Econometrica, Vol. 93, No. 5 (September, 2025), 1739–1778

LANDMINES AND SPATIAL DEVELOPMENT

GIORGIO CHIOVELLI
Department of Economics, Universidad de Montevideo

STELIOS MICHALOPOULOS
Department of Economics, Brown University, CEPR, and NBER

ELIAS PAPAIOANNOU
Economics Department, London Business School and CEPR

Landmines affect the lives of millions in many conflict-ridden communities long after the end of hostilities. However, there is little research on the role of demining. We examine the economic consequences of landmine removal in Mozambique, the only

Giorgio Chiovelli: gchiovelli@um.edu.uy
Stelios Michalopoulos: smichalo@brown.edu
Elias Papaioannou: eliasp@london.edu

We thank seven anonymous referees of this journal for insightful comments and useful suggestions. We thank the UK's Department of Foreign International Development, the EPSRC, and the Centre for Economic Policy Research for generous funding via the PEDL programme. We are grateful to the London Business School Institute for Innovation and Entrepreneurship and the Wheeler Institute for Business and Development for support. A special thanks to Sebastian Hohmann for help in various phases and aspects of this project and Kirill Borusyak, who generously shared much of his time and commented extensively on our work. We thank Suzana Moreira and the MoWoza team for helping us collect and organize some data. We want to thank all demining operators involved in the Mine Action program in Mozambique, in particular, APOPO, HALO Trust, Handicap International (Humanity and Inclusion), and Norwegian's People Aid for kindly sharing the original data on their interventions and their on-the-ground experience. This project could not have been completed without the generous support of many. We thank Olivier Cottray, Anne-Li Naucler, and Wendi Pedersen from the Geneva International Center for Humanitarian Demining (GICHD) for assisting us in various project stages. Our gratitude goes to Paul Heslop (UNMAS) and Martin Barber for sharing their time, knowledge, and expertise about Mine Action. We are grateful to Alberto Maverengue Augusto from Mozambique's National Institute of Demining; Mica Bevington, Jean-Baptiste Richardier, and Gilles Delecourt, Alma Al Osta, and Emanuel Sauvage from Humanity and Inclusion; Camille Wallen and Rachel Boddy from HALO Trust; Afedra Robert Iga and Hans Peter Risser from NPA; Ashley S. Fitzpatrick and Tess Tewelde from APOPO; Chris Pearce and Richard Holmes from Dynasafe; Manuel Sitoe from UNADP. A special thanks to Peter Ainsworth, Richard Boulter, Johan Coetzee, Aderito Ismael, David Hewitson, and Ulrich Weyl for helping us understand the history and technical aspects of demining in Mozambique. We are also thankful to the Greek Orthodox Diocese Archbishop of Zambia, Malawi, and Mozambique Ioannis, Stergios Varvaroussis from the EU mission in Maputo, and Maro Spanoudi. We thank Alberto Marden da Cruz, Novella Maugeri, and Jorrit Oppewal from the International Growth Center and Antonio Francisco from the Instituto de Estudos Sociais e Economicos (IESE). Panos Kosmas and Jamie Barras kindly shared their technical expertise in landmine detection and removal technology. Thanks to Patrick Domingues for kindly sharing data on the civil war incidents and Jacob Moscona World Bank's project data. We thank for their valuable feedback Francesco Amodio, Costas Arkolakis, Lorenzo Casaburi, Alejandro Cunat, Francesco Caselli, Ruben Enikolopov, Remi Jedwab, Nuno Limao, Ted Paterson, Thorsten Persson, Yannick Pengl, Ricardo Reis, Thodoris Rapanos, Sandra Sequeira, Ina Simonovska, Silvana Tenreyro, Jaume Ventura, Joachim Voth, and Austin L. Wright. We thank Chris Woodruff for his support as well as seminar participants at the 15th Meeting of State Parties to the Mine Ban Treaty, Brown, CREI, CSAE (Oxford), EIEF, Harvard, IIES, Maryland, George Washington, John Hopkins, Zurich, Vienna, Macedonia, Glasgow, King's, McGill, Mondlane, LBS, LSE, the 20th National Directors' Meeting at UN Mine Action, NBER's Economics of National Security Meeting, Queen Mary, Sussex, Universidad Catolica del Uruguay, Universidad de Montevideo, and "Geodata in Economics" workshop at the University of Brunswick, and the IGC-PEDL-LSE conference. Gonzalo Ferrés, Federico Ferro, and Julian Marenz provided superb research assistance. All errors are our responsibility. Additional web material can be found at www.land-mines.com.

country to transition from heavily contaminated in 1992 to mine-free in 2015. First, we present the self-assembled georeferenced catalog of areas suspected of contamination, along with a detailed record of demining operations. Second, the event-study analysis reveals a robust association between demining activities and subsequent local economic performance, reflected in luminosity. Economic activity does not pick up in the years leading up to clearance, nor does it increase when operators investigate areas mistakenly marked as contaminated in prior surveys. Third, recognizing that landmine removal reshapes transportation access, we use a market-access approach to explore direct and indirect effects. To advance on identification, we isolate changes in market access caused by removing landmines in previously considered safe areas, far from earlier nationwide surveys. Fourth, policy simulations reveal the substantial economywide dividends of clearance, but only when factoring in market-access effects, which dwarf direct productivity links. Additionally, policy counterfactuals uncover significant aggregate costs when demining does not prioritize the unblocking of transportation routes. These results offer insights into the design of demining programs in Ukraine and elsewhere, highlighting the need for centralized coordination and prioritization of areas facilitating commerce.

KEYWORDS: Africa, development, history, conflict, landmines, market access, transportation infrastructure.

1. INTRODUCTION

"PEACE AGREEMENTS *may be signed and hostilities may cease, but landmines and explosive remnants of war are an enduring legacy of conflict*" states in its introduction the 2017 Landmine Monitor.[1] Despite the extensive use of landmines in civil wars after WWII and the importance of this topic for the international community, there is little quantitative research on their role. We try to fill this gap by focusing on Mozambique, the only country to date that has moved from "heavily contaminated by landmines" in 1992 to "landmine-free" status in 2015.

