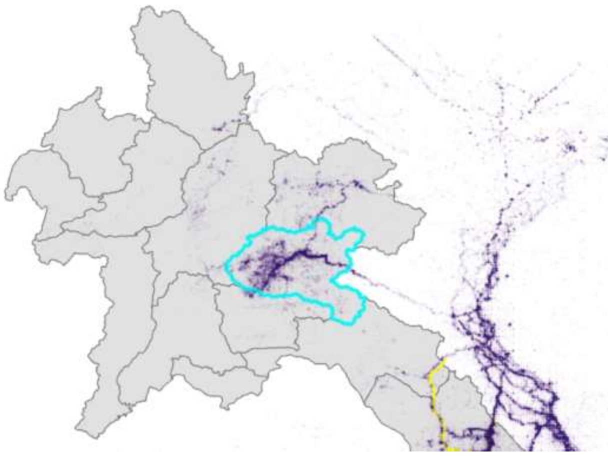
This study additionally asks if conditional within-country economic convergence existed after the war. Specifically, we test whether poor regions (villages in our data) grew faster than rich ones. This is typically called beta-convergence, as typified by the seminal papers of Barro and Sala-i-Martin (1992a) and Mankiw et al. (1992).

To our knowledge, there is no rigorous quantitative investigation of the effect of the bombing missions in Laos (Figure 1, Panel A) during the Vietnam War. To examine the effect, we take advantage of the historical fact that the U.S. army dropped a vast number of bombs on the communist supply lines, called the Ho Chi Minh Trail (HCMT, Figure 1, Panel B), and Xieng Khouang province (Figure 1, Panel C). To overcome the plausibly non-random feature of the U.S. bombing distribution, we use the distance from the nearest point on the HCMT in the case of southern Laos or the centroid of Xieng Khouang Province in the case of northern Laos to each geographical centroid of a village boundary as an instrumental variable for the bombing missions. The strength of the instrumental variables approach also addresses the attenuation bias that may result due to measurement errors in U.S. bombing missions. This is plausible because some of the original tape archives of bombing missions were reportedly damaged, and the equivalent of up to several months of data may be missing (Miguel and Roland, p5, 2011).

Panel A: Entire country *Panel B: Southern Laos*



Panel C: Northern Laos



Source: Author's compilation based on THOR Vietnam bombing operations and CartoGIS Services, College of Asia and the Pacific, The Australian National University.
Note: The dark purple dots denote the distribution of US bombing missions. The gray area denotes the level 0 and 1 administrative boundaries of Laos (Panel A and Panel C). The yellow line denotes the main routes of the Ho Chi Minh Trail, 1967 (Panel B). The light blue frame border indicates the location of Xieng Khouang Province.

Figure 1: Distributions of US bombing missions

In the literature, research investigating the causal relationship between conflicts and long-term economic growth is still scarce due to the lack of reliable statistics on the aftermath of the catastrophic damages and credible identification strategies. More specifically, one country studies investigating causality between conflicts and later economic growth are seemingly limited to Miguel and Roland (2011), Davis and

Weinstein (2002), Brakman et al. (2004), and Organski and Kugler (1977, 1980). Miguel and Roland (2011) investigate the long-term causal effect of bombing missions during the Vietnam War on population density in 1985 and 1999, a post-war timeframe of about 10–25 years.[1] They use district and province level analysis based on an instrumental variables approach, and employ the distance from the 17th parallel demilitarized zone as the intensity of bombing missions. The estimation results show no robust impact of the bombing missions on the dependent variables, indicating local recovery in Vietnam in the long-term. Davis and Weinstein (2002) show the destruction caused by U.S. bombing of Japanese cities during World War II (WWII) had no long-run impact on the relative size of Japanese cities after less than 20 years. Brakman et al. (2004) test the case of post-war Germany and find a similar result. Organski and Kugler (1977, 1980) find that there was a recovery to the pre-WWII growth trend for both socialist and capitalist economies after 15–20 years. In addition, in a cross country investigation, Przeworski et al. (2000) find a similar result, indicating rapid postwar recovery after 15–20 years.

Our study contributes by providing rigorous evidence of the long-term impacts of bombing missions on later economic development using detailed bombing records and high-resolution grid level data—the three rounds of average nightlight strength data (1992, 2005, and 2013) and two rounds of population density data (1990 and 2005). The reason for using data from different times in the 1990s and 2000s, is to verify the chronological change in bombing impacts on later economic development. The New Economic Mechanism (NEM), introduced in 1986, has facilitated market-oriented reforms and relatively decentralized control in Laos. It takes time for a series of reforms to bear fruit, and the country was still very poor in the 1990s due to the legacy of conflicts and the inefficient central planning system. However, since the mid-2000s, economic activities have accelerated in conjunction with formal participation in the Association of South-East Asian Nations (ASEAN) in 1997 and the surge of foreign direct investments, mainly in the resource sector.[2]

[1] Moreover, Miguel and Roland (2011) verify the impact of U.S. bombing missions on various development indicators (i.e., poverty rates, consumption levels, household access to electricity, and literacy). They also find no long-run impact for those indicators.

[2] The effect of the financial crisis in the late 2000s was limited to a slight downturn in the country's economic growth rate.

More specifically, our study makes four contributions to the literature. First, we employ village level analysis, which is a smaller observation unit compared to past studies that use more aggregated administrative units. In general, government statistics are not readily available for detailed village level information. Therefore, we compile geo-coded bombing and other high-resolution grid level data to conduct our village level analysis. Second, unlike past research that depends on observational data, we use satellite images for the main dependent variable (the average nightlight strength) and most of the control variables, which are deemed to be objective and more accurate (fewer measurement errors) than observational data. This would be a particular advantage for analysis of less developed countries where statistical capacity building by donor communities is ongoing. Third, this study extends previous research investigating the long-term impact of U.S. bombing missions on economic development by employing nightlight strength data. Using nightlight strength, Henderson et al. (2012) substantiated a strong correlation between variations in nightlights and the economic growth rate using panel data composed of around 190 countries from 1992–2008. Fourth, importantly, we use historical population density data to control for the pre-bombing economic condition, which was not done by Miguel and Roland (2011) in their verification of the impact of U.S. bombing missions during the Vietnam War. As described in the analytical section, the coefficients of the bombing variable are overestimated and the statistical significance is somewhat better without a control for pre-bombing economic conditions. By controlling for pre-bombing economic conditions, the estimation results are deemed to be less biased.

The remainder of this paper is organized as follows. Section 2 discusses the background of the secret war. Section 3 describes the data and methodology. Section 4 argues the analytical results, their robustness, and the possible mechanisms. Section 5 concludes.

2. BACKGROUND: FROM THE OPENING OF THE HCMT TO THE MASSIVE BOMBING CAMPAIGNS IN LAOS BY THE U.S. AIR FORCE

The Vietnam War is also known as the second Indochina War. The first Indochina War was the battle between Vietnam and France over the independence of Vietnam, during the period 1946–1954. After the defeat at the Dien Bien Phu Battle in 1954, France initiated peace negotiations with Vietnam, which resulted in the withdrawal of France and the agreement of the Geneva Accords. The Geneva Accords was a cease fire deal accompanied by the independence of Indochinese countries (Vietnam, Laos, and Cambodia) and establishment of the 17th parallel provisional military demarcation line in Vietnam to regroup the south by French Union forces and the north by Viet Minh as a step to unifying the country. Contrary to expectations, however, the north-south unification election based on the accords was not realized due to the refusal of the south, backed by the U.S., which was afraid of the rise of communism in South-East Asia. This became a trigger for the subsequent Second Indochina/Vietnam War, a battle between the communist north and capitalist south from 1955 to the fall of Saigon in the south in 1975. During the midst of the Vietnam War, the U.S. Army secretly attempted to destroy the communist supply lines, the Ho Chi Minh Trail (henceforth HCMT) on the western border of Vietnam, from spreading to Laos. The U.S. Army also dropped numerous bombs in Xieng Khouang province in northern Laos to signal its strength to North Vietnam. Of the bombs dropped on Laos, 30 percent are estimated as unexploded, contaminating up to 25 percent of the villages and 14 out of 17 provinces in Laos (NRA, 2015); this likely hampers the country's socio-economic development. Unlike the intense attention paid to Vietnam as a primary actor in the Vietnam War, not many people know that Laos is one of the most intensely bombed countries per capita in history.

