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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 effects of U.S. bombing missions during the Vietnam War on later economic development in Laos. Following an instrumental variables approach, we use the distance between the centroid of village-level administrative boundaries and heavily bombed targets, namely, the Ho Chi Minh Trail in southern Laos and Xieng Khouang Province in northern Laos, as an instrument for the intensity of U.S. bombing missions. We use three datasets of mean nighttime light intensity (1992, 2005, and 2013) and two datasets of population density (1990 and 2005) as outcome variables. The estimation results show no robust long-term effects of U.S. bombing missions on economic development in southern Laos but show negative effects in northern Laos, even 40 years after the war. We also found that the results do not necessarily support the conditional convergence hypothesis within a given country, although this result could be unique to Laos.

1. Introduction

On September 6, 2016, during a summit of Southeast Asian countries, Barack Obama became the first sitting U.S. president to acknowledge America's secret war in Laos. 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; from 1964 to 1973, in the midst of the Vietnam War, more than 2 million tons of ordnance, equivalent to 580,000 bombs, was dropped on Laos, exceeding the amounts used in Japan and Germany in World War II combined (Kurlanzick, 2017; NRA, 2015; The White House, 2016; Woodruff and Yiu, 2016). Despite its historical significance, this tragedy is not well known outside of Laos. However, the facts reveal a hideous truth; since 1964, more than 50,000 people have been killed or injured, including the victims of unexploded bombs that remained after the war (NRA, 2015). War inevitably leads to catastrophic losses, including human casualties and widespread destruction of infrastructures and ecosystems.

In the literature, there is little research on causal relationships between conflicts and long-term economic development, mostly due to the lack of reliable statistics on the aftermath of catastrophic damage as well as credible identification strategies. More specifically, studies investigating the link between conflicts and later economic growth or level of economic intensity appear to be limited to Miguel and Roland (2011), Davis and Weinstein (2002), Brakman et al. (2004), and Organski and Kugler (1977, 1980). It is therefore necessary to externally validate these past studies by focusing on new and understudied contexts, such as those that were more heavily affected by bombings per capita compared with the contexts explored in other papers. Miguel and Roland (2011) investigated the long-term causal effects of bombing missions during the Vietnam War on the population density of Vietnam 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, employing the distance from the 17th parallel demilitarized zone to represent the intensity of bombing missions. The estimation results show no robust impact of the bombing missions on the dependent variables, indicating long-term local recovery in Vietnam. Davis and Weinstein (2002) show that 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)

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

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examine post-war Germany and found a similar result. Organski and Kugler (1977, 1980) find that both socialist and capitalist economies recovered to pre-WWII growth trends after 15–20 years. In an investigation of 135 countries, Przeworski et al. (2000) find a similar result indicating rapid postwar recovery after 15–20 years.

Our study contributes to the literature by providing rigorous evidence of the long-term impacts of bombing missions on later economic development. We do this by using detailed bombing records and high-resolution grid-level data comprising three datasets of mean nighttime light intensity data (1992, 2005, and 2013) and two datasets of population density (1990 and 2005). We use data from different times in the 1990s and 2000s to verify the chronological change in bombing impacts on later economic development. The New Economic Mechanism, which was introduced in 1986, has facilitated market-oriented reforms and relatively decentralized control in Laos. It takes time for such reforms to bear fruit, and the country was still very poor in the 1990s due to the legacy of conflict and an inefficient central planning system. However, since the mid-2000s, economic activities have accelerated in conjunction with formal participation in the Association of Southeast Asian Nations (ASEAN) beginning in 1997 and a surge of foreign direct investments, mainly in the resource sector.[2]

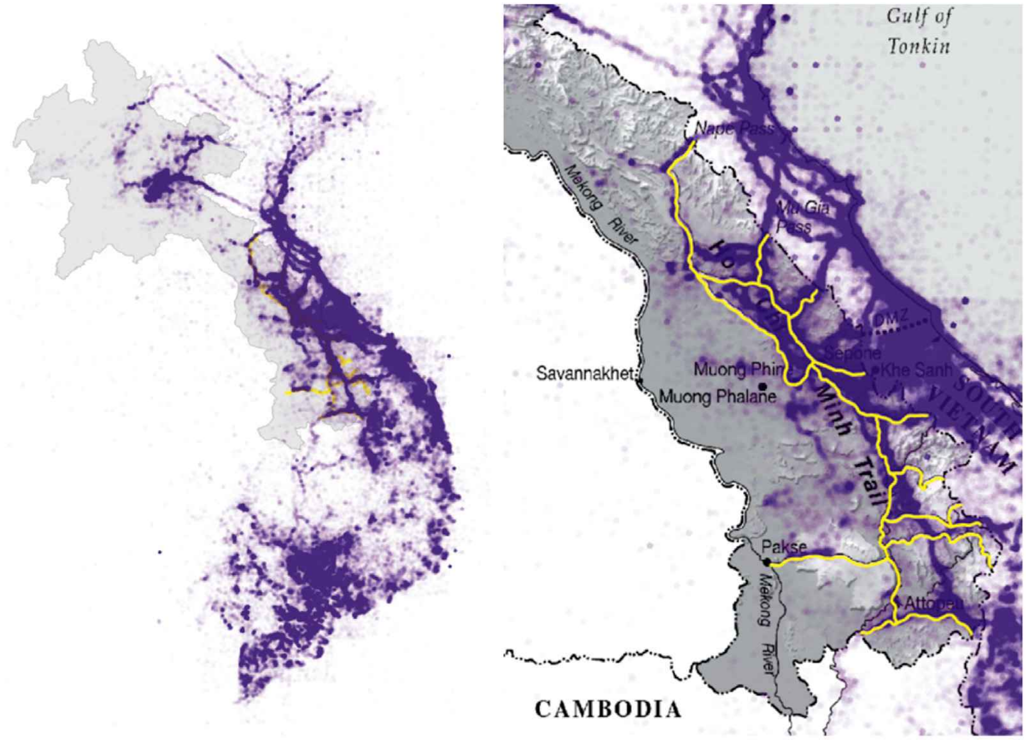
This study first asks whether the bombing missions during the Secret War affected later economic development in terms of the level of economic activities in Laos. Although the question of whether external shocks affect long-run economic development is likely to ultimately be an empirical one (Cavallo et al., 2013), we believe it is useful to refer to existing theories, including neoclassical growth, creative destruction, and conflict trap, which have attempted to explain the relationship between external shocks, such as wartime bombings, and subsequent long-term economic development. 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, the traditional neoclassical growth theory predicts that the destruction of war leads to losses in both physical and human capital but does not affect the rate of technological progress. That is, affected areas experience an accumulation of capital (a short-term increase in investment results in a higher growth rate) and the economy converges back to a balanced growth trend and a steady-state level. 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 economic development compared with before the shock (Aghion and Howitt, 1992). This is because destruction may provide the opportunity for the affected area to introduce higher-quality physical capital that facilitates greater technological progress; this is supported by the empirical findings of Hornbeck and Keniston (2017), among others. The main difference between the two models is that technological progress is a given in neoclassical growth theory, whereas it is endogenously determined in Schumpeter's creative destruction. Typically, technological progress cannot be directly observed, especially in the case of developing countries such as Laos, where (quality) data are not readily available—suggesting that it is a very difficult task to distinguish the two models. Third, the conflict trap theory, based on the poverty trap concept 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 results of Abadie and Gardeazabal (2003). Although there is some empirical support for these three different theoretical explanations of the post-shock growth trajectory and the level of economic activities of an affected economy, there is no unified answer, which indicates that the question of whether external shocks affect long-run economic development is an empirical one after all (Cavallo et al., 2013).

This study additionally asks whether conditional economic convergence existed within Laos after the war. Specifically, we test whether poor regions (villages in our data) grow 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).

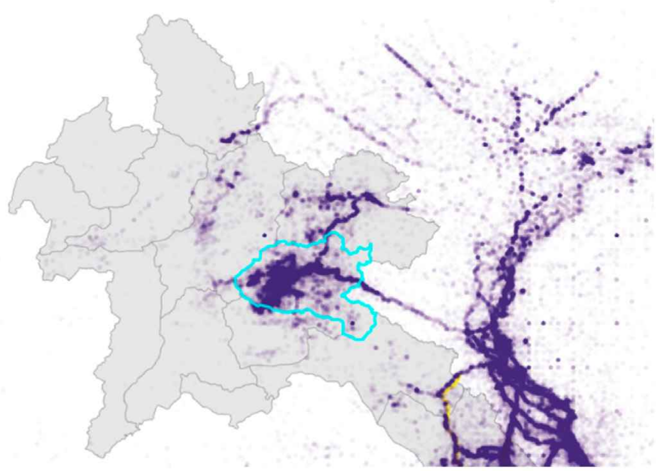
To our knowledge, there have been no rigorous quantitative investigations of the effect of bombing missions in Laos (Fig. 1, Panel A) during the Vietnam War. To examine this effect, we take advantage of the historical fact that the U.S. Army dropped vast numbers of bombs on communist supply lines along the Ho Chi Minh Trail (HCMT; Fig. 1, Panel B) as well as in parts of Xieng Khouang Province (Fig. 1, Panel C). To overcome the plausibly non-random feature of 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 the most bombed village per km^2 in Xieng Khouang Province in the case of northern Laos to the respective geographical centroid of each 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 from 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). Having said that, it is challenging to find valid instruments for empirical exercises. Some researchers consider distance instruments to be potentially problematic due to the weak instrument issue or the violation of exclusion restriction. Although the latter cannot be examined by a formal statistical test, for the former, some papers are susceptible to estimation bias toward ordinary least squares (OLS) due to weak instruments. For instance, Nunn (2008) uses the distances from each African country to locations where there was a demand for slaves in order to show that distances to slave markets are not necessarily correlated with distances to other locations that are important for economic development, but most of the weak instrument test results failed to show a strong relevance. Miguel and Roland (2011) use the distance from the 17th parallel demilitarized zone to represent the intensity of bombing missions in Vietnam during the Vietnam War, but the paper does not show the results of the weak instrument test (see Fig. 2).