Landmines have been called "*the weapon of the poor*," as they cost as little as one dollar to build. Pol Pot, Cambodia's Khmer Rouge infamous leader, reportedly argued that "*a landmine is a perfect soldier, it doesn't need food or water, it doesn't take any salary or rest, and it will lie in wait for its victim*." Hence, it is unsurprising that landmines have been extensively used, among others, in Cambodia, Congo, Afghanistan, the Caucasus, and during the breakup of Yugoslavia. Today, mine contamination remains a threat in around 60 countries. Alarmingly, there is ongoing use in Syria, Iraq, Libya, Yemen, Myanmar, and most noticeably, Ukraine, which has become one the world's most heavily mined places since Russia's annexation of Crimea and its full-scale invasion in February 2022. The numbers are staggering. Human Rights Watch (HRW) and news agencies report moderate and severe contamination spanning almost a third of Ukraine. The problem worsens by the day due to the widespread use of cluster munitions that scatter explosives indiscriminately. The World Bank estimates that demining Ukraine will cost more than 37 billion US dollars.

Since the historic visit of Princess Diana to Angola to raise awareness on minefields and the United Nations (UN) Mine Ban Treaty in 1997, the attention of the international community and media has been on the immediate victims: the lives lost, the incapacitated, and

[1]Landmines are containers of explosive material with detonating systems that are triggered by contact. They are designed to incapacitate that person or vehicle by an explosive blast. Unexploded ordnance (UXO) refers to explosive weapons that did not detonate upon deployment and persist as hazardous remnants, presenting an ongoing risk.

the isolation of rural communities. This is also reflected in the various cost-benefit analyses of landmine removal, centered around the lives saved and the value of land released. Such valuations of demining often reach contradictory conclusions due to the wide range of assumptions regarding the statistical value of life and the (often considerable) degree of underreporting. For example, Cameron et al. (2010) estimate positive returns from demining in Cambodia, while Elliot and Harris (2001) and Harris (2000) calculate negative returns from clearance in Mozambique and Cambodia, respectively. Similarly, most impact assessment reports, which focus on a single or a few communities, do not uncover significantly positive effects of clearance in the local community (e.g., DFID (2014)). And the scant medical research that shows considerable adverse effects of mines is based on tiny samples (see Frost et al. (2017) for a review).[2]

It is instinctive to focus on the direct victims of landmine detonations. However, even in the absence of physical harm, landmines disrupt the daily lives and economic activities of millions. For example, the United Nations Development Program calculates that about 10.7 million Ukrainians require services to clear mines. In the context of our study, the 2001 Mozambique Landmine Impact Survey found that approximately 3 out of 18 million lived in communities significantly affected by remnants of war. The economic consequences appear important. Yet a detailed assessment is missing. Our study is a first step in quantifying the economic consequences of demining.

1.1. *Results Preview*

We examine the economic impact of freeing Mozambique of contamination, a country that in 1992 had hundreds of thousands of landmines scattered across roughly 8000 minefields of its vast territory. In September 2015, Mozambique was officially declared "landmine-free."

Our analysis proceeds in four steps. First, we provide an almost complete documentation of all landmine operations for any country, a nonnegligible contribution as such data are neither available from governments nor the UN for any heavily mined country. We present the self-assembled, validated, and georeferenced data on the areas suspected of contamination according to the nationwide surveys and the thousands of operations conducted by dozens of demining actors.

Second, we trace the dynamics of economic activity as the clearance evolved within Mozambican localities. To bypass data unavailability for one of the world's poorest nations, we employ a harmonized satellite series of light density at night from 1992 until 2017.[3] The difference-in-difference analysis, estimated with the staggered event "imputation" method of Borusyak, Jaravel, and Spiess (2024) reveals that compared to nonmined and not-yet-cleared localities, economic activity picks up following the removal of landmines. Luminosity stabilizes at a higher level 4 to 6 years after the commencement of clearance, the average time it takes to clear a locality from all hazards. Crucially, luminosity neither increases in anticipation of clearance nor changes when operators visit areas erroneously recorded in the preceding surveys as suspected of contamination. We

[2] Ascherio et al. (1995) conducted surveys in two Mozambican provinces shortly after the war and estimated ratios of fatal and nonfatal landmine injuries of 8.1–8.2 per 1000; these are ten times larger than the ones based on hospital or amputee-assistance programs. Roughly 75% of fatalities occur before the victim reaches a health center.

[3] In Chiovelli, Michalopoulos, Papaioannou, and Regan (2023a), we construct a yearly luminosity series from 1992–2020, harmonizing the underlying information from satellites with different characteristics, accuracy, and resolution.

then explore the relationship between demining and World Bank (WB) aid and road maintenance to shed some light on the mechanisms. Both outcomes seem to respond to the clearance of hazards, uncovering plausible mechanisms. Nonetheless, the clearance-development link is still strong when we exclude all localities with either a WB project or road improvements.

Third, we explore the economywide effects, recognizing that clearing landmines in one area may impact economic activity in other interconnected regions. The "market access" analysis reveals that along with the direct "productivity" effects, landmine removal entails significantly positive spillovers, by unblocking the prewar transportation network. Market access effects are (at least) twice as large as the direct ones, revealing a quantitatively important aspect of clearance. To advance on causation, we develop an identification strategy that takes advantage of the numerous errors in the countrywide surveys that guided demining. To isolate changes in market access that could not have been part of any centralized prioritization scheme, we leverage the clearance of hazards that previous surveys missed. There is a strong association between market access increases from such "not-in-surveys" landmine removals and economic activity, telling of a significant dividend of clearance.