The secret supply network of the HCMT was named after Ho Chi Minh, the leader of Communist Vietnam. During the sixteen years of its operation, the HCMT ran through North and South Vietnam, Laos, and Cambodia with a length of about 20,000 km; most of the trail ran through Laos in the 1960s. The HCMT in Laos was passible only on foot initially, but was gradually expanded to become passible for vehicles (Morris and Hills, pp.15-16, 2006).

By the early 1960s, the network of the HCMT near the Laos and southern Vietnam border that connected to the camps of the Viet Cong in southern Laos evolved into a truck route during the dry season. As part of the assistance to South Vietnam to reduce the army power and supplies of the Democratic Republic of Vietnam to the Viet Cong, the U.S. provided border control of South Vietnam's long boundary with Laos and Cambodia. In this regard, the United States Military Assistance Command Vietnam (USMACV), established in February 1962, was principally in charge of analyzing the infiltration data. The USMACV underestimated the number of infiltrations, which is reflects the fact that Michael V. Forrestal, a presidential aide, and Roger Hilsman, Director of the Bureau of Intelligence and Research in the State Department, downgraded the importance of infiltration in March 1963. Later, when faced with the fact that the number of infiltrations was far greater than expected, the USMACV was forced to revise the number upward and explain that most South Vietnamese veterans of the French War had now joined the Viet Cong again and Hanoi had sent its own draftees (Van Staaveren, pp.8-12, 1993). While the main activity of the South had been limited so far to monitoring the movement of the North, the U.S. Air Force (USAF) started the first systematic bombing campaigns in December 1964. Called the first mission of Operation Barrel Roll, flights were made from the Da Nang-based USAF with 750-pound bombs, CBU-2A bomblets, and AGM-12 Bullpup missiles (Van Staaveren, p.44, 1993). The bombing missions spread in the eastern part of Laos, ranging from around Samneua in the north to Salavan in the south. The main targets of Operation Barrel Roll were the Plain of Jars in the north and the HCMT in the south, respectively (Appendix Figure A1, Panel A).

The main role of Operation Barrel Roll was to signal the strength of the U.S. Army and impose greater military pressure on the North at around the Plain of Jars (Xieng Khouang province) where the North Vietnamese army held power. However, this did not work, as there were no public or other reactions from Hanoi after the first half-dozen Barrel Roll missions (Van Staaveran, 1993). In addition, Operation Rolling Thunder was initiated in March 1965 with a similar objective to Barrel Roll, dropping bombs in the north-eastern part of Laos. It is said that the amount was massive, far greater than the amount used in the entire Korean War (Polmar and Marolda, p.61, 2015). After the initiation of Rolling Thunder, northern bombings were implemented under both Rolling Thunder and Barrel Roll and the southern bombings were done under Operation Steel Tiger, which began in April 1965 (Appendix figure A1, Panel B). The main objective of Steel Tiger was aerial interdiction efforts to stop the infiltrations and material movements from the communist North to South Vietnam through the HCMT. Following this, one of the major aerial interdiction campaigns, Operation Commando Hunt, which began in November 1968, continued. President Johnson decided to halt the bombing campaigns in northern Laos under Operation Rolling Thunder and shifted the military power to southern Laos (Nguyen, p.28, 2013).

Based on these main aerial operations, Laos was hit with a great number of bombs, particularly around the Plain of Jars and along the HCMT. Furthermore, importantly, anecdotal evidence suggests that the Plain of Jars in northern Laos was used as a dumping ground for a massive number of bombs when the original targets of planes that had taken off from U.S. air bases were not available before the planes returned to their bases, and the planes could not land with explosives (Congressional Research Service (CRS), p.8, 2019; Reuter, 2016) (Appendix figure A2). At its peak, it is estimated that there were about 120,000 workers on the HCMT. However, the series of operations by the USAF largely contributed to the loss of about 20,000 who died, 30,000 who were seriously injured, and 6,000 missing people throughout the war. The majority were along the route of the HCMT (Morris and Hills, p17, 2006).[3]

3. DATA AND METHODOLOGY

3.1. DATA

Focus on the village level administrative unit

The analysis is implemented at the disaggregated level of administrative units or villages. For compilation of village level data, we use the shapefile of the village level administrative boundary that is based on the Lao Population and Housing Census 2005. To distinguish the impact of bombing missions on the HCMT from those in Northern Laos, we split the sample into halves using the latitude at around the 18th–19th parallel north. By using data in southern Laos, we are able to mitigate the impact of bombing missions other than on the HCMT, particularly that of the most heavily bombed province, Xieng Khouang—famous for making spoons using the U.S.'s unexploded ordnances (UXOs). Xieng Khouang province is in the northeastern part of the country. Anecdotal evidence suggests that this province was used as a "free drop zone"—a dumping ground for bombs when the original targets of planes that had taken off from air bases were unavailable before they returned to base, and the planes could not land with explosives (CRS, p.8, 2019; Reuter, 2016). Also, as a military strategy, the bombings northwest of Laos were reportedly intended to deny territory around Xieng Khouang province to the communist North Vietnam forces and Pathet Lao (CRS, p.8, 2019; Van Staaveran, 1993). In fact, based on the U.S. Department of Defense released Theater History of Operations Reports (THOR). the province was hit by a great number of bombs.

Bombing missions

For information on U.S. bombing missions, we use THOR, which is publicly available from the U.S. Department of Defense. THOR provides a reliable way to view air strike activity from 1915 to 1975, and provides the capability of generating historical

[3] The huge losses are also the result of diseases such as malaria and dysentery.

summaries based on user-selected criteria to answer basic questions of who (callsign, service, country), how many (strikes, weapons, etc.), what kind (aircraft, weapons, etc.), when, and, importantly, where (i.e., geographical coordinates). This database is the largest compilation in existence of releasable U.S. air operations data over the course of the Vietnam War, 1955–1975. The oldest available year of data is 1965 and the latest is 1973. This study uses the cleaned-up bombing data—1,010,950 out of a total of 1,048,576 bombs, including one with incomplete information.[4] The types of bombs used during the Vietnam War included free-fall bombs, guided bombs, and fuel air explosives. Out of the entire dataset, we extracted 277,520 bombs that were flown into Laos. Normalizing the size difference of each village by transforming the number of bombs into squared kilometers, we consider the density of bombs in each village.

Night light emissions as a proxy for economic activities

We employ the nightlights data that are collected by the Defense Meteorological Satellite Program (DMSP), which is managed by the Space and Missile Systems Center, Los Angeles Air Force Base, California. Using the nightlights from the DMSP, Henderson et al. (2012) substantiate a strong correlation between variations in nightlights and the economic growth rate using panel data comprising around 190 countries from 1992–2008. Hence, to proxy for economic activities, we use the nightlights satellite images released by the National Oceanic and Atmospheric Administration (NOAA). Satellite images are deemed to be more accurate and objective than sectoral output data compiled by government authorities, particularly in developing countries where the measurement errors in government statistics are large. Satellite images also enable us to capture tiny economic activities up to the grid level, which allows us to conduct a village level analysis.[5] The products are 30x30 arc second grids that are equivalent to

[4]The bombing missions are cleaned up by deleting entries without geographical coordinates.

[5] More specifically, for the nightlights variable, we use "average visible, stable lights, and cloud free coverages" of Version 4 DMSP-OLS Nighttime Lights Time Series processed by NOAA's National Geophysical Data Center (NGDC). In the course of processing, nightlights outliers (e.g., sunlit and glare data are excluded based on the solar elevation angle) and cloud cover that makes the earth surfaces unobservable are properly rejected by the scientists at the NGDC so the nightlights are mostly artificial. Out of the available image types for Version 4 DMSP-OLS Nighttime Lights Time Series, we use the cleaned one that contains lights from cities, towns, and other sites with persistent lighting, including gas flares. Ephemeral events, such as fires, have been discarded in this image type. The background noise is then identified and replaced with values of zero. Areas with zero cloud-free observations are represented by the value 255.

approximately 0.86 km^2 at the equator, spanning -180 to 180 degrees longitude and -65 to 75 degrees latitude. Data values range from 0–63. Although nightlight data is useful as a proxy for the intensity of economic activities, some low-density and low-income pixels do not get counted; as a result, there are very few pixels with the digital numbers 1 to 2. This is due to the algorithms used to filter out noise in the raw data, which leads to an undercount of lights nationally (Henderson et al., p.1000, 2012). Hence, following Henderson et al. (2012), Michalopoulos and Papaioannou (2013, 2014), and Hodler and Raschky (2014), we add a small constant term, 0.01, before taking the logarithm of average nightlight intensity in each village. This is also useful to avoid losing observations with zero value nightlight intensity after logarithm transformation. For the village level compilation of grid level nightlight data, we first collect all nightlight grids that overlap each village level administrative boundary, and then compute the average intensity of nightlight of the respective village.