Our study makes four contributions to the literature. First, we employ village-level analysis, which is an observation unit smaller than those used in past studies, which used more aggregated administrative units. In general, government statistics are not readily available for detailed village-level information. Therefore, we compiled geocoded bombing and other high-resolution grid-level data to conduct our village-level analysis. Second, unlike past research that relied on observational data, we use satellite images for the main dependent variable (mean nighttime light intensity) and most of the control variables, which are deemed to be objective and more accurate (fewer measurement errors) compared with observational data. This is particularly advantageous for an analysis of less-developed countries in which the statistical capacity building by donor communities is ongoing. Third, this study extends previous research that investigated the long-term impact of U.S. bombing missions on economic development by employing nighttime light intensity data. Henderson et al. (2012) use nighttime light intensity panel data from around 190 countries during 1992–2008 to substantiate a strong correlation between variations in nighttime lights and economic growth rate. Fourth, and most 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 below in the analytical section, the coefficients of the bombing variable are overestimated and the statistical significance is somewhat improved without use of a control for pre-bombing economic conditions. By controlling for pre-bombing economic conditions, the estimation results can be considered 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 presents the analytical results, argues their



Panel C: Northern Laos



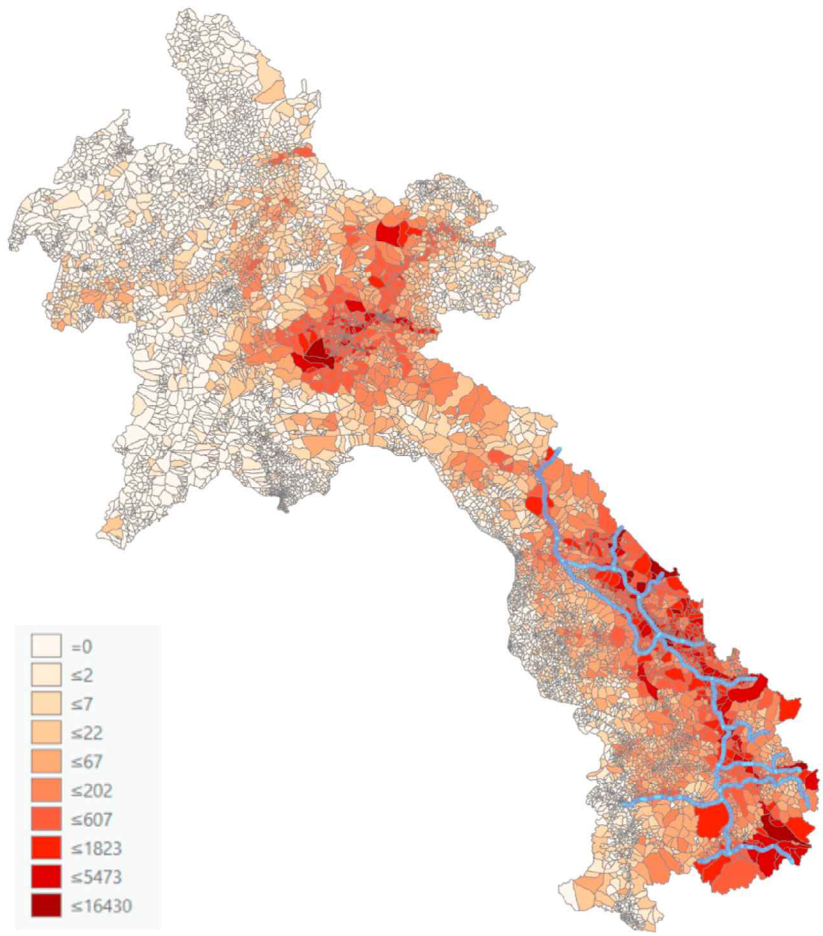
Source: Author's compilation based on THOR Vietnam bombing operations and CartoGIS Services, College of Asia and the Pacific, The Australian National University
Note: Dark purple dots denote the distribution of U.S. bombing missions. Gray areas denote level 0 and level 1 administrative boundaries of Laos (Panel A and Panel C, respectively). Yellow lines denote the main routes of the HCMT, 1967 (Panel B). The light blue outline shows the border of Xieng Khouang Province (Panel C).

Fig. 1. Distributions of U.S. bombing missions.

robustness, and discusses the possible mechanisms. Section 5 concludes the paper.

2. Background: from the opening of the HO CHI MINH trail 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 its defeat at the Battle of Dien Bien Phu in 1954, France initiated peace negotiations with Vietnam, which resulted in the withdrawal of France and the signing of the Geneva Accords. The Geneva Accords included a ceasefire agreement, recognized the independence of the Indochinese countries (Vietnam, Laos, and Cambodia), and established the 17th parallel



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 classification of colors approximates the geometry interval, giving an equal class width and consistent frequency for observations per class. The light blue line denotes the HCMT.

Fig. 2. Number of U.S. bombing missions in Laos by village.

provisional military demarcation line in Vietnam to allow the French Union forces in the south and the Viet Minh in the north to regroup as a step toward unifying the country. Contrary to expectations, however, the north–south unification election based on the accords was not realized because the south, which was backed by the U.S., refused to participate out of fear of the rise of communism in Southeast 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 along the HCMT on the western border of Vietnam, to keep them 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, an estimated 30% failed to explode, thereby contaminating up to 25% of the villages and 14 of the 17 provinces in Laos (NRA, 2015); this likely still hampers the country's socio-economic development. In contrast to the intense attention paid to Vietnam as a primary actor in the Vietnam War, relatively few 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 16 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 initially passable only on foot but was gradually expanded to accommodate vehicles (Morris and Hills, pp.15–16, 2006).

By the early 1960s, the network of the HCMT near the border between Laos and Southern Vietnam, which linked to the camps of the Viet Cong in southern Laos, evolved into a truck route during the dry season. As part of its assistance to South Vietnam, the U.S. provided border control along South Vietnam's long boundary with Laos and Cambodia with the aim of reducing the flow of supplies from the Democratic Republic of Vietnam to the Viet Cong. In this regard, the United States Military Assistance Command Vietnam (USMACV), established in February 1962, was principally in charge of analyzing infiltration data. The USMACV underestimated the number of infiltrations, which reflects the fact that presidential aide Michael V. Forrestal and Roger Hilsman, the Director of the Bureau of Intelligence and Research at 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 First Indochina War had now joined the Viet Cong and that Hanoi had sent its

Table 1
Summary of statistics for villages in southern and northern Laos.