Fourth, we conduct policy counterfactuals to assess the countrywide consequences of clearance. We start by approximating the evolution of luminosity without any clearance; in this extreme scenario, aggregate luminosity in 2017 would have been roughly 20% lower, which, given a lights-GDP elasticity of around 0.2–0.3, yields an output boost of about 3.5–5 trade corridors" connecting the main port cities (Maputo, Beira, and Nacala) with the interior, followed by the clearance of the single highway connecting the south to the central regions. The comparison of actual demining with this counterfactual reveals substantial losses from the absence of prioritization of central nodes with sizable spillovers.

1.2. *Related Literature*

Our study connects to several research strands that have developed in parallel. First, on a broad scale, our findings contribute to our understanding of the economic legacy of civil wars (see Blattman and Miguel (2010), for a thorough overview). Cross-country comparisons and case studies show that, while growth resumes after conflict, the strength and timing of the recovery vary considerably. Landmine contamination may partially account for the observed heterogeneity, a point the literature has not stressed. Second, since landmine removal activities are often funded by foreign donors and agencies (as in our setting), our study also connects to works on foreign aid (see Easterly and Pfutze (2008) for a review), showing that such assistance may be quite beneficial, especially when one factors spatial spillovers. Third, few academic research studies have assessed the role of landmine clearance, and no attention has been devoted to its aggregate economic impact. Exceptions include the cross-sectional works of Merrouche (2008), and Arcand, Rodella-Boitreaud, and Rieger (2014), linking contamination to poverty and health across Mozambican and Angolan regions, respectively. In subsequent work, Prem, Purroy, and Vargas (2025) distinguish between military and humanitarian demining in Colombia, finding that the latter is more conducive to local growth.In addition to estimating the local consequences of clearance, we bring into this body of research a theoretically grounded approach well suited to quantify both direct (productivity-enhancing) effects and spatial spillovers (from regional commerce). We find that landmine clearance generates sizeable spatial spillovers, a novel result to the best of our knowledge, which is far from salient in the practitioner community. For example, neither the United Nations Mine Action Service (2024) nor the Landmine Monitor (2023) mention any potential benefits of clearance in fostering local trade and commerce, while the reports extensively discuss land release, injuries and fatalities, and better access to schools, health facilities, public agencies, and aid. Hence, our framework helps address some policy-relevant questions. What are the aggregate effects of landmines? How shall international organizations, states, and NGOs design clearance, a critical issue nowadays in Ukraine and elsewhere?

Fourth, our paper relates to recent works in spatial economics that apply insights from general equilibrium trade theory to study the aggregate effects of transportation infrastructure (see Donaldson (2015), for an overview). Donaldson and Hornbeck (2016) adopt the Ricardian model of Eaton and Kortum (2002) to derive an expression linking changes in regional welfare to changes in its proximity to all other markets (see Harris (1954), and Redding and Venables (2004), for early contributions). A considerable body of research uses (variants of) the market-access framework to quantify the impact of railroads and roads on land values, income, population, and other development proxies in agricultural economies similar to our setting. For example, Donaldson (2018) studies the role of colonial railroads in India, where agriculture's share in GDP was around 66%, and most Indian farmers were engaged in farming. Alder (2017) quantifies the development impact of the expansion of India's highway system in the 2000s on development, while Alder, Croke, Duhaut, Marty, and Vaisey (2022) quantify a large-scale road project in Ethiopia between 1997–2016. Jedwab and Storeygard (2022) assess roads' role on population growth via market access across Sub-Saharan Africa. We uncover a strong link between development and swings in market access, driven by the unblocking from landmines of the pre-war transportation network in a low-income setting with very few paved roads and railroads that do not much connect the main cities and towns.

Paper Structure. The following section gives an overview of the use of landmines in Mozambique and the 23-year-long clearance process. In Section 3, we describe the data on demining and luminosity. In Section 4, we review the underlying theoretical framework, present the "market access" statistics, and discuss identification. Section 5 reports event-study specifications that examine the dynamic link between landmine clearance and local development. Section 6 reports the results when jointly estimating productivity and market access effects of landmine clearing. Section 7 presents counterfactual policy experiments that evaluate the aggregate effects of clearance and the losses from the absence of prioritization. In Section 8, we discuss the implications of our findings and offer some thoughts on future research.

2. HISTORICAL BACKGROUND

This section provides a brief account of the use of landmines during the War of Independence and the ensuing civil war (1964–1992), the situation in 1992, and the subsequent clearance (1993–2017). The Additional Appendix (henceforth AA) provides a more detailed overview (Chiovelli, Michalopoulos, and Papaioannou (2025b)).

2.1. *Conflict and Landmine Use*

Mozambique's experience with landmines started with the War of Independence (1964–1974). The Portuguese planted extensive minefields along the border with Tanzania to prevent the fighters of the Front for Liberation of Mozambique (FRELIMO), the main independence movement, from entering the country. They also mined critical infrastructure to protect it from the insurgents, including a ring of 80,000 mines along the Cahora-Bassa dam, one of Africa's largest. In turn, FRELIMO used landmines in its military operations, to demoralize the colonial army, destabilize the countryside, and impair road transportation. Mozambique became independent in 1975, but conditions did not improve, as one of the most disruptive civil wars since WWII began shortly after. The two main warring parties, FRELIMO, now in government, backed by socialist countries, and the Mozambique Resistance Movement (RENAMO), initially supported (1977–1980) by Rhodesia and subsequently by South Africa's apartheid regime, used landmines extensively; for military purposes, to protect infrastructure (e.g., electricity pylons and roads), to terrorize civilians, to block rearmament, and to protect towns, villages, and labor camps. Militias, rebels, and other groups also used landmines.