Population density as a proxy for economic activities

We use the gridded population data from the History Database of the Global Environment (HYDE) version 3.1.[6] The resolution of the data is 5-minute resolution grids (approximately 10 km at the equator). By controlling for pre-bombing economic conditions, the estimation results are deemed to be less biased; therefore, to control for pre-bombing economic conditions, we compute the population density data in 1950. We use the outcome variable in 1980, 1990, and 2005.

Distance from the centroid of villages to the HCMT for the instrumental variable of the impact of bombing missions in southern Laos

We use a georeferencing technique to provide the coordinates of the HCMT based on the map generated by CartoGIS Services, College of Asia and the Pacific, The Australian National University. We regard the distance from the geographical centroid of the village-level administrative boundary to the nearest point on the HCMT as an instrumental variable for the impact of bombing missions. Given the fact that the HCMT was strategically heavily bombed by the U.S. army to destroy the communist supply lines, this distance can be deemed an instrumental variable for the bombing missions in southern Laos.

[6] See Klein Goldewijk et al. (2010) and Klein Goldewijk et al. (2011) for more details.

Distance from the centroid of villages to the centroid of Xieng Khouang Province for the instrumental variable of the impact of bombing missions in northern Laos

As discussed in the first part of this subsection, Xieng Khouang province in the north-eastern part of the country once became a target of heavy bombardment campaigns by U.S. airplanes during the secret war. Given this anecdotal evidence, we use the distance between the centroid of Xieng Khouang province and the centroid of each village as an instrumental variable for northern Laos.

Temperature and precipitation

Weather variations are popular instruments for gross domestic product in economies where rain induced agriculture is largely linked to income (e.g., countries in Africa). As it can be said that agriculture in Laos is linked to income for people working in agricultural activities, we use weather variations as control variables in the econometric specifications. The temperature and precipitation data depend on the Terrestrial Air Temperature and Terrestrial Precipitation of Version 5.01 Gridded Monthly Time Series 1900-2017. Both are interpolated and documented by Kenji Matsuura and Cort J. Willmott from the University of Delaware. The monthly averages of station temperature (degrees) and precipitation (mm) are interpolated to a 0.5-degree by 0.5-degree resolution (about 55.5 kilometers by 55.5 kilometers) latitude and longitude grid.[7]

Altitude

As one of the regional characteristics, altitude is used as an additional control variable. Altitude data is obtained from NASA's Shuttle Radar Topography Mission (SRTM), whose goal is to measure geographical features of the earth. We use the grid level 30 seconds resolution (about 900 meter) dataset, SRTM30. The altitude of each village is represented by that at the geographical centroid of each village.

[7] The gridded fields are estimated from monthly station averages. Willmott and Matsuura (1995) also employed station-by-station cross validation to indicate spatial interpolation errors.

Panel A: Villages in Southern Laos					
	Mean	S.D.	Max	Min	Observations
Average night lights intensity in 1992	0.2	1.4	23.3	0	4351
Average night lights intensity in 2005	0.6	3.1	34.7	0	4351
Average night lights intensity in 2013	2.1	7.4	62.5	0	4351
Total population per km^2 in 1950 (before the Vietnam War)	13.0	22.2	274.6	0.2	4180
Total population per km^2 in 1980	38.7	67.7	655.7	0.1	4189
Total population per km^2 in 1990	56.2	101.3	778.7	0.1	4191
Total population per km^2 in 2005	75.2	131.5	915.7	0.2	4192
Total number of U.S. bombs from 1965 to 1975 per km^2	3.3	13.4	353.6	0	4351
Distance from the centroid of villages to HCMT (km)	35.8	28.4	107.6	0	4351
Average monthly temperature in 1950 (degree at the centroid)	24.6	1.4	26.4	17.1	4351
Average monthly temperature in 1990 (degree at the centroid)	24.9	1.4	27.1	17.5	4351
Average monthly temperature in 1992 (degree at the centroid)	24.8	1.5	27.2	16.0	4351
Average monthly temperature in 2005 (degree at the centroid)	25.4	1.5	27.4	17.9	4351
Average monthly temperature in 2013 (degree at the centroid)	25.6	1.4	28.0	17.9	4351
Average monthly precipitation in 1950 (mm at the centroid)	191.4	32.8	241.8	128.8	4351
Average monthly precipitation in 1990 (mm at the centroid)	170.5	29.8	244.2	99.3	4351
Average monthly precipitation in 1992 (mm at the centroid)	150.6	27.6	206.1	88.8	4351
Average monthly precipitation in 2005 (mm at the centroid)	194.1	28.7	265.6	143.7	4351
Average monthly precipitation in 2013 (mm at the centroid)	182.2	25.9	241.0	141.2	4351
Altitude of administrative boundary (meter at the centroid)	286.2	261.8	1635.2	64.5	4351

Panel B: Villages in Northern Laos					
	Mean	S.D.	Max	Min	Observations
Average night lights intensity in 1992	0.9	5.1	58.5	0	5684
Average night lights intensity in 2005	1.5	6.9	61.0	0	5684
Average night lights intensity in 2013	3.5	10.8	63	0	5684
Total population per km^2 in 1950 (before the Vietnam War)	15.7	24.7	164.7	0.11	5677
Total population per km^2 in 1980	44.8	113.9	891.7	0.06	5678
Total population per km^2 in 1990	61.1	163.4	1103.7	0.06	5678
Total population per km^2 in 2005	84.7	218.8	1417.8	0.11	5678
Total number of U.S. bombs from 1965 to 1975 per km^2	1.2	5.1	98.8	0.003	5684
Distance from the centroid of villages to the one of Xieng	184.1	84.0	380.0	2.5	5684
Average monthly temperature in 1950 (degree at the centroid)	21.8	2.0	25.5	16.6	5684
Average monthly temperature in 1990 (degree at the centroid)	22.4	2.2	26.8	17.4	5684
Average monthly temperature in 1992 (degree at the centroid)	22.3	2.2	26.6	17.1	5684
Average monthly temperature in 2005 (degree at the centroid)	22.7	2.2	27.2	17.5	5684
Average monthly temperature in 2013 (degree at the centroid)	23.0	1.8	26.6	18.1	5684
Average monthly precipitation in 1950 (mm at the centroid)	138.1	27.1	260.4	105.7	5684
Average monthly precipitation in 1990 (mm at the centroid)	133.2	29.7	268.6	77.9	5684
Average monthly precipitation in 1992 (mm at the centroid)	114.8	37.6	222.3	35.3	5684
Average monthly precipitation in 2005 (mm at the centroid)	145.2	26.1	275.1	99.8	5684
Average monthly precipitation in 2013 (mm at the centroid)	145.4	24.4	247.8	100.4	5684
Altitude of administrative boundary (meter at the centroid)	670.5	350.8	2219.6	150.2	5684

Source: Author's compilation based on THOR, NOAA, HYDE version 3.1, Terrestrial Air Temperature and Terrestrial Precipitation of Version 5.01 Gridded Monthly Time Series 1900-2017 and SRTM30.

Note: Villages with zero population are excluded from the observations in population data. In DMSP-OLS Nighttime Lights Time Series, the recorded data are saturated in the bright cores of urban centers. However, this would not the case for countries where the share of bright core is small.

Table 1: Summary statistics: Villages in Southern and Northern Laos

3.2. METHODOLOGY

Cross-sectional regression using OLS and the instrumental variables approach

To investigate the effect of bombing missions during the Vietnam War, 1965–1975, on later long-term economic outcomes, an instrumental variables approach and a cross-sectional dataset are employed to overcome the possible non-random spatial distributions of the bombing missions, as well as measurement errors in the bombing records. We use OLS regression for reference purposes to show the existence of estimation biases. As the instrument of bombing intensity in southern and northern Laos, we employ the distance from the centroid of villages to the nearest point of the communist supply lines, HCMT (DISTANCE_HCMT) and the centroid of Xieng Khouang Province (DISTANCE_XIENG_KHOUANG), respectively.