Panel A: Villages in Southern Laos	Mean	S.D.	Max	Min	Observations
Mean nighttime light intensity in 1992	0.2	1.4	23.3	0	4351
Mean nighttime light intensity in 2005	0.6	3.1	34.7	0	4351
Mean nighttime light 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 1973 per km^2	10.4	39.5	949.8	0	4351
Distance from the centroid of villages to HCMT (km)	35.8	28.4	107.6	0	4351
Mean monthly temperature in 1950 (°C at the centroid)	24.6	1.4	26.4	17.1	4351
Mean monthly temperature in 1980 (°C at the centroid)	25.3	1.5	27.1	18.0	4351
Mean monthly temperature in 1990 (°C at the centroid)	24.9	1.4	27.1	17.5	4351
Mean monthly temperature in 1992 (°C at the centroid)	24.8	1.5	27.2	16.0	4351
Mean monthly temperature in 2005 (°C at the centroid)	25.4	1.5	27.4	17.9	4351
Mean monthly temperature in 2013 (°C at the centroid)	25.6	1.4	28.0	17.9	4351
Mean monthly precipitation in 1950 (mm at the centroid)	191.4	32.8	241.8	128.8	4351
Mean monthly precipitation in 1980 (mm at the centroid)	179.5	29.2	232.8	122.0	4351
Mean monthly precipitation in 1990 (mm at the centroid)	170.5	29.8	244.2	99.3	4351
Mean monthly precipitation in 1992 (mm at the centroid)	150.6	27.6	206.1	88.8	4351
Mean monthly precipitation in 2005 (mm at the centroid)	194.1	28.7	265.6	143.7	4351
Mean monthly precipitation in 2013 (mm at the centroid)	182.2	25.9	241.0	141.2	4351
Altitude of administrative boundary (m at the centroid)	286.2	261.8	1635.2	64.5	4351
Terrain slope (degrees at the centroid)	7.5	8.6	70	0	4351
Panel B: Villages in Northern Laos	Mean	S.D.	Max	Min	Observations
Mean nighttime light intensity in 1992	0.9	5.1	58.5	0	5684
Mean nighttime light intensity in 2005	1.5	6.9	61.0	0	5684
Mean nighttime light 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 1973 per km^2	2.9	15.8	343.6	0	5684
Distance from the centroid of the most bombed village in Xieng Khouang Province (km)	187.6	86.0	377.8	0	5684
Mean monthly temperature in 1950 (°C at the centroid)	21.8	2.0	25.5	16.6	5684
Mean monthly temperature in 1980 (°C at the centroid)	22.7	2.2	27.2	17.5	5684
Mean monthly temperature in 1990 (°C at the centroid)	22.4	2.2	26.8	17.4	5684
Mean monthly temperature in 1992 (°C at the centroid)	22.3	2.2	26.6	17.1	5684
Mean monthly temperature in 2005 (°C at the centroid)	22.7	2.2	27.2	17.5	5684
Mean monthly temperature in 2013 (°C at the centroid)	23.0	1.8	26.6	18.1	5684
Mean monthly precipitation in 1950 (mm at the centroid)	138.1	27.1	260.4	105.7	5684
Mean monthly precipitation in 1980 (mm at the centroid)	107.3	31.6	222.5	42.1	5684
Mean monthly precipitation in 1990 (mm at the centroid)	133.2	29.7	268.6	77.9	5684
Mean monthly precipitation in 1992 (mm at the centroid)	114.8	37.6	222.3	35.3	5684
Mean monthly precipitation in 2005 (mm at the centroid)	145.2	26.1	275.1	99.8	5684
Mean monthly precipitation in 2013 (mm at the centroid)	145.4	24.4	247.8	100.4	5684
Altitude of administrative boundary (m at the centroid)	670.5	350.8	2219.6	150.2	5684
Terrain slope (degrees at the centroid)	18.5	12.3	68	0	5684

Note: Villages with zero population were excluded from the observations in population data. In the 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 in which the share of bright core is small.
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, SRTM30, and USGS.

own draftees (Van Staaveren, pp.8–12, 1993). While the main activity of the South had so far been limited to monitoring the movement of the North, the U.S. Air Force (USAF) started the first systematic bombing campaigns in December 1964. The first mission of Operation Barrel Roll was carried out by USAF aircraft based in Da Nang that carried 750-pound bombs, CBU-2A bomblets, and AGM-12 Bullpup missiles (Van Staaveren, p.44, 1993). The bombing missions spread throughout the eastern part of Laos, ranging from near 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 (Appendix Figure A1, Panel A).

The main role of Operation Barrel Roll was to signal the strength of the U.S. Army and exert greater military pressure on the North near the Plain of Jars in Xieng Khouang Province, where the North Vietnamese army held power. However, this did not work because there was no reaction, public or otherwise, from Hanoi after the first half-dozen Barrel Roll missions (Van Staaveran, 1993). In addition, Operation Rolling Thunder was initiated in March 1965 with an objective similar to that of Barrel Roll, namely, dropping bombs on the northeastern part of Laos. It is said that the amount of ordinance was massive, far greater than that used during the entire Korean War (Polmar and Marolda, p.61, 2015). After the initiation of Rolling Thunder, northern bombings were carried out under both Rolling Thunder and Barrel Roll and the southern bombings were carried out under Operation Steel Tiger, which began in April 1965 (Appendix Figure A1, Panel B). The main objective of Steel Tiger was to stop infiltrations and material movements from the communist North to South Vietnam through the HCMT. Operation Commando Hunt, a major aerial interdiction campaign that began in November 1968, continued during that time. President Johnson would later halt the bombing campaigns in northern Laos under Operation Rolling Thunder and shift the military power to southern Laos (Nguyen, p.28, 2013).

As a result of these major aerial operations, Laos was hit with a great number of bombs, particularly around the Plain of Jars and along the HCMT. Furthermore, anecdotal evidence suggests that the Plain of Jars 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 because the planes could not land with their explosives still attached (Congressional Research Service [CRS], p.8, 2019; Reuter, 2016) (Appendix Figure A2). At its peak, there were an estimated 120,000 workers on the HCMT. However, the series of operations by the USAF contributed to about 20,000 deaths, 30,000 serious injuries, and 6000 missing persons throughout the war. The majority of these casualties were along the routes of the HCMT (Morris and Hills, p17, 2006).[3]

3. Data and methodology

3.1. Data

Table 1 summarizes the variables used in this paper. Each variable is explained in order below.

3.1.1. Village-level administrative unit

The analysis was performed at the disaggregated level of administrative units, namely, villages. To compile village-level data, we used the shapefile of village-level administrative boundaries from 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 and 19th parallels north. By using data from southern Laos, we were able to mitigate the impact of bombing missions other than those on the HCMT, particularly that of Xieng Khouang, the most heavily bombed province, which is famous for making spoons from 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, because the planes could not land with explosives still attached (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 Theater History of Operations Reports (THOR) released by the U.S. Department of Defense, the province was hit by a great number of bombs.

3.1.2. Bombing missions

For information on U.S. bombing missions, we referred to THOR, which is publicly available from the U.S. Department of Defense. THOR is a reliable source for reviewing U.S. air activity from 1915 to 1975, and allows for historical summaries based on user-selected criteria to be generated for the purpose of answering basic questions such as 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 collection of releasable U.S. air operations data, with a total 4,670,416 records of bombing missions over the course of the Vietnam War (1965–1975) alone. Starting with the entire dataset, we first deleted 1,478,304 non-kinetic missions (31.7% of the total) and then removed 186,824 missions that did not have geographical coordinates. Next, we extracted the bombing missions that intersected with the border of Laos. Finally, we had a total of 900,065 missions, 707,834 of which took place in the south and 192,231 in the north. The oldest available data for Laos is from 1965 and the most recent from 1973. A potential concern about this bombing data is the possibility of systematic attrition due to the lack of geographic coordinates; however, this constitutes only around 3.5% (31,392 missions) of the total available data for Laos.[4] Having said that, the measurement error issue remains and we address this by employing the instrumental variable approach (see Section 3.2). The types of bombs used during the Vietnam War included free-fall bombs, guided bombs, and fuel–air explosives. The size difference of each village was accounted for by normalizing the number of bombing missions by village area in square kilometers, we consider the density of bombing missions in each village.

3.1.3. Nighttime light emissions as a proxy for economic activities

We employ the nighttime light intensity data 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 these data, Henderson et al. (2012) substantiate a strong correlation between variations in nighttime lights and economic growth rate by using panel data for around 190 countries from 1992 to 2008. Hence, to provide a proxy for economic activities, we use the satellite images of nighttime lights released by the U.S. 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 tend to be large. Satellite images also enable us to capture smaller economic activities up to the grid level, allowing us to conduct village-level analyses.[5] The products are 30×30 arc-second grids equivalent to approximately 0.86 km^2 at the equator, spanning $-180°$ to $180°$ longitude and $-65°$ to $75°$ latitude. Data values range from 0 to 63. Although nighttime light data are 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, which is due to the algorithms used to filter out noise in the raw data, and this leads to an undercount of lights nationally (Henderson et al., p.1000, 2012). Henderson et al. (2012); Michalopoulos and Papaioannou (2013, 2014), and Hodler and Raschky (2014) add a small constant term before taking the logarithm of mean nighttime light intensity in each village. This is also useful to prevent losing observations with zero value nighttime light intensity after logarithm transformation. However, estimation results are susceptible to the magnitude of the small constant term, and thus we use an inverse hyperbolic sine (IHS) transformation similar to logarithm transformation, which allows zero-valued observations to be retained.[6] For the village-level compilation of grid-level nightlight data, we first collect all nighttime light grids that overlap each village-level administrative boundary, and then compute the mean intensity of nighttime light for the respective village. We use this outcome variable for 1992, 2005, and 2013.

[3] Massive losses were due in part to diseases such as malaria and dysentery.

[4] Of the bombing missions without geographical coordinates, which already excludes non-kinetic missions, South Vietnam accounts for the largest share at 58.5%, followed by Laos (26.9%), North Vietnam (8%), and Cambodia (4.8%).

[5] More specifically, for the nighttime lights 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, nighttime light outliers (e.g., sunlit and glare data, which are excluded based on the solar elevation angle) and cloud cover that makes surfaces of the earth unobservable are properly rejected by scientists at the NGDC, and thus the nighttime lights are mostly artificial. Out of the available image types for Version 4 DMSP-OLS Nighttime Lights Time Series, we use the cleaned one containing 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. Background noise is identified and replaced with values of zero. Areas with zero cloud-free observations are represented by the value 255.

[6] The IHS transformation of x is denoted by the following equation: $\log(x + ((x\hat{2} + 1)\hat{0}.5))$. In our specification, results using an IHS transformation are qualitatively the same as those that add a small constant term (i.e., 0.01) before taking the logarithm of mean nighttime light intensity for each village.