2.2. *Mozambique in 1992. The Problem of Landmines*

According to the Penn World Tables, Mozambique was the third poorest country in the world at the end of the civil war. Landmines and unexploded ordnance, the destruction of infrastructure, and the return of about 3–4 million internally and externally displaced (from a population of 12 million) posed significant challenges. The Peace Accord signed in Rome in September 1992 required that FRELIMO and RENAMO "*organize and implement mine-clearing operations*." The Halo Trust 1993–1994 survey (SHAMAN), the first attempt to characterize contamination throughout the country, revealed the following. First, "*the use of landmines is characterized by a highly dispersed pattern*," as suspected hazardous areas (SHAs) were spread across all provinces and most districts. Second, even the presence of a few contaminants could have adverse effects.[4] Third, infrastructure was deemed heavily mined, with the report specifying that in the southern and central provinces "*all dams, railway lines, electricity substations, and pylon lines should be assumed to be mined*," with a somewhat better assessment for the northern districts. Fourth, mines had been planted around schools and government buildings, often used as rebel or government headquarters. Fifth, floods and landslides had rendered contaminant detection and eventual removal even more challenging.

2.3. *Landmine Clearance. Process and Periods*

Mozambique is among the first countries in the world, alongside Afghanistan in 1989 and Cambodia in 1992, to experiment with humanitarian demining (in 1992), where NGOs and commercial firms, rather than the military, led clearance. Best practices had not been developed; expertise was limited; civilians had to be trained to detect and clear minefields; survey standards were missing; and the use of IT was limited. There was little (if any) coordination among operators, and the government's capacity was minimal. The clearance process was ad hoc, localized, and fragmented. The country's vast size and the limited transportation made surveying and clearance challenging. Unlike contamination during wars involving conventional armies that keep records of minefields (facilitating their subsequent clearance), maps of landmine placement were unavailable, as multiple actors laid the mines, and the warring parties, both with decentralized structures, were not keeping records. Many mines were planted years ago, and those who placed them had

[4] For example, eight mines cleared in 1996 were preventing 20,000 people in Mahniça valley from returning to their villages. Similarly, HRW (1997) reads: "*During a Norwegian Peoples Aid mine clearance operation in Maputo province, a team was sent to clear the village of Mapulenge, the center of a community of about 10,000 people. It had been deserted for four years because it was locally believed to be heavily mined. After 3 months of work, the clearance team reported finding four mines; these, and the rumor of many more, were sufficient to depopulate the entire area*.".

passed away or returned to their hometowns. As a result, clearance proceeded slowly. The mistakes and lessons from Mozambique became the basis for the standardization of practices in the humanitarian demining community after the mid-2000s.

Periods. The process of freeing Mozambique from landmines spanned three periods. Each phase started with a nationwide survey that laid the groundwork for the subsequent demining.

Initial Phase. 1993–2000/1. The 1993/4 SHAMAN survey set the stage for the commencement of clearance. Resources were scarce, and the survey was done in a rush.[5] Until the first post-war elections in October 1994, the return of the refugees was the priority; thus, the handful of interventions targeted war camps and border passages. Then, demining formed along three parallel programs. First, the HALO Trust (HT), a British-American NGO, started operating in the less-developed northern provinces. Second, in the central provinces, the Norwegian People's Aid (NPA) and, after 1999, Handicap International (HI), now Humanity and Inclusion, took the lead. Third, with the UN's help, the government established the Accelerated Demining Program (ADP) in 1995 that contracted with commercial operators in the southern provinces of Maputo, Gaza, and later Inhambane. The first phase was preparatory. SHAMAN provided a rough contamination mapping, and training centers were established. But progress on clearance was limited, as along with on-the-ground challenges, humanitarian demining was in its infancy. Given the survey's flaws (discussed below), the government, the UN, and NGOs had an incomplete picture. Osório Mateus Severino, director of Mozambique's mine program describes the situation in 1997: "*We are in the dark about that [landmines], and without a sound knowledge of the situation, it is impossible to define a strategy, let alone determine the cost and resources needed for clearance operations*" (Human Rights Watch (1997)).

Second Phase. 2001/2–2007/8. The second phase starts with the 2000/1 Landmine Impact Survey (LIS), commissioned by the then-established National Institute of Demining to serve as the road map of Mozambique's 5-year (2002–2006) mine-action plan.[6] While the survey was noisy (as shown below), it followed some standards for the first time. Surveyors could visit more areas as security was restored, the displaced had long returned, and more information was becoming available. Guided by the new survey, clearance proceeded quicker until 2004, when allegations of corruption and the government's shortcomings in coordination and planning led to donor fatigue.

Third Phase. 2008/9–2015/7. The 2007/8 Baseline Survey combined information from many operators, serving as the key document for the government's final Mine Action Program. The survey was more accurate than the previous ones, as specialized NGOs, now with considerable experience, provided most of the information. The survey revealed

[5]The survey in the four Northern provinces, whose size combined is approximately that of Italy, was done by two teams of four people in less than 6 months. The survey in the Southern provinces and Tete (the size of Spain) was carried out by three teams of four people in 5 months.

[6]The request of the Government of Mozambique for the extension in 2008 summarizes the challenges of Phase 2: "*The large size of Mozambique and the absence of a functional road network in much of it, extensive flooding in parts of the country in 2001, the widespread distribution of mine-affected communities, the lack of comprehensive and accurate national gazetteer (i.e., the official listing of communities and their geographic coordinates), the lack of accurate maps at an appropriate scale, the impossibility of applying in its entirety the protocol for false-negative sampling, and the nature, availability, and quality of expert opinion.*".

three times as many mines as previously thought. Donors returned, and aid increased fourfold. Clearance proceeded steadily as the government and NGOs had learned from mistakes, and process standardization was now in place. In September 2015, Mozambique was declared "landmine-free," although some new minefields were identified and cleared in 2016 and 2017.

3. DATA

This section presents the newly compiled data on clearance and the digitization of the three nationwide surveys. We then discuss the harmonized yearly series of nighttime lights that proxy local development and other data. Mozambique is divided into 10 provinces and Maputo, the capital. There are 140 districts (admin-2 units) and 416 *postos administrativos* (admin-3). We conduct the analysis across 1184 localities (admin-4 units) using the 2007 administrative boundaries. Mozambican localities have an average (median) size of 658.45 (414.89) km^2; median population was 8428 in 1997 and 10,686 in 2007. Agriculture is the dominant sector. The traditional cash crops include sugarcane, cotton, tobacco, cassava, maize, tea, and cashews whereas horticultural crops such as bananas, mangos, sesame, baby corn, green beans, and tomatoes are also important (IMF (2014)).