In our empirical approach, we employ two types of data as outcome variables: the average nightlight strength in 1992, 2005, and 2013, and the total population per km^2 in 1990 and 2005. The reason for using the different timings of data in the 1990s and 2000s is to verify the chronological change in bombing impacts on later economic development. The country was still very poor in the 1990s due to the legacy of conflicts and the inefficient central planning system. However, after the mid-2000s, economic activities accelerated in conjunction with formal participation in the ASEAN in 1997 and the surge of foreign direct investments, which were mainly in the resource sector. In detail, the estimation model is denoted in equation (1).

$$NIGHTSLIGHTS_{i;1992,2005,2013} \ or \ POPULATION_{i;1990,2005} = \alpha + \beta BOMBS_{i,1965\text{-}1975} + \gamma PRE\_BOMBING\_POPULATION_{i,1950} + \delta OTHER\_CONTROLS_{it} + \eta_d + \varepsilon_{it} \qquad (1)$$

where the log average nightlight intensity in the years 1992, 2005, or 2013 and the log total population per squared kilometer in 1990 or 2005 of village i in district d are the outcome variables;[8] the log total bombing missions from 1965 to 1975 per squared kilometer for BOMBS; the log total population per squared kilometer in 1950 (before the Vietnam War) for PRE_BOMBING_POPULATION, temperature, precipitation, and

[8] For the nightlight variable, a small constant term, 0.01, is added to each observation before taking the logarithm of average nightlight intensity in each village (see the rationale in the data section). Also, villages with zero population in 1990 and 2005 are excluded from the observations.

elevation in the respective year for OTHER_CONTROLS; district fixed effects for η_d; and the error term ε. The unit of observation *i* denotes a village and t corresponds to the year of the outcome variable. The first stage estimation predicts bombing intensity by DISTANCE_HCMT or DISTANCE_XIENG_KHOUANG, as in equation 2:

$$BOMBS_{i,1965\text{-}1975} = a + bDISTANCE\_HCMT_i \; or \; DISTANCE\_XIENG\_KHOUANG_i + cPRE\_BOMBING\_POPULATION_{i,1950} + dOTHER\_CONTROLS_{i,t} + e_d + f_{it}. \quad (2)$$

Growth regressions to test within country convergence

In addition, we conduct growth regressions to test the conditional convergence hypothesis, arguing that poorer countries or regions tend to grow faster. There has been a surge of empirical studies testing the hypothesis using two approaches: (i) for cross-country income convergence: Baumol (1986), Barro and Sala-i-Martin (1992a), Sala-i-Martin (1996), Barro (2015), and Lessmann and Seidel (2017), among others; and (ii) for regional income convergence within a country: Barro and Sala-i-Martin (1991, 1992b), among others. We test the latter within country convergence hypothesis using population density data in 1980 (right after the war) and 2005. The following is the econometric specification (equation 3).

$$POPULATION\_GROWTH\_RATE_{i,1980-2005} = \theta + \vartheta BOMBS_{i,1965\text{-}1975} + \pi PRE\_BOMBING\_POPULATION_{i,1950} + \sigma OTHER\_CONTROLS_{it} + \tau_d + \omega_{it}. \quad (3)$$

where the dependent variable is the growth rate of total population per squared kilometer from 1980 to 2005 of village i in district d, measured as log(Total population per km^2 in 2005)- log(Total population per km^2 in 1980). Our main variable of interest is the PRE_BOMBING_POPULATION in 1950. We interpret a negative and statistically significant coefficient of PRE_BOMBING_POPULATION as an indication the less developed villages grow faster, which supports the conditional convergence hypothesis. A caution is that the growth in income is used as the dependent variable in a typical test of conditional convergence while we use growth in population density. However, this specification is supported by the regional science literature: Glaeser et al. (1995) show that income and population growth move together, while Crihfield and Panggabean (1995) claim that population convergence is not unrelated to convergence in per capita income.

4. ANALYSIS

4.1. PREDICTING BOMBING INTENSITY

The first stage estimation of the instrumental variables approach predicts bombing intensity using the two instruments, DISTANCE_HCMT and DISTANCE_XIENG_KHOUANG for southern and northern Laos, respectively (equation 2). The estimation results in Table 2 show the strong correlation between them, significant at the 1 percent level. The negative coefficients indicate that the number of bombs per squared kilometer gets smaller the further the distance from the HCMT and Xieng Khouang province.[9] Furthermore, the relevance of the instrumental variable is confirmed by the F-statistic from the first stage regression. If the F-statistic exceeds 10 in the threshold for weak instruments test formalized by Staiger and Stock (1997), the instrument is regarded as acceptable. The F-statistic is reported in the tables in the following sections, and they are above 10 except in a few cases.

As previously discussed, we mitigate the biases from the existence of endogeneity and measurement errors by employing an instrumental variables approach. However, we have a remaining concern about the violation of the exclusion restriction, meaning DISTANCE_HCMT and DISTANCE_XIENG_KHOUANG directly affect economic activities in the villages, not indirectly through bombing missions. We test this possibility by including DISTANCE_HCMT or DISTANCE_XIENG_KHOUANG in our OLS estimations of equation 1. We confirm that most of the coefficients of DISTANCE_HCMT or DISTANCE_XIENG_KHOUANG are statistically insignificant, with the exception of a few cases that use data from recent years.[10]

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[9] In the results in Table 2, the control variables included (i.e., temperature, precipitation) are those in 1950. However, the results are qualitatively the same even if the control variables are those in the year of the corresponding outcomes. These results are available from the authors upon request.

[10] The results are available from the authors upon request.

	Dependent variable: Log total U.S. bombs per km^2					
	Panel A: Villages in Southern Laos			*Panel B: Villages in Northern Laos*		
	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) OLS
Log distance from the centroid of administrative boundary to HCMT (km)	-1.088 ***	-0.292 ***	-0.292 ***			
	(0.043)	(0.044)	(0.086)			
Log distance from the centroid of administrative boundary to the centroid of Xieng Khouang Province (km)				-1.136 ***	-0.999 ***	-0.999 ***
				(0.035)	(0.132)	(0.351)
Total population per km^2 in 1950 (before the Vietnam War)	0.138 **	0.229 ***	0.229 *	0.908 ***	1.099 ***	1.099 ***
	(0.056)	(0.056)	(0.125)	(0.022)	(0.037)	(0.077)
Other control variables	Yes	Yes	Yes	Yes	Yes	Yes
District fixed effects	No	Yes	Yes	No	Yes	Yes
S.E. clustered at district level	No	No	Yes	No	No	Yes
Observations	4191	4191	4191	5678	5678	5678
R-squared	0.362	0.631	0.631	0.455	0.594	0.594

Source: Author's compilation based on THOR, NOAA, HYDE version 3.1, Terrestrial Air Temperature and Terrestrial Precipitation of Version 5.01 Gridded Monthly Time Series 1900-2017 and SRTM30.

Note: Significant at the 90 (*), 95 (**), and 99 (***) percent levels. Standard errors in parentheses. Small constant terms are added to the following variables before the log transformation: Nighttime lights (plus 0.01), population only in 1950 (plus 1), and the distance from the centroid of villages to HCMT (plus 0.01). Villages with zero population as of 2005 and 1990 are excluded from the observations.

Table 2: Predicting bombing intensity: Villages in Southern and Northern Laos

4.2. LOCAL BOMBING IMPACTS ON ECONOMIC ACTIVITIES PROXIED BY NIGHTLIGHT INTENSITY

Table 3 shows the long-term impacts of bombing missions on nightlight emissions in 1992, 2005, and 2013. All regressions control for district fixed effects with standard errors clustered at the district level.[11] Panel A (regressions 1–9) uses data from southern Laos and Panel B (regressions 10-18) uses data from northern Laos.