3.1.4. 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.[7] The data have a resolution of 5-min grids (approximately 10 km at the equator). To control for pre-bombing economic conditions, which provides estimation results that can be considered less biased, we compute the population density data for 1950 and use the outcome variable for 1990 and 2005. The correlations between the mean nighttime light intensity and total population per km^2 were high: 65.5% in the early 1990s and 70.6% in 2005 in southern Laos, and 73.6% in the early 1990s and 79.5% in 2005 in northern Laos.[8]

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

We used a georeferencing technique to derive 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 that the HCMT was strategically and heavily bombed by the U.S. Army to destroy the communist supply lines, this distance can be deemed an instrumental variable for bombing missions in southern Laos.

3.1.6. Distance from the centroid of villages to the centroid of the most bombed village in 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 northeastern part of the country was a target of heavy bombardment campaigns by U.S. airplanes during the Secret War. Accordingly, we used the distance between the centroid of the most bombed village in Xieng Khouang Province and the centroid of each village as an instrumental variable for northern Laos.

3.1.7. 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). Given that agriculture in Laos is linked to income for agricultural workers, we use weather variations as control variables in the econometric specifications. Temperature and precipitation data are from the Terrestrial Air Temperature and Terrestrial Precipitation of Version 5.01 Gridded Monthly Time Series 1900–2017, and both are interpolated and documented by Kenji Matsuura and Cort J. Willmott from the University of Delaware. The monthly averages of station temperature (°C) and precipitation (mm) are interpolated to a 0.5 ° × 0.5 ° resolution (about 55.5 × 55.5 km) latitude and longitude grid.[9]

3.1.8. Altitude

As a regional topographic characteristic, altitude is used as an additional control variable. Altitude data are 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-s resolution (about 900 m) dataset SRTM30. The altitude at the geographical centroid of each village is taken as the altitude of that village.

3.1.9. Terrain slope

Similar to altitude, terrain slope reflects the nation's natural topography. Areas with a steep slope tend to have difficulty introducing infrastructure investments for both mechanization of agriculture and industrialization. Terrain slope data are from the 3D Elevation Program of the United States Geological Survey (USGS) National Geospatial Program. The terrain slope of each village is represented by the slope at the geographical centroid of each village.

3.2. Methodology

Cross-sectional regression using OLS and the instrumental variables approach.

To investigate the effect of bombing missions during the Vietnam War on later long-term economic outcomes, an instrumental variables approach and a cross-sectional dataset were employed to overcome the possibility of non-random spatial distributions of 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 an instrument of bombing intensity in southern and northern Laos, we employ the *distance from the centroid of villages to the nearest point of the HCMT (DISTANCE_HCMT) and the centroid of the most bombed village in Xieng Khouang Province (DISTANCE_XIENG_KHOUANG), respectively.*

In our empirical approach, we employ two types of data as outcome variables: mean nighttime light intensity in 1992, 2005, and 2013, and total population per km^2 in 1990 and 2005. The reason for using 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 conflict and an inefficient central planning system. However, after the mid-2000s, economic activities accelerated in conjunction with formal participation in ASEAN in 1997 and a surge of foreign direct investments, which were mainly in the resource sector. The estimation model is formulated as Equation (1).

$$\begin{aligned} &NIGHTSLIGHTS_{i;1992,2005,2013} \ or \ POPULATION_{i;1990,2005} = \alpha \\ &+ \beta BOMBS_{i,1965-1973} + \gamma PRE\_BOMBING\_POPULATION_{i,\ 1950} \\ &+ \delta OTHER\_CONTROLS_{it} + \eta_d + \varepsilon_{it} \end{aligned} \tag{1}$$

Here, the mean nighttime light intensity for the years 1992, 2005, or 2013 and total population per km2 in 1990 or 2005 of village i*in district* d*are the outcome variables*[10] total bombing missions from 1965 to 1973 per km^2 *for BOMBS; total population per km2 in 1950 (before the Vietnam War) for PRE_BOMBING_POPULATION, temperature, precipitation, elevation, and terrain slope 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):*

$$\begin{aligned} &BOMBS_{i,1965-1973} = a \\ &+ bDISTANCE\_HCMT_i \ or \ DISTANCE\_XIENG\_KHOUANG_i \\ &+ cPRE\_BOMBING\_POPULATION_{i,\ 1950} + dOTHER\_CONTROLS_{i,t} + e_d \\ &+ f_{it}. \end{aligned} \tag{2}$$

3.2.1. Growth regressions to test within country convergence

Next, we conduct growth regressions to test the conditional convergence hypothesis, arguing that poorer countries or regions tend to grow faster. There have been many empirical studies that tested the hypothesis by using two approaches: (i) cross-country income convergence, Baumol (1986), Barro and Sala-i-Martin (1992a), Sala-i-Martin (1996), Barro (2015), and Lessmann and Andre (2017), among others; and (ii) regional income convergence within a country, Barro and Sala-i-Martin (1991, 1992b), among others. We test the latter within-country convergence

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

[8] Because nighttime light data is only available from 1992 onward, we compare the village-level population density per km^2 in 1990 and the mean nighttime light intensity in 1992 as the oldest year of comparison.

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

[10] Villages with zero population in 1990 and 2005 were excluded from the observations.

Table 2
Predicting bombing intensity: Villages in southern and northern Laos.

	Dependent variable: 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
Distance from the centroid of administrative boundary to the HCMT (km)	−0.664*** (0.0218)	−0.258*** (0.0296)	−0.258*** (0.0725)			
Distance from the centroid of administrative boundary to the centroid of most bombed village in Xieng Khouang Province (km)				−1.033*** (0.0242)	−1.05*** (0.0870)	−1.05*** (0.169)
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	0.386	0.678	0.678	0.532	0.712	0.712

Note: Significant at the 90% (*), 95% (**), and 99% (***) levels. Standard errors in parentheses. The authors used IHS transformation for the following variables: population, bombing missions, distance from the centroid of villages to the HCMT, distance from the centroid of villages to the centroid of the most bombed village in Xieng Khouang Province, and terrain slope. The control variables (i.e., temperature, precipitation) are those from 1950. Villages with zero population as of 2005 and 1990 were excluded from the observations.
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, SRTM30, and USGS

hypothesis by using population density data in 1980 (right after the war) and in 2005. The following is the econometric specification (Equation (3)).

$$POPULATION\_GROWTH\_RATE_{i,1980-2005} = \theta + \vartheta BOMBS_{i,1965-1973} + \pi PRE\_BOMBING\_POPULATION_{i,\ 1950} + \sigma OTHER\_CONTROLS_{it} + \tau_d + \omega_{it}. \tag{3}$$

Here, the dependent variable is the growth rate of *total population per km2* 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 that the less-developed villages grew faster, which supports the conditional convergence hypothesis. It should be noted that although growth in income is typically used as the dependent variable in conditional convergence tests, we used growth in population density. However, this specification is supported by the regional science literature; for example, Glaeser et al. (1995) show that income and population growth move together, and Crihfield and Panggabean (1995) claim that population convergence is not unrelated to convergence in per capita income. Indeed, village-level total population per km^2 and mean nighttime light intensity are highly correlated, as we discussed in Section 3.1.

4. Analysis

4.1. Predicting BOMBING intensity

T*he first-stage estimation of the instrumental variables approach predicts bombing intensity by using two instruments, DISTANCE_HCMT and DISTANCE_XIENG_KHOUANG, for southern and northern Laos, respectively (Equation (2)). The estimation results in Table 2 show a strong correlation between them, which was significant at the 1% level. The negative coefficients indicate that the number of bombs per km2 becomes smaller as the distance from the HCMT and Xieng Khouang Province becomes greater. Furthermore, the relevance of the instrumental variable is confirmed by the weak instrumental variable test statistics from the first-stage regression. If* the weak instrumental variable test statistic exceeds 10 in the threshold for the weak instruments test formalized by Staiger and Stock (1997), the instrument is regarded as sufficient. The weak instrumental variable test statistics in the present study are reported in the tables in the following subsections, and they are above 10 in most cases.

As previously discussed, we mitigate biases from the existence of endogeneity and measurement errors by employing an instrumental variables approach. *However, we have one remaining concern about the violation of the exclusion restriction, namely, that DISTANCE_HCMT and DISTANCE_XIENG_KHOUANG directly affect economic activities in the villages, not indirectly through bombing missions. In fact, the HCMT was located mostly in underdeveloped areas, initially in the jungle, and was passable only on foot. The HCMT was also called 'Trường Sơn' by the communist North, after the rugged Annamite Range mountains, which extend through Laos, Vietnam, and northern Cambodia. Similarly, Xieng Khouang Province is characterized by its mountainous topography. Hence, proximity to the HCMT and Xieng Khouang Province can represent areas with relatively less economic activities.* Ultimately, however, there is no established test that definitively investigates the validity of instruments in the context of exclusion restriction (Kiviet, 2020).