3.1. *Contamination and Clearance*

The backbone of our database is the 24,719 progress and clearance completion reports, technical surveys, work plans, and tenders, which describe the interventions that took place from 1993 to 2017. Homogenizing this material into a coherent database is part of our contribution, as such data is unavailable for any other heavily contaminated country. We briefly discuss the data, reserving for the AA a detailed overview of the institutional setting, information on the data construction, examples, and visualizations.

Demining starts with collecting information on SHAs. A SHA turns to either a confirmed hazardous area (CHA), which means clearance eventually takes place, or it is reclassified as "canceled." Updating the status of a SHA is usually done via nontechnical surveys. When the latter delivers sufficient evidence of contamination, a technical survey follows that concludes with the CHA clearance, detailed in a completion report. The SHA is canceled if the nontechnical survey finds no evidence of contamination. Our dataset stores 8436 clearance operations ("interventions") in 7657 CHAs. Most CHAs (91%) were cleared in one 'intervention," lasting on average (median) 4 (zero) months. The remaining 680 CHAs had 2.1 interventions (and reports). We will use the two terms interchangeably.[7]

3.1.1. *Constructing the Clearance Database*

We proceeded as follows: First, we accessed the Information Management System for Mine Action (IMSMA) database at the National Institute of Demining in Maputo. During the initial phase, entries' quality, accuracy, and detail are rather imprecise, and coverage

[7]The average (median) size of CHAs with available information on area (typically available after 2007) is 79,751 (2782) squared meters; a square of side 282 (52) meters. SHAs are, on average, larger. In the 2001 LIS, the average (median) area was 409,094 (5000) squared meters, a square of side 639.6 (70.7) meters. Some hazards regard large (suspected) minefields close to the border, dams, and big farms, while others consider smaller areas, for example, mines blocking access to wells, rivers, and buildings. We use SHA and CHA centroids to assign them to localities.

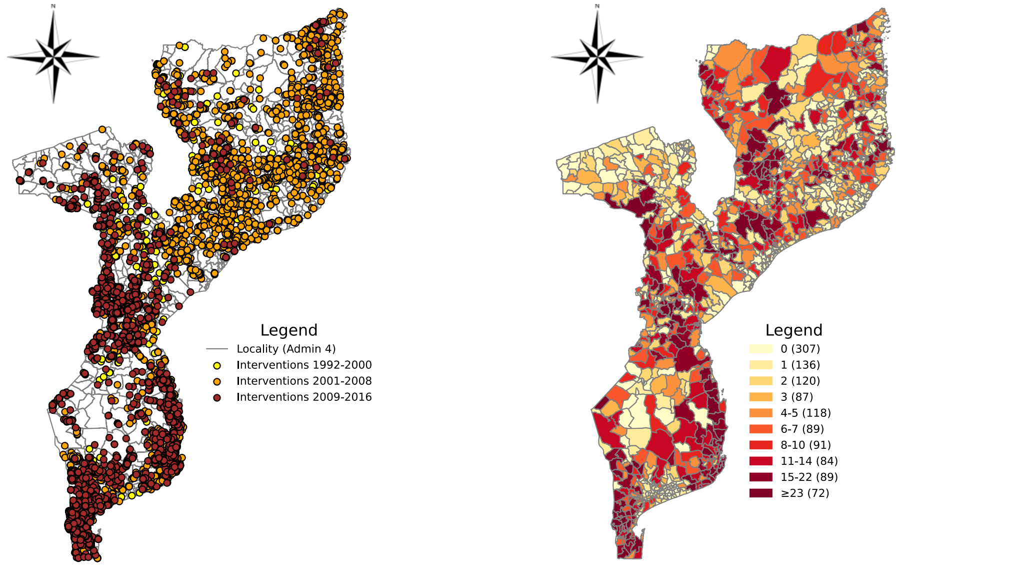
is incomplete, as the Institute started using this system in the mid-2000s. Coverage improves somewhat in the second phase (2002–2008) but becomes precise only after 2007, when according to officials and practitioners, the database is (almost) complete. We corrected inconsistencies after reading the reports and interviewing dozens of deminers and officials. Our dataset includes 7032 interventions from the IMSMA database. Second, we collected, processed, and digitized Halo Trust and NPA clearance reports. Doing so allowed us to validate and improve the detail of the IMSMA entries and expand coverage pre-2007. We also adjusted, when necessary, the exact year of clearance. We added 1033 clearances from HALO Trust's inventory and 38 from the NPA after visiting their (now closed) warehouse in Tete. Third, we retrieved information from smaller operators in the 1990s from various sources. For example, we added 19 interventions from the German Agency for Technical Operations with MineTech in Manica and 35 from ADP's operations interviewing deminers. Fourth, we digitized maps of interventions in 1993–1994 from the UN archives in New York and USAID. Fifth, from the digitization of the national surveys, we uncovered 236 clearance operations, not recorded elsewhere.

3.1.2. *Mapping Contamination and Clearance*

Figure 1, Panel *A* illustrates the spatial distribution of clearance, providing an ex post visualization of the extent of the contamination. 1384 operations took place in the first, 4212 in the second, and 2840 in the third phase. Contamination, though widespread, is higher in the southern and central provinces, Maputo (1365), Zambezia (1182), Manica (1095), Inhambane (1095), and Sofala (962), where RENAMO was active in the brutal phases of the civil war in the mid/late 1980s. [AA Table W2 gives the statistics by province and period]. Figure 1, Panel *B* aggregates clearances across localities, our unit of analysis. Supplementary Material (Chiovelli, Michalopoulos, and Papaioannou (2025a), henceforth SM) Table D2 reports summary statistics. 886 (of 1184) localities were affected, having, on average, 9.52 hazards (median 5, standard deviation, 16.52); it takes, on average (median), 7 years (6 years) to clear a locality from all hazards.