The effect of total U.S. bombing intensity on the average nightlight emissions is statistically insignificant in most of the OLS regression results, suggesting that there is no robust relationship between bombing missions and long-term economic development (Table 3, regressions 1, 4, 7, 10, and 16). However, these results are subject to estimation bias due to endogeneity and measurement errors—the rationale for employing the instrumental variables approach. Based on an investigation of the results of the first stage estimation, the instrument is confirmed to be a strong predictor of bombing intensity for all regressions conditional on the full set of controls. Hence, the instrumental variables approach generally corrects OLS regression results for endogeneity and deals with potential measurement errors in the bombing records. Moreover, control of pre-bombing economic activity using the log population per km^2 in 1950 plays an important role as the coefficient of the log total U.S. bombs per km^2 tends to have an upward bias without the control. Furthermore, the pre-bombing control even affects statistical significance—the statistical significance of total bombing intensity without the pre-bombing control is at the 5 percent level in regression 8, but decreases to the 10 percent level once the pre-bombing control is included in regression 9.

The results of the instrumental variables approach show that there is no robust relationship between bombing missions and long-term economic development as proxied by nightlight intensity except in 2013. In southern Laos, the coefficient of bombing is negative in 1992 and turns positive in 2005, but they are not statistically significant. However, the coefficient is positive and statistically significant at the 10% level in 2013. We will return to this point later. In northern Laos, the coefficients of bombing are consistently negative, implying a negative impact of the bombing missions, but they are not at all statistically significant.

[11] There are 52 and 88 districts in southern and northern Laos, respectively.

Bombing intensity in regression 9 is positive and statistically significant at the 10 percent level in southern Laos in 2013, which is different from the other estimation results. This may reflect the positive spillover effect of the HCMT as a transportation network that fostered later economic development in southern Laos. While it was originally in the jungle and a small route passible only on foot, the HCMT has developed into a comprehensive transportation network covering nearly 12,500 miles. It is plausible that the HCMT began playing a role as a crucial transportation infrastructure, pushing economic activities up to a certain point. Also, the two-lane highway project along the HCMT linking the Lao southern province of Salavan to Vietnam announced in 2000 by the Government of Vietnam could have further increased investments in southern Laos (New York Times, 2000; Communist Party of Vietnam, 2010).[12] Given these developments, a creative destruction model may apply in the very long run (i.e., in 2013, about forty years after the end of the war).

[12] The project covered about 1,000 miles between the Northern province of Ha Tay and Ho Chi Minh City, and was scheduled for completion in 2003 with a cost of about USD375 million.

	1992			2005			2013		
	Panel A: Villages in Southern Laos								
	Dependent variable: Log average nighttime lights intensity per km ^{2}								
	(1) OLS	(2) IV/2SLS	(3) IV/2SLS	(4) OLS	(5) IV/2SLS	(6) IV/2SLS	(7) OLS	(8) IV/2SLS	(9) IV/2SLS
Log total U.S. bombs per km ^{2}	-0.013	-0.009	-0.047	-0.001	0.247	0.182	0.050	1.114 **	1.044 *
	(0.013)	(0.067)	(0.074)	(0.023)	(0.234)	(0.239)	(0.032)	(0.543)	(0.539)
Log population in 1950 per km ^{2}	0.398 **		0.407 **	0.559 ***		0.516 **	0.845 ***		0.589 **
	(0.178)		(0.183)	(0.190)		(0.204)	(0.167)		(0.240)
Other control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
District fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
S.E. clustered at district level	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	4191	4191	4191	4191	4191	4191	4191	4191	4191
R-squared	0.438	-	-	0.428	-	-	0.364	-	-
First-stage F-statistic	-	10.0	9.8	-	22.6	17.7	-	21.2	17.5
IV at the first-stage significant?	-	1%	1%	-	1%	1%	-	1%	1%
	Panel B: Villages in Northern Laos								
	Dependent variable: Log average nighttime lights intensity per km ^{2}								
	1992			*2005*			*2013*		
	(10) OLS	(11) IV/2SLS	(12) IV/2SLS	(13) OLS	(14) IV/2SLS	(15) IV/2SLS	(16) OLS	(17) IV/2SLS	(18) IV/2SLS
Log total U.S. bombs per km ^{2}	0.025	-0.095	-0.195	0.055 *	-0.130	-0.322	0.064	-0.346	-0.691
	(0.017)	(0.101)	(0.175)	(0.029)	(0.190)	(0.272)	(0.045)	(0.270)	(0.502)
Log population in 1950 per km ^{2}	0.386 **		0.630 **	0.725 ***		1.145 ***	1.165 ***		2.008 ***
	(0.149)		(0.274)	(0.190)		(0.363)	(0.223)		(0.531)
Other control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
District fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
S.E. clustered at district level	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	5678	5678	5678	5678	5678	5678	5678	5678	5678
R-squared	0.707	-	-	0.641	-	-	0.591	-	-
First-stage F-statistic	-	1.2	13.0	-	0.7	13.7	-	0.8	14.2
IV at the first-stage significant?	-	1%	1%	-	1%	1%	-	1%	1%

Source: Author's compilation based on THOR, NOAA, HYDE version 3.1, Terrestrial Air Temperature and Terrestrial Precipitation of Version 5.01 Gridded Monthly Time Series 1900-2017 and SRTM30.

Note: Significant at the 90 (*), 95 (**), and 99 (***) percent levels. Clustered standard errors at the district level are in parentheses. Small constant terms are added to the following variables to avoid losing observations after the log transformation: Nighttime lights (plus 0.01), population (plus 1), and the distance from the centroid of villages to HCMT (plus 0.01). "IV at the first-stage significant?" shows the level of significance of the instrumental variable at the first stage.

Table 3: Long-term impacts of bombing missions on average nighttime lights intensity in 1992, 2005, and 2013

4.3. LOCAL BOMBING IMPACTS ON ECONOMIC ACTIVITIES PROXIED BY POPULATION DENSITY DATA

Table 4 shows the long-term impacts of bombing missions on population density in the years 1990 and 2005. Population density is also regarded as a useful proxy for reflecting the density of economic activities, as discussed at the end of Section 3. Hence, the estimation results using population density data would be a good reference for the results using average nightlight emissions in Table 3. All regressions control for district fixed effects with standard errors clustered at the district level. Panel A uses data from southern Laos and Panel B uses data from northern Laos.

The OLS regression results of the long-term effect of bombing on population density is negative and statistically significant at the 1 percent level (Table 4, regressions 1, 4, 7, and 10). This indicates that the bombing impact persists for later economic development. However, again, these OLS regression results are affected by estimation bias due to endogeneity and measurement errors in the bombing records. Hence, we rely on the instrumental variables approach to overcome these challenges. The first-stage estimation results show the effectiveness of the instruments for all regressions, conditional on the full set of controls. The results of the instrumental variables approach suggest no robust relationship between bombing missions and long-term economic development (Table 4, regressions 2, 3, 5, 6, 8, 9, 11, and 12). In addition, we found that the coefficient of log total U.S. bombs per km^2 is largely overestimated without the pre-bombing control, as in Table 3.

	(1) OLS	(2) IV/2SLS	(3) IV/2SLS	(4) OLS	(5) IV/2SLS	(6) IV/2SLS
	Panel A: Villages in Southern Laos					
	Dependent variable: Log population per km^2					
	1990			2005		
Log total U.S. bombs per km^2	-0.053 ***	0.221	0.103	-0.062 ***	0.271	0.108
	(0.003)	(0.167)	(0.077)	(0.003)	(0.174)	(0.076)
Log population in 1950 per km^2	1.075 ***		1.282 ***	1.101 ***		1.293 ***
	(0.013)		(0.050)	(0.014)		(0.055)
Other control variables	Yes	Yes	Yes	Yes	Yes	Yes
District fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
S.E. clustered at district level	Yes	Yes	Yes	Yes	Yes	Yes
Observations	4191	4191	4191	4191	4191	4191
R-squared	0.809	-	-	0.800	-	-
First-stage F-statistic	-	19.2	15.4	-	22.6	17.7
IV at the first-stage significant?	-	1%	1%	-	1%	1%
	Panel B: Villages in Northern Laos					
	Dependent variable: Log population per km^2					
	1990			2005		
	(7) OLS	(8) IV/2SLS	(9) IV/2SLS	(10) OLS	(11) IV/2SLS	(12) IV/2SLS
Log total U.S. bombs per km^2	-0.042 ***	0.174	-0.083	-0.038 ***	0.198	-0.073
	(0.007)	(0.468)	(0.107)	(0.008)	(0.448)	(0.104)
Log population in 1950 per km^2	1.568 ***		1.614 ***	1.573 ***		1.612 ***
	(0.029)		(0.122)	(0.031)		(0.118)
Other control variables	Yes	Yes	Yes	Yes	Yes	Yes
District fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
S.E. clustered at district level	Yes	Yes	Yes	Yes	Yes	Yes
Observations	5678	5678	5678	5678	5678	5678
R-squared	0.972	-	-	0.967	-	-
First-stage F-statistic		0.9	13.3		0.7	13.7
IV at the first-stage significant?	-	1%	1%	-	1%	1%

Source: Author's compilation based on THOR, HYDE version 3.1, Terrestrial Air Temperature and Terrestrial Precipitation of Version 5.01 Gridded Monthly Time Series 1900-2017 and SRTM30.