To alleviate this concern about the violation of exclusion restriction as much as possible, we first used 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 in Vietnam during the Vietnam War. By controlling for pre-bombing economic conditions, the estimation results can be considered to be less biased (see Sections 4.2 and 4.3). Furthermore, we control for precipitation and temperature, which are factors likely to affect subsequent economic activities, particularly in Laos, where agriculture has long been a dominant part of the economic structure. To consider topographic characteristics, we control for elevation and terrain slope. Typically, hilly and mountainous areas have difficulty introducing physical infrastructures such as roads and highways because they require vast amounts of investments for cutting trees, tunneling through mountains, and leveling land. Finally, although some relevant literature does not control region fixed effects (e.g., Miguel and Roland, 2011), in the present study, we control some of the other district-level characteristics by using district fixed effects.

4.2. Local BOMBING impacts on economic activities proxied by nighttime light intensity

Table 3a shows the long-term impacts of bombing missions on nighttime light intensity 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.

All coefficients of the total U.S. bombing intensity on the mean nighttime light intensity are negative except for southern Laos in 2013 in

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

Table 3a
Long-term impacts of bombing missions on mean nighttime light intensity in 1992, 2005, and 2013.

Panel A: The nearest 25% of villages to the centroid of the most bombed village in Xieng Khouang Province in northern Laos					
	Mean	S.D.	Max	Min	Observations
Mean nighttime light intensity in 1992	0	0	0	0	1421
Mean nighttime light intensity in 2005	0.1	0.6	6.5	0	1421
Mean nighttime light intensity in 2013	0.8	3.9	51	0	1421
Altitude	935.1	331.7	2219.6	155.2	1421
Terrain slope	21.1	11.3	53	0	1421
Panel B: All villages in northern Laos					
	Mean	S.D.	Max	Min	Observations
Mean nighttime light intensity in 1992	0.9	5.1	58.5	0	5684
Mean nighttime light intensity in 2005	1.5	6.9	61.0	0	5684
Mean nighttime light intensity in 2013	3.5	10.8	63	0	5684
Altitude	670.5	350.8	2219.6	150.2	5684
Terrain slope	18.5	12.3	68	0	5684

Note: Significant at the 90% (*), 95% (**), and 99% (***) levels. Standard errors in parentheses. The authors used IHS transformation for the following variables: nighttime light intensity, population, bombing missions, distance from the centroid of villages to the HCMT, the distance from the centroid of villages to the centroid of the most bombed village in Xieng Khouang Province, and terrain slope. Villages with zero population as of 2005 and 1990 were excluded from the observations.
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, SRTM30, and USGS

the OLS regression results, suggesting that there was a negative impact from the bombing missions on subsequent economic level (Table 3a, Regressions 1, 4, 10, 13, and 16). However, these results are not always statistically significant and are subject to estimation bias from endogeneity and measurement errors, which provides the rationale for employing the instrumental variables approach. Based on an investigation of the results of the first-stage estimation, the instrument was 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, controlling for pre-bombing economic activity by using the population per km^2 in 1950 plays an important role given that the coefficient of total U.S. bombs per km^2 tends to have an upward bias without the control. Furthermore, the pre-bombing control affects even the statistical significance; the statistical significance of total bombing intensity without the pre-bombing control is at the 5% level in Regression 8 but decreases to the 10% level when the pre-bombing control is included in Regression 9.

The results of the instrumental variables approach, which is conditional on the full control variables, show contrasting results between southern and northern Laos. In southern Laos, there is no robust relationship between bombing missions and long-term economic development as proxied by nighttime light intensity, except in 2013. 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. This may reflect the positive spillover effect of the HCMT as a transportation network that fostered later economic development in southern Laos. Although originally a small jungle route passable only on foot, the HCMT developed into a comprehensive transportation network covering nearly 12,500 miles (more than 20,000 km). It is plausible that the HCMT began playing a crucial role as transportation infrastructure, driving economic activities to a certain extent. In addition, the two-lane highway project along the HCMT linking the southern Lao province of Salavan to Vietnam, which was announced in 2000 by the Government of Vietnam, might have further increased investments in southern Laos (New York Times, 2000; Communist Party of Vietnam, 2010).[12] Given these developments, a creative destruction model might have been dominant over the very long run (i.e., in 2013, about 40 years after the end of the war).

Meanwhile, in northern Laos, the instrumental variable results, which were conditional on all the control variables in Columns 12, 15, and 18, were negative and statistically significant at the 5% level in 1992 and the 1% level in 2005 and 2013, implying a negative impact of the bombing missions. Furthermore, the magnitude of the coefficient is becoming more negative. These results imply that the bombings in northern Laos left sustained negative impacts in severely bombed villages even about 40 years after the war, which may imply that we cannot rule out prediction by the conflict trap theory. In fact, the nighttime light intensity is much smaller in the nearest 25% of villages to the centroid of the most bombed village in northern Laos, where the topography is characterized as the highest elevation and most mountainous landscape (Table 3b). The economy there is underdeveloped and dependent on farming, which is not very productive, and micro-scale retail activities such as selling souvenir spoons made from UXO scrap metal. Unlike the case in southern Laos, the economic integration of major cities such as Vientiane (the official capital) and Luang Prabang (the religious and cultural capital) with neighboring Vietnam has been hampered by the lack of transportation infrastructure due to the disadvantageous topography. Moreover, there is anecdotal evidence supporting claims of vast numbers of unexploded cluster bombs in Xieng Khouang Province (Al Jazeera, 2018).

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 for the years 1990 and 2005. Population density is also considered a useful proxy for the density of economic activities, as discussed in Section 3. Hence, the estimation results using population density data would be a good reference for the results based on mean nighttime light intensity shown in Table 3a. All the regressions controlled for district fixed effects with standard errors clustered at the district level. Panel A shows data from southern Laos and Panel B shows data from northern Laos.

The OLS regression results of the long-term effect of bombing on population density was not statistically significant for all the regressions (Table 4, Regressions 1, 4, 7, and 10), indicating that the bombing impact did not persist for later economic development in Laos. However, again, these OLS regression results were affected by estimation bias from endogeneity and measurement errors in the bombing records. Hence, we relied on the instrumental variables approach to overcome these challenges. The first-stage estimation results show the effectiveness of the instruments for all regressions, which were conditional on the full set of controls. Most of the results of the instrumental variables approach indicate no robust relationship between bombing missions and long-term economic development (Table 4, Regressions 2, 5, 8, 9, 11, and 12). In addition, we found that the coefficient of total U.S. bombs per km^2 was largely overestimated without the pre-bombing control, as in Table 3a. However, it is noteworthy that the results of the instrumental variables approach in Regressions 3 and 6 in southern Laos were positive and statistically significant at the 10% level, implying rapid recovery in relatively heavily bombed villages. These are not necessarily consistent with the results shown in Table 3a based on nighttime light intensity as

[12] The project covered about 1000 miles between the northern province of Ha Tay and Ho Chi Minh City and was scheduled for completion in 2003 at a cost of about USD 375 million.

Table 3b

Summary statistics on mean nighttime light intensity, altitude, and terrain slope of northern Laos.

Panel A: Villages in southern Laos									
	Dependent variable: Mean nighttime light intensity per km^2								
	1992			2005			2013		
	(1) OLS	(2) IV/2SLS	(3) IV/2SLS	(4) OLS	(5) IV/2SLS	(6) IV/2SLS	(7) OLS	(8) IV/2SLS	(9) IV/2SLS
Total U.S. bombs per km^2	−0.021 **	−0.0153	−0.0272	−0.00224	0.120	0.0968	0.0871 **	0.648 **	0.616 *
	(0.00991)	(0.0426)	(0.0450)	(0.0271)	(0.125)	(0.126)	(0.0421)	(0.324)	(0.318)
Population in 1950 per km2	0.176 **		0.176 **	0.256 **		0.245 **	0.406 ***		0.34 ***
	(0.0784)		(0.0786)	(0.0964)		(0.101)	(0.0949)		(0.118)
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	0.461	–	–	0.492	–	–	0.449	–	–
Weak IV test statistics	–	15.5	15.5	–	13.2	12.9	–	15.1	14.9
IV at the first-stage significant?	–	1%	1%	–	1%	1%	–	1%	1%
Panel B: Villages in northern Laos									
	Dependent variable: Mean nighttime light 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
Total U.S. bombs per km^2	−0.0453**	−0.0434	−0.101**	−0.0662*	−0.0853	−0.194***	−0.0905	−0.233**	−0.422***
	(0.0204)	(0.0304)	(0.0496)	(0.0367)	(0.0623)	(0.0716)	(0.0560)	(0.114)	(0.113)
Population in 1950 per km^2	0.195***		0.21***	0.352***		0.386***	0.576***		0.664***
	(0.0650)		(0.0668)	(0.0907)		(0.0907)	(0.106)		(0.0989)
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	0.778	–	–	0.717	–	–	0.662	–	–
Weak IV test statistics	–	44.8	64.5	–	30.2	40.9	–	31.7	41.1
IV at the first-stage significant?	–	1%	1%	–	1%	1%	–	1%	1%

Source: Author's compilation based on NOAA

Table 4

Long-term impacts of bombing missions on the population per km[21] in 1990 and 2005.