Correlates of Contamination. To better understand contamination, we examined its correlates, running linear probability and Poisson ML models associating the likelihood (and number) of CHAs with geographic/location characteristics (e.g., presence of roads, railroads, border indicators), early development proxies (e.g., population density in 1980), and civil war intensity. Contamination is higher in larger localities with more civil war events and along the transportation network. However, the explanatory power of the empirical models is low, in line with anecdotes and surveys on the indiscriminate use of landmines. [AA Figure W3.]

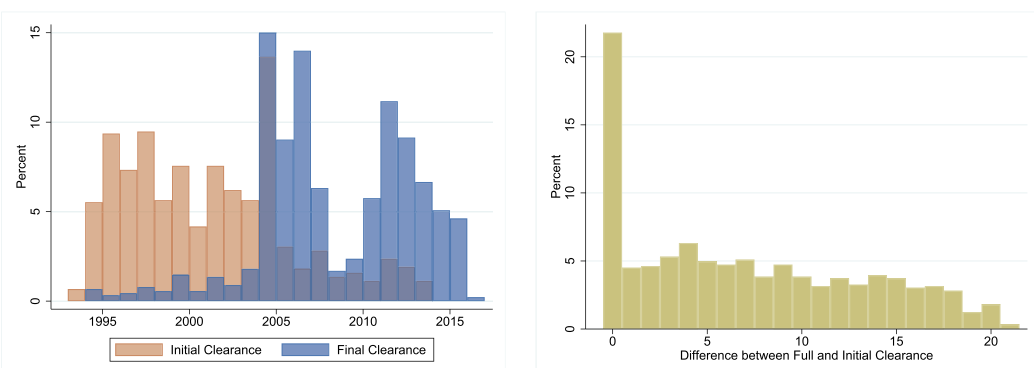
Timing of Clearance. Figure 2, Panel *A* plots (lighter bars) the share of localities where demining occurs for the first time by year. By 1994, some demining had occurred in just 55 localities. By 2002, 563 of 886 localities had seen some clearance; the share jumps to 93.45% in 2009. The darker bars depict the share of fully cleared localities. At the end of 1994, only 6 localities were fully cleared. This increases to 7.11% in 2002 and 57.34% in 2009. The average (median) number of years to clear a locality, plotted in Panel *B*, is 7.09 (6). The extended time to completely clear a locality does not reflect the duration of operations, as clearing a CHA typically takes 4 months, but from the multiple hazards in a locality, the piecemeal approach to demining, and survey inaccuracies.



Panel A: Clearance Interventions **Panel B: Clearance Interventions Across Localities**

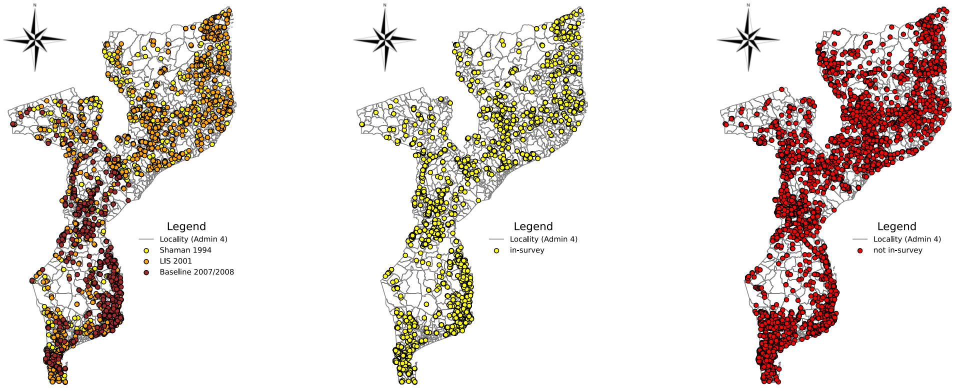
FIGURE 1.—Confirmed Hazardous Areas (CHAs). Panel *A* portrays the spatial distribution of 8436 CHAs, alongside information on the period of clearance. Panel *B* portrays the distribution of contamination across 1184 localities using the 2007 administrative boundaries. In parentheses, the legend reports the number of localities with the corresponding interventions.

Correlates of the Timing of Clearance. We associated the years elapsed until the initial and the final intervention with locality features; see AA Figure W4 and W5. First, the timing of the initial intervention is primarily influenced by proximity to borders, aiming to



Panel *A*: Initial and Full Clearance **Panel *B*: Difference Between Full and Initial Clearance**

FIGURE 2.—Timing of Clearance. Panel *A* plots for every year the share of contaminated localities where clearance operations begin (lighter bars), and the share of localities that get fully cleared (darker bars). There are 886 contaminated localities. Panel *B* gives the histogram of the difference in the number of years between the final and initial clearance.



Panel A: Suspected Hazardous Areas in Nationwide Surveys **Panel B: Clearance Interventions close to Nationwide Surveys** **Panel C: Clearance Interventions far from Nationwide Surveys**

FIGURE 3.—Suspected Hazardous Areas (SHAs). Panel A portrays 2889 SHAs, as identified in the three nationwide surveys. Panels B and C plot CHA, distinguishing clearances occurring within a $2km$ radius of a previous SHA [Panel B] or further [Panel C].

facilitate the return of refugees.[8] The economic significance of these variables is weak, and the model's explanatory power is poor. When we turn to the correlates of years elapsed until full clearance, most variables enter with small and statistically insignificant estimates, telling of the challenges of prioritizing localities and removing all hazards. By and large, clearance did not follow a systematic pattern, reflecting, among other constraints, the lack of coordination, IND's limited capacity, the ad hoc, and the short-term nature of contractors (as financially constrained NGOs were doing fund-raising for specific CHA), the flaws of the surveys, the massive floods of 2000–2001, and the irregular ebb and flow of funding.