Note: Significant at the 90 (*), 95 (**), and 99 (***) percent levels. Clustered standard errors at the district level are in parentheses. Small constant terms are added to the following variables to avoid losing observations after the log transformation: Nighttime lights (plus 0.01), population (plus 1), and the distance from the centroid of villages to the HCMT (plus 0.01). "IV at the first-stage significant?" shows the level of significance of the instrumental variable at the first stage.

Table 4: Long-term impacts of bombing missions on the population per km^2 in 1990 and 2005

4.4. ROBUSTNESS TESTS: EXCLUDING VILLAGES THE HCMT PASSED THROUGH AND WITHIN XIENG KHOUANG PROVINCE

To deal with the concern regarding endogeneity and measurement errors, we depend on the instrumental variables approach in Sections 4.2. and 4.3. Given the generally sufficient F-statistic in the first-stage regressions, the instrumental variables approach mitigates the estimation biases. However, the route of the HCMT might have been determined based on some information that is unmeasurable and unobservable to researchers, such as certain economic conditions and political complexity among the villages. This is a potential threat to our identification strategy, because the location of the HCMT itself could be endogenous. While concern about this type of threat is less likely in the case of northern Laos because it was likely that the U.S. army's decision to use Xieng Khouang province as a dumping ground for bombs when planes could not land with explosives and their original target was unavailable was almost purely exogenous to the villages in northern Laos, we remain cautious about this potential threat to our identification strategy.[13] To deal with this concern, we employ sub-sample estimations for robustness tests by excluding the villages the HCMT passed through and the villages in Xieng Khouang Province.

Table 8 shows the sub-sample estimation results of excluding the villages the HCMT passed through and those in Xieng Khouang Province. Even in the robustness test results in Table 8, we again find no statistically significant relationship between bombing intensity and later long-term economic development when we use the instrumental variables approach to correct the estimation biases of endogeneity and measurement errors in OLS regressions (not shown).

[13] It also should be noted that communist North Vietnam forces and Pathet Lao were notably concentrated around the Plain of Jars in Xieng Khouang province beginning in 1964, which was also rather exogenous to villages in other northern provinces.

	Panel A: Villages in Southern Laos excluding those the HCMT passed through				
	Dependent variable: Log average nighttime lights intensity per km²			Dependent variable: Log population per km²	
	1992	*2005*	*2013*	*1990*	*2005*
	(1) IV/2SLS	(2) IV/2SLS	(3) IV/2SLS	(4) IV/2SLS	(5) IV/2SLS
Log total U.S. bombs per km²	-0.085	0.194	1.351	0.169	0.191
	(0.123)	(0.361)	(0.884)	(0.150)	(0.169)
Log population in 1950 per km²	0.439 **	0.513 **	0.459	1.249 ***	1.252 ***
	(0.203)	(0.253)	(0.365)	(0.063)	(0.071)
Other control variables	Yes	Yes	Yes	Yes	Yes
District fixed effects	Yes	Yes	Yes	Yes	Yes
S.E. clustered at district level	Yes	Yes	Yes	Yes	Yes
Observations	3839	3839	3839	3839	3839
R-squared	-	-	-	-	-
First-stage F-statistic	7.9	14.2	13.3	13.3	14.2
IV at the first-stage significant?	5%	5%	1%	5%	5%
	Panel B: Villages in Northern Laos excluding those in Xieng Khouang Province				
	Dependent variable: Log average nighttime lights intensity per km²			Dependent variable: Log population per km²	
	1992	*2005*	*2013*	*1990*	*2005*
	(6) IV/2SLS	(7) IV/2SLS	(8) IV/2SLS	(9) IV/2SLS	(10) IV/2SLS
Log total U.S. bombs per km²	-0.322	-0.184	-0.503	-0.060	-0.057
	(0.235)	(0.249)	(0.449)	(0.217)	(0.208)
Log population in 1950 per km²	0.837 ***	1.069 ***	1.912 ***	1.567 ***	1.572 ***
	(0.326)	(0.373)	(0.494)	(0.230)	(0.219)
Other control variables	Yes	Yes	Yes	Yes	Yes
District fixed effects	Yes	Yes	Yes	Yes	Yes
S.E. clustered at district level	Yes	Yes	Yes	Yes	Yes
Observations	5129	5129	5129	5129	5129
R-squared	-	-	-	-	-
First-stage F-statistic	10.1	20.1	31.6	30.2	20.1
IV at the first-stage significant?	1%	1%	1%	1%	1%

Source: Author's compilation based on THOR, NOAA, HYDE version 3.1, Terrestrial Air Temperature and Terrestrial Precipitation of Version 5.01 Gridded Monthly Time Series 1900-2017 and SRTM30.

Note: Significant at the 90 (*), 95 (**), and 99 (***) percent levels. Clustered standard errors at the district level are in parentheses. Small constant terms are added to the following variables to avoid losing observations after the log transformation: Nighttime lights (plus 0.01), population (plus 1), and the distance from the centroid of villages to HCMT (plus 0.01). "IV at the first-stage significant?" shows the level of significance of the instrumental variable at the first stage.

Table 5: Long-term impacts of bombing missions on average nighttime lights emissions in 1992, 2005, and 2013 and the population per km² in 1990 and 2005: Villages excluding those the HCMT passed through and in Xieng Khouang Province

4.5. GROWTH REGRESSIONS TO TEST THE REGIONAL ECONOMIC CONVERGENCE WITHIN A COUNTRY

We conduct growth regressions to test the regional economic convergence hypothesis, arguing that poorer regions tend to grow faster. More specifically, we test the conditional regional economic convergence within a country to add additional evidence to Barro and Sala-i-Martin (1991, 1992b), among others. Our main variable of interest is PRE_BOMBING_POPULATION in 1950 in equation 3 in Section 3.2. We interpret a negative and statistically significant coefficient of PRE_BOMBING_POPULATION as an indication that less developed villages grew faster, which supports the conditional (beta-) convergence hypothesis.

The coefficient of PRE_BOMBING_POPULATION in 1950 is negative and statistically significant at the 10 percent level according to the OLS regression results (Table 5, regressions 1, 3, and 7). However, after correcting for the plausible estimation bias in the OLS regressions using the instrumental variables approach, the estimation results do not necessarily show a negative and statistically significant coefficient of PRE_BOMBING_POPULATION in 1950 (Table 5, regressions 2, 4, 6, and 8). Thus, we suggest that the conditional regional economic convergence hypothesis within a country does not necessarily hold in the case of Laos after the substantial destruction of war. However, deep caution is necessary here because we cannot observe any counterfactual states of Laos. That is, we cannot tell whether regional economic convergence would have occurred had there been no massive bombing. Therefore, all we can do is provide one example case in which regional economic convergence has not occurred. In the next subsection, we discuss briefly why we did not observe conditional convergence in Laos.

To our knowledge, this is the first study to investigate conditional regional growth convergence within Laos using village level administrative boundaries. In developing countries, individual country case studies testing growth convergence are still scarce, partly because of the lack of disaggregated data. For those papers that investigate cases of developing countries, Cárdenas and Pontón (1995) analyze the case of Colombia from 1950 to 1990 and find strong per-capita income convergence across regions at the rate of about 4 percent per year. Jian et al. (1996) examine China and find that (i) the convergence of real income per-capita has emerged only since the reform period began in 1978; (ii) there is some evidence of a slight convergence during the initial phase of central planning from 1952 to 1965, but it was weak; and (iii) there is strong evidence of divergence during the cultural revolution, 1965–1978.[14]

[14] Jian et al. (1996) conclude that regional convergence is strongly associated with the extent of marketization and openness in the case of China.