	Panel A: Villages in southern Laos					
	Dependent variable: Population per km^2					
	1990			2005		
	(1) OLS	(2) IV/2SLS	(3) IV/2SLS	(4) OLS	(5) IV/2SLS	(6) IV/2SLS
Total U.S. bombs per km^2	0.00634	0.274	0.206*	0.00943	0.357	0.229*
	(0.0116)	(0.231)	(0.124)	(0.0126)	(0.251)	(0.128)
Population in 1950 per km^2	1.343***		1.321***	1.37***		1.344***
	(0.0550)		(0.0518)	(0.0645)		(0.0591)
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	0.950	–	–	0.948	–	–
Weak IV test statistics	–	13.9	13.7	–	13.2	12.9
IV at the first-stage significant?	–	1%	1%	–	1%	1%
	Panel B: Villages in northern Laos					
	Dependent variable: Population per km^2					
	1990			2005		
	(7) OLS	(8) IV/2SLS	(9) IV/2SLS	(10) OLS	(11) IV/2SLS	(12) IV/2SLS
Total U.S. bombs per km^2	−0.000782	0.394	−0.0430	0.00199	0.408	−0.0343
	(0.0148)	(0.349)	(0.0852)	(0.0160)	(0.343)	(0.0820)
Population in 1950 per km^2	1.545***		1.556***	1.564***		1.573***
	(0.0269)		(0.0342)	(0.0291)		(0.0353)
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	0.976	–	–	0.970	–	–
Weak IV test statistics		30.5	42.7		30.2	40.9
IV at the first-stage significant?	–	1%	1%	–	1%	1%

Note: Significant at the 90% (*), 95% (**), and 99% (***) levels. Standard errors in parentheses. The authors used IHS transformation for the following variables: nighttime light intensity, population, bombing missions, distance from the centroid of villages to the HCMT, distance from the centroid of villages to the centroid of the most bombed village in Xieng Khouang Province, and terrain slope. Villages with zero population as of 2005 and 1990 were excluded from the observations.

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, SRTM30, and USGS an outcome variable. In the early 1990s, the coefficient in Column 3 of Table 3a was negative, whereas that in Column 3 of Table 4 was positive. In 2005, both coefficients were positive, but only Column 6 in Table 4 is statistically significant. These differences could indicate that recovery time varies between population density and economic activities proxied by nighttime light intensity. That is, after catastrophic external shocks such as bombings have ceased, the population level recovers first, and then economic activities expand (the level of the economic expansion should rely on the level of capital investments given that the marginal product of labor in an agrarian economy is limited). Furthermore, Columns 12 and 15 in Table 3a show the negative and statistically significant coefficients of the bombing impacts on nightlight intensity in northern Laos in 1992 and 2005. The bombing impacts on population density are not statistically significant but show similarly negative coefficients in Columns 9 and 12 of Table 4. This difference could imply that, again, population level recovers faster than economic activities, as proxied by nighttime light intensity.

4.4. Robustness tests: local BOMBING impacts on economic activities by DISTANCE from the HCMT or the most bombed village in XIENG KHOUANG province

As a robustness check of the estimation results in Sections 4.2 and 4.3, we estimate the bombing impacts on nighttime light intensity and population density according to proximity to the HCMT and the most bombed village in Xieng Khouang Province (Table 5). This robustness test is critical because the high first-stage significance of the instrument may be driven entirely by less bombed villages that are located far from the HCMT and the most bombed village in Xieng Khouang Province. To address these concerns, we estimated the results based on three categories of proximity to the HCMT and the most bombed village in Xieng Khouang Province, namely, the 75th, 50th, and 25th percentiles (e.g., *p75* denotes the top 75% of closest villages to either the HCMT in southern Laos or the most bombed village in Xieng Khouang Province in northern Laos).

The first-stage F-values decrease when we restrict the samples to closer distance to either the HCMT or the most bombed village in Xieng Khouang Province, whereas all the specifications show sufficient F-values except *p25* in southern Laos (Columns 3, 6, 9, 12, and 15 in Panel A). The overall conclusion from the estimation results in Table 5 is that the estimation results in Sections 4.2 and 4.3 are robust even when we restrict the samples based on the distance to the HCMT or the most bombed village in Xieng Khouang Province. In other words, (i) except for the positive and statistically significant effect in 2013 (Columns 7 and 8 show first-stage F-values greater than 10), there is no long-term bombing impact on nighttime light intensity in southern Laos; (ii) the long-term bombing impact on population density is positive and statistically significant for *p75* in southern Laos (Columns 10 and 13), but the positive effects disappear if we restrict this to the villages located closer to the HCMT (*p50* and *p25*; Columns 11, 12, 14, and 15); (iii) there is a sustained negative and statistically significant impact of long-term bombing on nighttime light intensity in northern Laos; and (iv) there is no bombing impact on population density in northern Laos.

4.5. Robustness tests: excluding villages through WHICH the HCMT passed and within XIENG KHOUANG province

We employed the instrumental variables approach in Sections 4.2 and 4.3. Given the 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 information that is unmeasurable and unobservable to researchers, such as economic conditions and political networks among the villages. This is a potential threat to our identification strategy because the location of the HCMT itself could be endogenous. Although 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 was almost purely exogenous to the villages in northern Laos, we remain cautious about this potential threat to our identification strategy.[13] To address this concern about endogeneity and measurement errors, we employed sub-sample estimations for robustness tests by excluding the villages through which the HCMT passed (Panel A) as well as the most bombed villages in Xieng Khouang Province (Panel B). Panel B excludes the 48 villages within 10 km from the centroid of the most bombed village in Xieng Khouang Province (0.8% of total villages, but 6.5% of the total bombings in northern Laos).[14]

Table 6 shows the sub-sample estimation results, excluding the villages through which the HCMT passed as well as the most bombed villages in Xieng Khouang Province. Here, too, we find robustness in the estimation results similar to that shown in Sections 4.2 and 4.3, even after excluding the villages through which the HCMT passed as well as the most bombed villages in Xieng Khouang Province.

4.6. Growth regressions to test the regional economic convergence within a country

We conducted growth regressions to test the regional economic convergence hypothesis, which argues that poorer regions tend to grow faster. More specifically, we tested the conditional regional economic convergence within a country to provide additional evidence to Barro and Sala-i-Martin (1991, 1992b), among others. Our main variable of interest was PRE_BOMBING_POPULATION in 1950 in Equation (3) (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.

None of the coefficients of PRE_BOMBING_POPULATION in 1950 were negative and statistically significant according to the OLS regression results (Table 7, Regressions 1, 3, 5, and 7). Moreover, after correcting for the plausible estimation bias in the OLS regressions by using the instrumental variables approach, the estimation results did not show a negative and statistically significant coefficient of PRE_BOMBING_POPULATION in 1950 (Table 7, Regressions 2, 4, 6, and 8). In addition, Panel B (northern Laos) shows divergence in both the OLS regression and instrumental variable results in Columns 5–8. 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 due to war. However, caution is warranted here because we cannot observe any counterfactual states for 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

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

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

[14] The results are qualitatively the same if we change the distance to 5 km (i.e., by excluding villages within 5 km from the centroid of the most bombed village in Xieng Khouang Province). However, if we extend the distance to 15 km, we cannot identify the impacts of the bombings because some of the estimation results start to show insufficient magnitude of F-values at about 6 in the weak instrument test.

Table 5
Long-term impacts of bombing missions on mean nighttime light intensity in 1992, 2005, and 2013 and the population per km[2] in 1990 and 2005 based on distance from the HCMT and the most bombed village in Xieng Khouang Province.

Panel A: Villages in southern Laos by the distance from the HCMT

	Dependent variable: Mean nighttime light intensity per km²								
	1992			*2005*			*2013*		
	p75	*p50*	*p25*	*p75*	*p50*	*p25*	*p75*	*p50*	*p25*
	(1) IV/2SLS	(2) IV/2SLS	(3) IV/2SLS	(4) IV/2SLS	(5) IV/2SLS	(6) IV/2SLS	(7) IV/2SLS	(8) IV/2SLS	(9) IV/2SLS
Total U.S. bombs per km²	0.00600	0.0237	−0.0144	0.132	0.163	−0.0825	0.707**	0.725**	0.155
	(0.0452)	(0.0372)	(0.0438)	(0.134)	(0.127)	(0.201)	(0.348)	(0.343)	(0.268)
Population in 1950 per km²	0.142	0.0601*	0.0795	0.215**	0.122**	0.273***	0.3**	0.243***	0.575***
	(0.0876)	(0.0388)	(0.0559)	(0.116)	(0.0551)	(0.0974)	(0.145)	(0.0941)	(0.128)
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	3182	2118	1078	3182	2118	1078	3182	2118	1078
R-squared	–	–	–	–	–	–	–	–	–
Weak IV test statistics	13.1	12.0	4.2	11.5	12.0	5.5	13.2	13.0	5.2
IV at the first-stage significant?	1%	1%	5%	1%	1%	5%	1%	1%	5%