3.2. *Nationwide Surveys. Suspected Hazardous Areas*

We processed, cleaned, and georeferenced the three nationwide surveys to grasp the information that authorities, funding agencies, and demining teams had at different points in time. Figure 3, Panel A maps (i) the 1993/4 SHAMAN survey that recorded 980 Suspected Hazardous Areas (SHAs) in 787 villages, (ii) the 2000/1 Landmine Impact Survey (LIS) that identified 1373 SHAs affecting 779 villages, and (iii) the 2007/8 Baseline Survey that listed 536 (SHAs).

3.2.1. *Clearance Close and Far From the Nationwide Surveys*

By comparing the SHAs to the CHAs, we can assess the precision of the surveys and identify "errors" that we exploit below for identification. To group the clearance interventions into "in-survey" and "not-in-survey," we matched, where possible, the completion reports with the survey entries describing the suspected contamination. Often, there is a

[8]See Chiovelli, Michalopoulos, Papaioannou, and Sequeira (2023b) for the impact of internal and external displacement.

TABLE I

CLEARANCE INTERVENTIONS, NATIONWIDE SURVEYS, AND CANCELLATIONS.

	Clearance Interventions			Cancellations	
	(1) Total	(2) In-Survey	(3) Not In-Survey	(4) Total	(5) Drop 2 km
Phase 1: 1993–2000	1384 (237)	379 (67)	1005 (170)	0 (0)	0 (0)
Phase 2: 2001–2008	4212 (739)	1842 (366)	2370 (373)	1952 (164)	1438 (80)
Phase 3: 2009–2017	2840 (265)	1118 (150)	1722 (115)	177 (20)	135 (18)
Total	8436 (1241)	3339 (583)	5097 (658)	2129 (184)	1573 (98)

Note: The table tabulates for the three main periods of demining: (i) Clearance interventions and their classification to "in-survey" and "not-in-survey," columns (1)–(3); (ii) All Cancellations of SHAs, column (4), and those that took place more than 2 km further from a clearance intervention in the same year, column (5). The numbers in parentheses reflect CHAs and cancellations within 100 meters of the pre-clearance transportation network. In period 1, we consider only the 1993–1994 Survey (SHAMAN); in period 2, we consider the SHAMAN and the 2000–2001 LIS; in period 3, we consider the 2007–2008 Baseline Survey and the two previous ones.

mention in the clearance report that the hazard had been previously identified as a SHA.[9] In addition, we use a $2km$ buffer around a SHA. About 40% of the interventions correspond to national surveys or are very close (3339); Figure 3, Panel B. But, there are 5097 clearances far from SHAs; Figure 3, Panel C.[10] Both types of clearances occurred in all provinces and in 138 out of the 140 districts. The tabulations in Table I reveal two patterns. First, surveys provided an incomplete picture of contamination across all periods, as many interventions occurred far from the surveys. Second, the 1993/4 survey was quite deficient, with less than 30% (379) of the 1384 interventions in the first phase occurring in SHAs pinpointed by the SHAMAN.

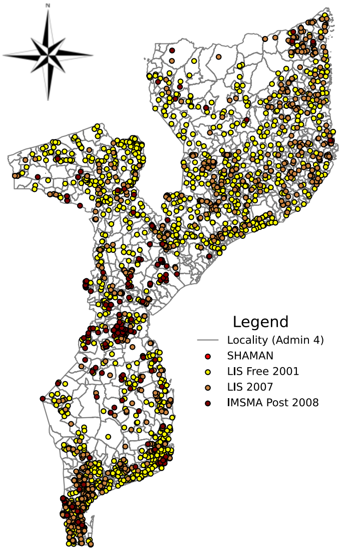
We compared geographic and location attributes of "not-in-survey" versus "in-survey" interventions [AA Figure W6, W8 and W9]. "In-survey" interventions are closer to trails, paved roads, and civil war events, consistent with surveys conducted in more accessible locations. Beyond road proximity, there are no significant differences between the two sets of interventions across numerous geographic, location, and economic features. There is also no significant difference in the timing of clearance. And the correlations between geography/location/development and the timing of "in-survey" and "not-in-survey" clearances are similar.

3.2.2. *Cancellations of SHA*

The information in the nationwide surveys was fragmentary, often based on rumors and word of mouth. Hence, not only did they fall short of charting the extent of contamination, but several SHAs turned out to be landmine-free. For example, the 1993–1994 survey listed Namigonha in Zambezia as a SHA since *"a motorcyclist died near the city"* even if the information was *"not confirmed by the residents."* When the LIS team visited in 2001, they declared it "unaffected by landmines." The bridge over the Messalo River (connecting the Macomia and Muidumbe districts in Cabo Delgado) was, according to

[9]For example, ADP cleared 3189 Anti-Personnel mines on the "protective ring" of Moamba between 1994 and 1998, an area that the 1994 survey pinpointed as potentially contaminated [SHA]. The survey reads "*perimeter minefield around entire village approx 12 km long...minefield is clearly visible from the road.*".

[10]For example, "*HALO Trust cleared 8 mines and 1 UXO on Djuba bridge located in Matola Rio (Maputo Province)*" in 2010; this area was neither identified as potentially contaminated nor in the vicinity of an SHA in the national surveys.



Location and Year of SHA Cancellations

FIGURE 4.—SHA Cancellations. The figure plots all cancellations of Suspected Hazardous Areas (SHAs), distinguishing by the source.

the 1993–1994 survey *"[..] mined on both sides of the road, immediately at the end of the concrete."* The LIS update of 2007 canceled this SHA. Another example is the *"Old Track of Guiriro [Cheringoma district, Sofala], abandoned in 1983 due to a suspected anti-tank mine."* The IMSMA dataset records an APOPO in-site check in 2013 "canceling" the SHA. To pinpoint SHAs reclassification as "canceled," which we use as placebos below, we read operator reports and the assessments on the nationwide surveys. Often, upon visiting the areas, the demining teams realized the initial information was erroneous as the communities already used the land.[11]

Figure 4 maps all 2129 cancellations. Often, cancellations occur alongside actual clearance operations in nearby areas. When we exclude cancellations in the same year in a radius of 2 km of actual clearance, we have a total of 1573. canceled SHA are spread across 754 localities in all provinces. Overall, canceled SHA compared to CHA are in locations with similar geographies, proximity to (primary) cities, the coast, and borders. Canceled SHA are somewhat further away from the transportation network and main civil war areas [AA Figure W6]. The within-locality comparisons suggest even smaller differences. AA Section W1.1 gives institutional details of in-survey and out-of-survey interventions and cancellations.