	Population growth rate, 1980-2005			
	Panel A: Southern Laos			
	All villages		Villages excluding those the HCMT passed through	
	(1) OLS	(2) IV/2SLS	(3) OLS	(4) IV/2SLS
Log total U.S. bombs per km^2	-0.014 ***	0.021	-0.012 **	0.048
	(0.005)	(0.016)	(0.005)	(0.037)
Log population in 1950 per km^2	-0.033 *	0.010	-0.037 *	-0.001
	(0.019)	(0.014)	(0.019)	(0.017)
Other control variables	Yes	Yes	Yes	Yes
District fixed effects	Yes	Yes	Yes	Yes
S.E. clustered at district level	Yes	Yes	Yes	Yes
Observations	4189	4189	3837	3837
R-squared	0.116	-	0.114	-
First-stage F-statistic	-	17.8	-	14.2
IV at the first-stage significant?	-	1%	-	5%
	Panel B: Northern Laos			
	All villages		Villages excluding those in Xieng Khouang Province	
	(5) OLS	(6) IV/2SLS	(7) OLS	(8) IV/2SLS
Log total U.S. bombs per km^2	0.008	-0.019	0.010	-0.014
	(0.008)	(0.031)	(0.008)	(0.065)
Log population in 1950 per km^2	-0.025	0.068 *	-0.039 *	0.059
	(0.019)	(0.035)	(0.020)	(0.068)
Other control variables	Yes	Yes	Yes	Yes
District fixed effects	Yes	Yes	Yes	Yes
S.E. clustered at district level	Yes	Yes	Yes	Yes
Observations	5678	5678	5129	5129
R-squared	0.332	-	0.346	-
First-stage F-statistic	-	13.7	-	20.1
IV at the first-stage significant?	-	1%	-	1%

Source: Author's compilation based on THOR, HYDE version 3.1, Terrestrial Air Temperature and Terrestrial Precipitation of Version 5.01 Gridded Monthly Time Series 1900-2017 and SRTM30.

Note: Significant at the 90 (*), 95 (**), and 99 (***) percent levels. Clustered standard errors at the district level are in parentheses. Small constant terms are added to the following variables to avoid losing observations after the log transformation: Nighttime lights (plus 0.01), population (plus 1), and the distance from the centroid of villages to HCMT (plus 0.01). "IV at the first-stage significant?" shows the level of significance of the instrumental variable at the first stage.

Table 6: Growth regressions using the population density growth rate, 1980-2005

4.6. DISCUSSION OF THE MECHANISIM: WHY ARE THERE NO LONG-TERM IMPACTS OF THE U.S. BOMBING CAMPAIGNS ON ECONOMIC DEVELOPMENT WITHOUT REGIONAL ECONOMIC CONVERGENCE IN LAOS?

Why there is no long-term impact of the U.S. bombing campaigns on later economic development, despite the historical fact that Laos had a vast number of bombing missions during the secret war? There is a possibility that the intense bombing campaigns did not necessarily lead to catastrophic economic collapse in Laos (Pentagon Papers, p.232, 1972). At the time of the Vietnam War, the Lao economy was very poor and heavily dependent on subsistence farming (which approximately holds in rural areas even now). Therefore, even if there were massive bombing missions, the locations of the dropped bombs were deemed to be on farmlands, unpaved roads, and forests—thus, there was no catastrophic destruction of infrastructure or any types of physical capital. Further, as the main purpose of the bombing missions in Laos was to undermine the war capability of the communist North by impeding the progress of troops and material flows to South Vietnam, the number of casualties was large but damage on the economic system was not likely to be fatal. On the other hand, as discussed in Section 4.2., it is noteworthy that the positive and statistically significant (but marginal) relationship between bombing missions and long-term economic development proxied by nightlight intensity emerges only in 2013 in southern Laos. However, this may not be applicable in mountainous northern Laos,[15] where there was less notable infrastructure development, such as highway projects connecting to the neighboring countries.

Meanwhile, the existence of UXOs, contaminating up to 25 percent of the villages and 14 out of 17 provinces in Laos (NRA, 2015), has hampered business and the introduction of new investments into the local economy. Despite the ongoing sustained efforts to clear UXOs, the expected number of UXOs and their locations are not known with reliable accuracy.[16] Under this uncertainty, it is highly probable that new investments will go only to safe locations that are confirmed by the baseline surveys of

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[15] See the mean and S.D. of altitude in Table 1. Northern Laos has rough hilly terrain compared to southern Laos.

[16] During an interview with personnel of the Lao National Unexploded Ordnance Programme (UXO Lao) in September 2016, it was mentioned that more UXOs remain in poor regions than in rich regions.

UXO clearance; this has resulted in an unbalanced distribution of capital and labor in post-war Laos. We believe this could be part of the reason there is no regional convergence within the country of Laos.

We discuss the possible mechanisms above. However, one caveat is that our discussion is limited to speculation due to the insufficient availability of statistical data to verify why there is no long-run impact of the U.S. bombing missions on later economic development and no conditional regional convergence within the country.

5. CONCLUSIONS

Amid the Vietnam War from 1964 to 1973, U.S. bombing missions in Laos as part of the secret war resulted in catastrophic losses. Because of this, Laos has been labeled as one of the most intensely bombed countries per capita in history. To our knowledge, there is no rigorous quantitative investigation of the long-term effect of the bombing missions in Laos during the Vietnam War. Hence, this study asks if the bombing missions during the secret war affected later economic growth in Laos and if within-country conditional economic convergence exists after the war.

To verify the effect of U.S. bombing missions on long-term economic development, we take advantage of the historical fact that the U.S. army heavily dropped bombs on the communist supply lines, the HCMT, and Xieng Khouang province. Using the distance from the nearest point on the HCMT and the centroid of Xieng Khouang Province to each geographical centroid of village boundaries as an instrumental variable for the bombing missions, we address the attenuation bias that may result from measurement errors in the bombing campaigns and the seemingly non-random characteristic of the bombing distribution. The estimation results show no robust evidence that bombing missions have a persistent effect on long-term economic outcomes. In addition, the results do not necessarily support the conditional convergence hypothesis within a country, although this result could be very Laos specific due to the existence of a large number of UXOs in the country.

As discussed, there is no lasting long-run impact of the U.S. bombing missions on economic outcomes in the case of Laos at the semi-macro level. Having said that, a large number of UXOs remain in the country. The presence of UXOs is an ongoing critical issue, as they continue to kill and injure many people every year. Clearance of

UXOs would be needed to help improve socio-economic development for the future of Laos, although it requires a significant amount of time and budget.

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APPENDIX

Panel A: Villages in Southern Laos excluding those the HCMT passed through					
	Mean	S.D.	Max	Min	Observations
Average night lights intensity in 1992	0.2	1.4	23.3	0	3999
Average night lights intensity in 2005	0.7	3.2	34.7	0	3999
Average night lights intensity in 2013	2.2	7.6	62.5	0	3999
Total population per km^2 in 1950 (before the Vietnam War)	13.7	23.1	274.5	0.2	3828
Total population per km^2 in 1980	41.1	70.0	0.1	655.9	3837
Total population per km^2 in 1990	59.8	104.5	778.9	0.1	3839
Total population per km^2 in 2005	80.0	135.4	915.8	0.2	3840
Total number of U.S. bombs from 1965 to 1975 per km^2	2.5	11.9	353.6	0	3999
Distance from the centroid of villages to HCMT (km)	38.8	27.7	107.6	0.3	3999
Average monthly temperature in 1950 (degree at the centroid)	24.6	1.4	26.4	17.1	3999
Average monthly temperature in 1990 (degree at the centroid)	24.9	1.3	27.1	17.5	3999
Average monthly temperature in 1992 (degree at the centroid)	24.9	1.5	27.2	16.0	3999
Average monthly temperature in 2005 (degree at the centroid)	25.5	1.4	27.4	17.9	3999
Average monthly temperature in 2013 (degree at the centroid)	25.7	1.4	28.0	17.9	3999
Average monthly precipitation in 1950 (mm at the centroid)	190.1	32.9	241.3	128.8	3999
Average monthly precipitation in 1990 (mm at the centroid)	171.1	29.5	244.2	99.3	3999
Average monthly precipitation in 1992 (mm at the centroid)	151.8	27.6	206.1	88.8	3999
Average monthly precipitation in 2005 (mm at the centroid)	192.9	28.9	265.6	143.7	3999
Average monthly precipitation in 2013 (mm at the centroid)	181.8	26.3	241.0	141.2	3999
Altitude of administrative boundary (meter at the centroid)	270.8	246.7	1597.3	64.5	3999