	Dependent variable: Population per km²					
	1990			2005		
	p75	*p50*	*p25*	*p75*	*p50*	*p25*
	(10) IV/2SLS	(11) IV/2SLS	(12) IV/2SLS	(13) IV/2SLS	(14) IV/2SLS	(15) IV/2SLS
Total U.S. bombs per km²	0.233*	0.120	0.0136	0.253	0.124	0.00206
	(0.136)	(0.0817)	(0.0499)	(0.139)	(0.0797)	(0.0427)
Population in 1950 per km²	1.337***	1.47***	1.541***	1.361***	1.513***	1.583***
	(0.0634)	(0.0489)	(0.0491)	(0.0730)	(0.0474)	(0.0501)
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	3182	2118	1078	3182	2118	1078
R-squared	–	–	–	–	–	–
Weak IV test statistics	12.2	11.8	4.6	11.5	12.0	5.5
IV at the first-stage significant?	1%	1%	5%	1%	1%	5%

Panel B: Villages in northern Laos by the distance from the centroid of the most bombed village in Xieng Khouang Province

	Dependent variable: Mean nighttime light intensity per km²								
	1992			*2005*			*2013*		
	p75	*p50*	*p25*	*p75*	*p50*	*p25*	*p75*	*p50*	*p25*
	(1) IV/2SLS	(2) IV/2SLS	(3) IV/2SLS	(4) IV/2SLS	(5) IV/2SLS	(6) IV/2SLS	(7) IV/2SLS	(8) IV/2SLS	(9) IV/2SLS
Total U.S. bombs per km²	−0.112*	−0.0693	–	−0.218***	−0.19*	−0.125*	−0.443***	−0.363**	−0.332**
	(0.0591)	(0.0647)	–	(0.0828)	(0.100)	(0.0659)	(0.119)	(0.141)	(0.151)
Population in 1950 per km²	0.245***	0.18	–	0.445***	0.393***	0.247**	0.699***	0.671***	0.584***
	(0.0796)	(0.0935)	–	(0.105)	(0.141)	(0.118)	(0.115)	(0.145)	(0.222)
Other control variables	Yes	Yes	–	Yes	Yes	Yes	Yes	Yes	Yes
District fixed effects	Yes	Yes	–	Yes	Yes	Yes	Yes	Yes	Yes
S.E. clustered at district level	Yes	Yes	–	Yes	Yes	Yes	Yes	Yes	Yes
Observations	4257	2836	–	4257	2836	1416	4257	2836	1416
R-squared	–	–	–	–	–	–	–	–	–
Weak IV test statistics	74.1	68.6	–	45.4	42.4	12.1	44.7	40.3	10.4
IV at the first-stage significant?	1%	1%	–	1%	1%	1%	1%	1%	1%

	Dependent variable: Population per km²					
	1990			*2005*		
	p75	*p50*	*p25*	*p75*	*p50*	*p25*
	(10) IV/2SLS	(11) IV/2SLS	(12) IV/2SLS	(13) IV/2SLS	(14) IV/2SLS	(15) IV/2SLS
Total U.S. bombs per km²	−0.0410	−0.0320	−0.0337	−0.0359	−0.0217	−0.0332
	(0.0884)	(0.0938)	(0.108)	(0.0834)	(0.0864)	(0.103)
Population in 1950 per km²	1.541***	1.539***	1.6***	1.565***	1.574***	1.645***
	(0.0412)	(0.0579)	(0.118)	(0.0426)	(0.0573)	(0.120)
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	4257	2836	1416	4257	2836	1416
R-squared	–	–	–	–	–	–
Weak IV test statistics	48.8	49.6	13.0	45.4	42.4	12.1
IV at the first-stage significant?	1%	1%	1%	1%	1%	1%

Note: Significant at the 90% (*), 95% (**), and 99% (***) levels. Standard errors in parentheses. *p75*, *p50* and *p25* denote the 75th, 50th, and 25th percentiles, respectively, based on the proximity to the HCMT and the most bombed village in Xieng Khouang Province (e.g., *p75* denotes the top 75% of closest villages to either the HCMT in southern Laos or the most bombed village in Xieng Khouang Province in northern Laos). The authors used IHS transformation for the following variables: nighttime light intensity, population, bombing missions, distance from the centroid of villages to the HCMT, distance from the centroid of villages to the centroid of the

most bombed village in Xieng Khouang Province, and terrain slope. Villages with zero population as of 2005 and 1990 were excluded from the observations. Column (3) does not have estimation results because the nighttime light intensity had a zero value in the observation.
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, SRTM30, and USGS

Table 6
Long-term impacts of bombing missions on mean nighttime light intensity in 1992, 2005, and 2013 and population per km^2 in 1990 and 2005 for villages, excluding those through which the HCMT passed and for the most bombed villages in Xieng Khouang Province.

	Panel A: Villages in southern Laos, excluding those through which the HCMT passed				
	Dependent variable: Mean nighttime light intensity per km^2			Dependent variable: Population per km^2	
	1992	*2005*	*2013*	*1990*	*2005*
	(1) IV/2SLS	(2) IV/2SLS	(3) IV/2SLS	(4) IV/2SLS	(5) IV/2SLS
Total U.S. bombs per km^2	−0.0405	0.0900	0.761*	0.349*	0.385*
	(0.0708)	(0.165)	(0.435)	(0.210)	(0.221)
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	–	–	–	–	–
Weak IV test statistics	10.9	8.2	9.9	9.4	8.2
IV at the first-stage significant?	1%	1%	1%	1%	1%
	Panel B: Villages in northern Laos, excluding those bombed most in Xieng Khouang Province				
	Dependent variable: Mean nighttime light intensity per km^2			Dependent variable: Population per km	
	1992	*2005*	*2013*	*1990*	*2005*
	(6) IV/2SLS	(7) IV/2SLS	(8) IV/2SLS	(9) IV/2SLS	(10) IV/2SLS
Total U.S. bombs per km^2	−0.0688	−0.135*	−0.337**	−0.102	−0.0830
	(0.0609)	(0.0811)	(0.157)	(0.132)	(0.127)
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	5631	5631	5631	5631	5631
R-squared	–	–	–	–	–
Weak IV test statistics	18.3	11.4	11.6	11.7	11.4
IV at the first-stage significant?	1%	1%	1%	1%	1%

Note: Significant at the 90% (*), 95% (**), and 99% (***) levels. Standard errors in parentheses. Panel B excludes the 48 villages within 10 km from the centroid of most bombed village (0.8% of total villages, but 6.5% of the total bombings in northern Laos). The authors used the IHS transformation for the following variables: nighttime light intensity, population, bombing missions, distance from the centroid of villages to the HCMT, distance from the centroid of villages to the centroid of the most bombed village in Xieng Khouang Province, and terrain slope. Villages with zero population as of 2005 and 1990 were excluded from the observations.
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, SRTM30, and USGS

administrative boundaries. In developing countries, individual country case studies testing growth convergence are still scarce, partly because of the lack of disaggregated data. Among those studies, a few have investigated developing countries during roughly the same period examined in our study. For example, Cárdenas and Pontón (1995) analyze the case of Colombia during 1950–1990 and find strong per-capita income convergence across regions at a rate of about 4% per year. Jian et al. (1996) examine China and find that (i) the convergence of real income per capita emerged only after 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).[15]

4.7. Discussion of the mechanisim

Why were there no long-term adverse impacts of U.S. bombing campaigns on later economic development in southern Laos, despite the historical fact that Laos was subjected to massive bombing campaigns during the Secret War? One possibility is that the intense bombing campaigns did not necessarily lead to a 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, despite the massive numbers of bombs, they were dropped on farmlands, unpaved roads, and forests, and thus there was no catastrophic destruction of infrastructure or other types of physical capital. Furthermore, given that 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 the damage to the economic system was not catastrophic.

However, 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 nighttime light intensity emerges only in 2013 in southern Laos. However, this may not be applicable to the mountainous northern Laos,[16] which showed sustained negative and statistically significant bombing impacts on nighttime light intensity during the study period, when there was less notable infrastructure development, such as highway projects linking to neighboring countries, partly due to its difficult terrain. Moreover, there is anecdotal evidence supporting claims of vast numbers of unexploded cluster bombs in Xieng Khouang Province (Al Jazeera, 2018). Unlike the case in southern Laos, the economic integration of the intensely bombed villages within and near Xieng Khouang Province to

[15] Jian et al. (1996) concluded that regional convergence was strongly associated with the extent of marketization and openness in China.

[16] See the mean and S.D. of altitude and terrain slope in Table 1. Northern Laos has a rough hilly terrain at high altitude, unlike southern Laos.

Table 7
Growth regressions using population density growth rate, 1980–2005.

	Population growth rate, 1980–2005			
	Panel A: Southern Laos			
	All villages		Villages excluding those through which the HCMT passed	
	(1) OLS	(2) IV/2SLS	(3) OLS	(4) IV/2SLS
Total U.S. bombs per km^2	0.00328	0.0323	0.00516	0.0562
	(0.00287)	(0.0237)	(0.00321)	(0.0396)
Population in 1950 per km^2	0.0142	0.0106	0.0110	0.00397
	(0.0159)	(0.0150)	(0.0162)	(0.0151)
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	0.773	–	0.766	–
Weak IV test statistics	–	12.6	–	8.0
IV at the first-stage significant?	–	1%	–	1%
	Panel B: Northern Laos			
	All villages		Villages excluding those bombed most in Xieng Khouang Province	
	(5) OLS	(6) IV/2SLS	(7) OLS	(8) IV/2SLS
Total U.S. bombs per km^2	−0.00627	0.000028	−0.00715	−0.00609
	(0.00539)	(0.0226)	(0.00557)	(0.0388)
Population in 1950 per km^2	0.0516***	0.0499***	0.0512***	0.0509***
	(0.00742)	(0.00939)	(0.00752)	(0.0113)
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	5631	5631
R-squared	0.842	–	0.842	–
Weak IV test statistics	–	38.5	–	10.9
IV at the first-stage significant?	–	1%	–	1%

Note: Significant at the 90% (*), 95% (**), and 99% (***) levels. Standard errors in parentheses. The authors used IHS transformation for the following variables: population in 1950, bombing missions, distance from the centroid of villages to the HCMT, distance from the centroid of villages to the centroid of the most bombed village in Xieng Khouang Province, and terrain slope. Villages with zero population as of 2005 and 1990 were excluded from the observations.
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, SRTM30, and USGS

economic centers such as Vientiane, Luang Prabang and neighboring Vietnam has been hampered by the lack of transportation infrastructure due to the disadvantageous topography. Furthermore, we found differentiated impacts of bombing between nighttime light intensity and population density. This distinction may be explained by the time for recovery from large external shocks, meaning population level recovers first, and then the economic activities expand after catastrophic external shocks such as bombings have ceased.

Meanwhile, the existence of UXOs, which have contaminated up to 25% of the villages and 14 out of the 17 provinces in Laos (NRA, 2015), has impeded business as well as the introduction of new investments into the local economy. Despite the ongoing sustained efforts to clear UXOs, the number of UXOs and their exact locations are not known with reliable accuracy.[17] Under such uncertainty, it is highly probable that new investments will go only to safe locations that have been confirmed by the baseline surveys that accompany UXO clearance. This situation has resulted in an unbalanced distribution of capital and labor in post-war Laos. We believe this could be part of the reason for the lack of regional convergence in southern Laos and the divergence in northern Laos.

We have discussed possible mechanisms above. However, it should be noted that our discussion is limited to speculation due to the insufficient availability of statistical data that would be required to analyze why there is no adverse long-run impact of the U.S. bombing missions on later economic development in the south, why there is a sustained negative impact in the north, and why there is no conditional regional convergence within the country.

[17] 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.

5. Conclusions

Amid the Vietnam War from 1964 to 1973, U.S. bombing missions in Laos carried out as part of the Secret War resulted in catastrophic losses. Accordingly, Laos has been identified as one of the most intensely bombed countries per capita in history. To our knowledge, there have been no rigorous quantitative investigations of the long-term effect of these bombing missions in Laos during the Vietnam War. Hence, this study asked whether the bombing missions during the Secret War affected later economic development in Laos and whether within-country conditional economic convergence could be found after the war.

To verify the effect of U.S. bombing missions on long-term economic development, we took advantage of the historical fact that the U.S. Army heavily bombed communist supply lines along the HCMT as well as parts of Xieng Khouang Province. Using the distance from the nearest point on the HCMT and the centroid of most bombed village in Xieng Khouang Province to each geographical centroid of village boundaries as an instrumental variable for the bombing missions, we addressed 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 had a persistent adverse impact on long-term economic outcomes in southern Laos but that there was a sustained negative impact in northern Laos. These exceptional results might be explained by the large infrastructure projects and extended infrastructure network that was built upon the HCMT in southern Laos, which is considered to have driven the economy, as well as the hilly and mountainous topography that have hampered infrastructure investments in northern Laos. In addition, the results do not necessarily support the conditional convergence hypothesis within a given country, although this result could be unique to Laos due to the existence of a large number of UXOs in the country.

As discussed, there are no lasting long-run impacts of the U.S. bombing missions on economic outcomes in southern Laos at the semi-macro level. Having said that, a large number of UXOs remain in the country, not only in the north but also in the south. The presence of UXOs is a critical ongoing issue because they continue to kill and injure many people every year. Clearance of UXOs would be needed to improve the socio-economic development of Laos, but this would require a significant investment of time and money.

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Contributor roles taxonomy (Credit) author statement

Takahiro Yamada: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Data Curation, Writing - Original Draft, Writing - Review & Editing, Visualization, Funding acquisition Hiroyuki Yamada: Conceptualization, Methodology, Investigation, Writing - Review & Editing, Funding acquisition.

CRediT authorship contribution statement

Takahiro Yamada: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Hiroyuki Yamada:** Conceptualization, Methodology, Investigation, Writing – review & editing, Funding acquisition.

Data availability

Data will be made available on request.

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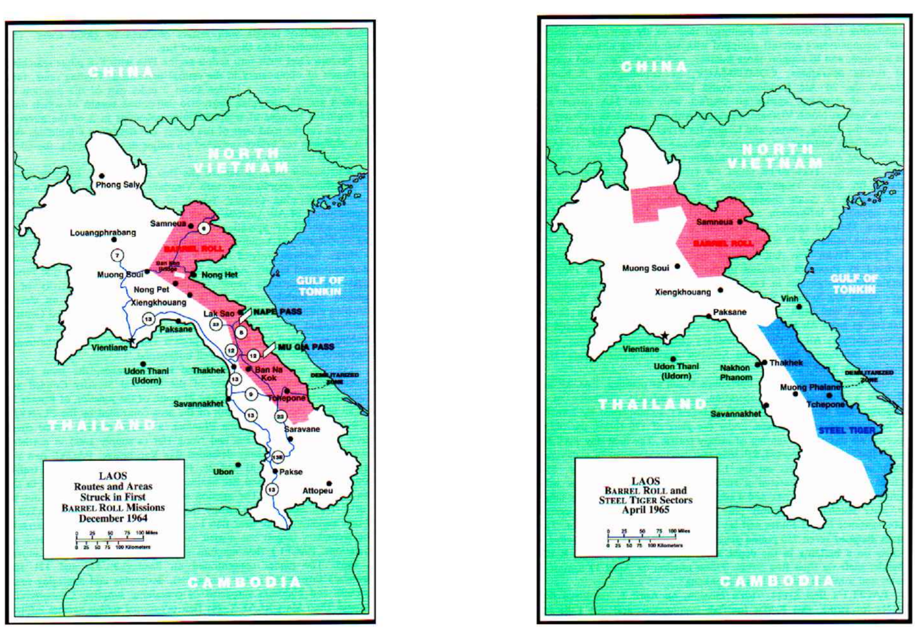
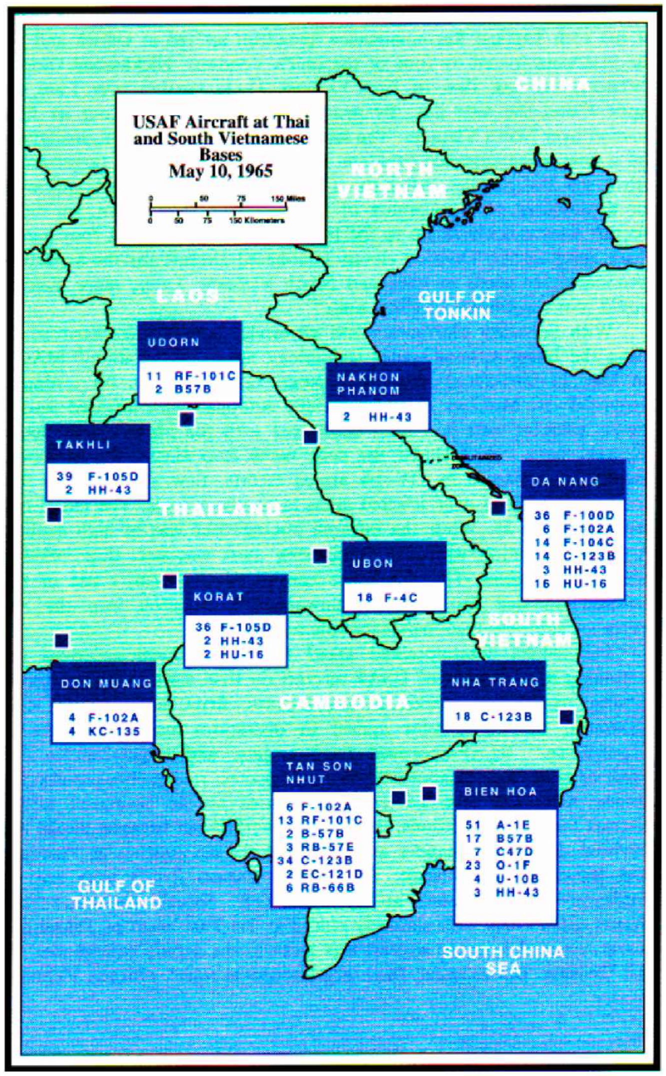
APPENDIX

Panel A: Barrel Roll as of December 1964 Panel B: Barrel Roll as of September 1965



Source: Van Staaveren (p.45, 1993) Source: Van Staaveren (p.60, 1993)

Appendix Fig. A1. Routes and areas struck by U.S. bombing missions



Source: Van Staaveren (p.64, 1993)

Appendix Fig. A2. USAF aircraft at Thai and South Vietnamese bases as of May 10, 1965

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