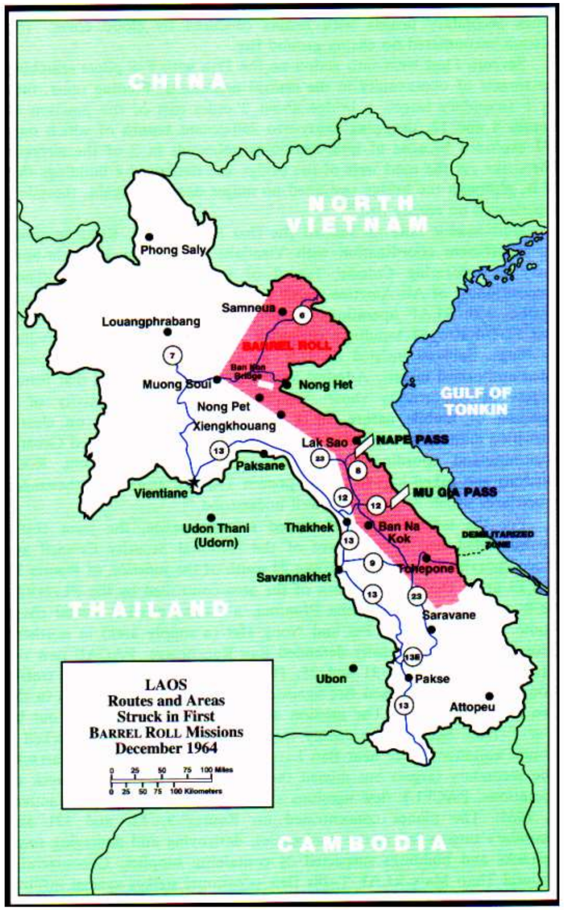
Panel B: Villages in Northern Laos excluding those in Xieng Khouang Province					
	Mean	S.D.	Max	Min	Observations
Average night lights intensity in 1992	1.0	5.4	58.5	0	5135
Average night lights intensity in 2005	1.7	7.2	61.0	0	5135
Average night lights intensity in 2013	3.7	11.2	63	0	5135
Total population per km^2 in 1950 (before the Vietnam War)	16.0	25.7	164.7	0.11	5128
Total population per km^2 in 1980	46.3	118.9	891.7	0.06	5129
Total population per km^2 in 1990	63.8	170.8	1103.7	0.06	5129
Total population per km^2 in 2005	88.4	228.6	1417.8	0.11	5129
Total number of U.S. bombs from 1965 to 1975 per km^2	0.5	1.9	50.0	0.003	5135
Distance from the centroid of villages to the one of Xieng Khouang province (km)	199.6	72.7	380.0	47.9	5135
Average monthly temperature in 1950 (degree at the centroid)	22.1	2.0	25.5	16.6	5135
Average monthly temperature in 1990 (degree at the centroid)	22.7	2.2	26.8	17.4	5135
Average monthly temperature in 1992 (degree at the centroid)	22.4	2.2	26.6	17.1	5135
Average monthly temperature in 2005 (degree at the centroid)	22.9	2.2	27.2	17.5	5135
Average monthly temperature in 2013 (degree at the centroid)	23.2	1.7	26.6	18.1	5135
Average monthly precipitation in 1950 (mm at the centroid)	137.5	27.8	105.7	260.4	5135
Average monthly precipitation in 1990 (mm at the centroid)	133.4	30.4	268.6	77.9	5135
Average monthly precipitation in 1992 (mm at the centroid)	117.5	37.7	222.3	35.3	5135
Average monthly precipitation in 2005 (mm at the centroid)	145.2	26.6	275.1	99.8	5135
Average monthly precipitation in 2013 (mm at the centroid)	147.1	24.2	247.8	101.2	5135
Altitude of administrative boundary (meter at the centroid)	630.9	331.1	2219.6	150.2	5135

Source: Author's compilation based on THOR, NOAA, HYDE version 3.1, Terrestrial Air Temperature and Terrestrial Precipitation of Version 5.01 Gridded Monthly Time Series 1900-2017 and SRTM30.

Note: Villages with zero population are excluded from the observations in population data. In DMSP-OLS Nighttime Lights Time Series, the recorded data are saturated in the bright cores of urban centers. However, this would not be the case for countries where the share of bright core is small.

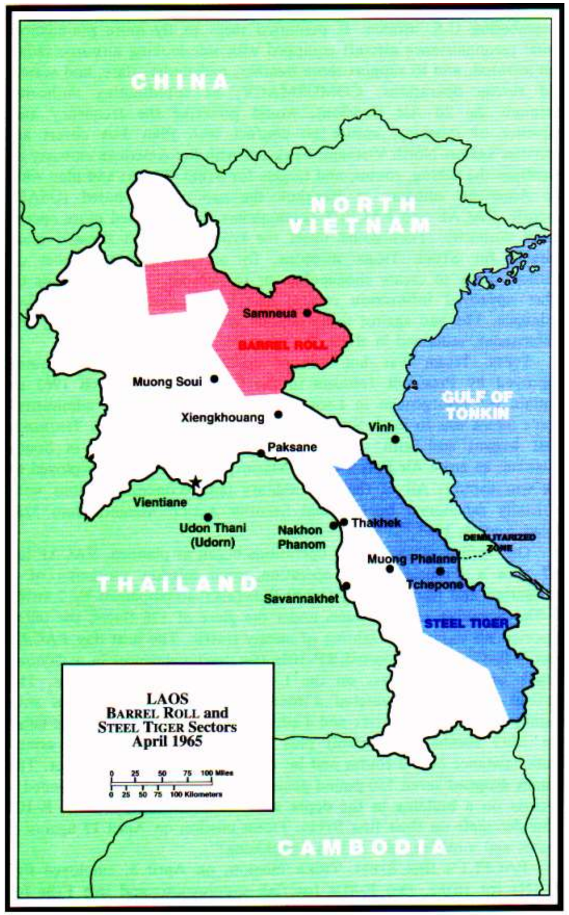
Appendix table A1: Summary statistics—Villages in Southern and Northern Laos, excluding those the HCMT passed through and those in Xieng Khouang Province

Panel A: First Barrel Roll as of December 1964



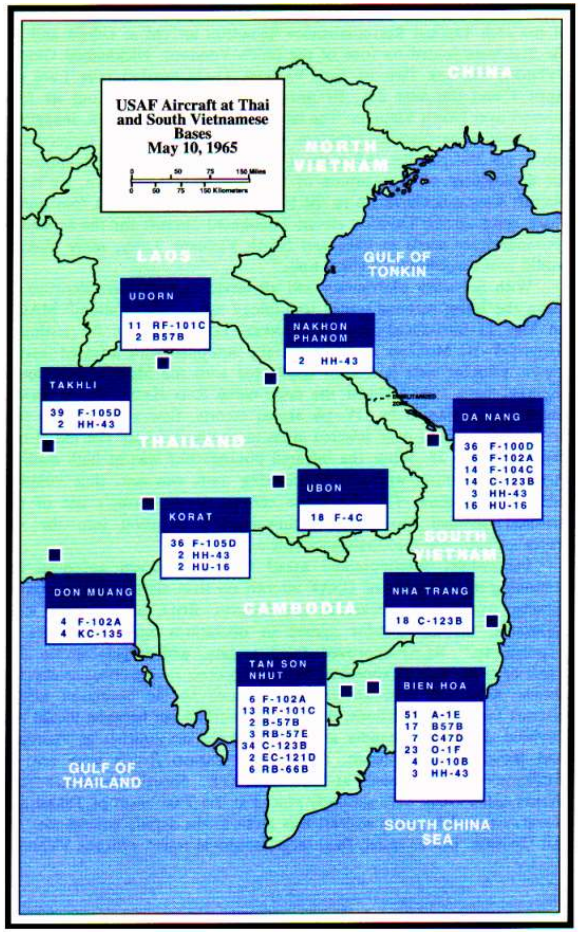
Source: Van Staaveren (p.45, 1993)

Panel B: Barrel Roll as of September 1965



Source: Van Staaveren (p.60, 1993)

Appendix figure A1: Routes and areas struck in U.S. bombing missions



Source: Van Staaveren (p.64, 1993)

Appendix figure A2: USAF aircraft at Thailand and South Vietnamese bases as of May 10, 1965