[11]The bulk of the cancellations took place in the beginning and at the end of the second period, as a result of the second nationwide survey and its update in 2007. Specifically, the LIS 2001 lists 932 villages, initially considered by experts as contaminated, but when visited in 2001, were reclassified as *"unaffected by landmines."* We also assign a canceled status to the 77 entries in SHAMAN within 2 km of these 932 landmine-free villages. A 2007 update explicitly states and lists that 721 (of the 1373 SHA in the LIS 2001) had been canceled due to insufficient evidence. Another 40 cancellations appear in the IMSMA dataset. We also assigned as canceled 176 SHAs in the SHAMAN survey since they were within 2 km (of these 721 and 40 cancellations). In the last period, there are 172 cancellations, 167 in the IMSMA database, and 5 from the SHAMAN (in a 2 km radius).

3.3. *Local Development. Nighttime Luminosity*

Obtaining a time-varying, fine-resolution proxy of economic activity for one of the world's poorest countries, devastated by years of violence, is challenging. Following Henderson, Storeygard, and Weil (2012) and subsequent works, we proxy local development using satellite imagery on light density, available since 1992. To have comparable data from 1992 until 2017—building on parallel research, we adjust, merge, and calibrate annual luminosity series available from satellites with different resolutions and accuracy. After adjusting the DMSP (National Geophysical Data Center (2010)) series for three well-documented deficiencies, sensor calibration, top-coding, and blooming, Chiovelli et al. (2023a) use an *"ensemble"* (extremely randomized forest) machine learning method to merge the DMSP-OLS data (1992–2013) with a "downgraded" version of the higher resolution VIIRS series, available since 2012 (Elvidge, Baugh, Zhizhin, Chi Hsu, and Ghosh (2017)).[12] As shown in SM Section B, the harmonized luminosity series correlates strongly in the cross-section and over time with proxies of well-being (schooling, household wealth, access to electricity) from 139 georeferenced Demographic and Health Surveys (DHS) across 34 African countries. A significant (within) association exists between luminosity and schooling across Mozambican localities. As of 1992, only 6% of the localities had detectable luminosity. The proportion of lit localities increases to 10.1% in 2002; rises to 16.6% in 2009 and about a third in 2017.

3.4. *Other Data*

We need information on transportation infrastructure and population for the market access analysis. We collected data on the length and quality of railways, primary and secondary roads, and trails in 2011, 2003, and 1998. We also digitized maps on the network conditions in 1973 that we merged with (rail)road status, indicating whether they were functional at the end of the civil war.[13] The three rail lines connect the main coastal cities to the interior. The Northern line links Nacala to Malawi, the central line connects Beira to Harare, and the Southern route goes from Maputo to South Africa (Zimbabwe and Swaziland). The rail lines are not connected, as the objective during colonial times was to export minerals and agricultural produce from the interior out of Mozambique. As colonial Mozambique was effectively split into three semiautonomously ruled areas, the main cities were (and still are) hardly connected. Except for the Zambezi, rivers do not accommodate large or medium-sized boats. Colonial investments in transportation were minimal; 17% of the localities at independence had some primary roads, and railroads were present in only 11%. For population, we accessed and digitized the censuses of 1980, 1997, 2007, and 2017 from the National Institute of Statistics. SM Section A provides definitions and sources of all data.

4. FRAMEWORK

In this section, we review the conceptual framework underlying our empirical analysis, lay down the estimating equation, present the market-access statistics, and discuss identification.

[12]The top-coding and sensor calibration corrections are unimportant, while the correction for blooming, for example, adjusting pixels that appear with very low luminosity levels due to light in neighboring pixels, has some effect. Below we show that using only the "raw" DMSP series does not change qualitatively the established patterns.

[13]For example, the Moatize-Sena-Dondo railway crossing Tete and Sofala, was destroyed by Renamo in the mid-1980s, and hence is not part of the pre-war network available before clearance.

4.1. *Theoretical Foundations*

Along with the apparent health benefits, the return of the displaced, and a humanitarian rationale, international agencies, donors, and NGOs often stress the impact of landmine clearance on agricultural productivity, primarily via the release of previously inaccessible land (e.g., United Nations Mine Action Service (2023)). Landmine clearance may also ease the flow of aid and productivity-enhancing investments, like irrigation and electrification. In addition to these "direct" links, we hypothesize that removing landmines may spur economic activity by easing access to goods produced elsewhere and by the same token opening up more markets for the locally produced goods. Building on recent works in the transportation infrastructure literature, we take a "market-access" approach to study these mechanisms in a unified theory-grounded setting.

The conceptual backbone follows Donaldson and Hornbeck (2016), who transpose the Ricardian trade model of Eaton and Kortum (2002) to a within-country interregion framework and derive an expression linking regional income to productivity (direct link) and market access (trade link). The origins of this approach can be traced to Harris (1954) that stresses the role of the "market potential," which captures the number and size of locations the origin is connected to (see also Redding and Venables (2004)). In the AA Section W2, we sketch the model that features regional differences in efficiency/technology, consumers with love-for-variety preferences, and costly trade yielding a gravity equation of bilateral trade.

This setup approximates agricultural economies, like Mozambique, where the share of employment in agriculture exceeded 80% in the 1990s, while nowadays, it hovers around 70%. Mozambique's primary sector has grown and become more integrated since the 1990s. Reports tell of the rising role of local markets in the trade of agricultural produce across districts and provinces (WFP (2016), IMF (2014), World Bank Publications (2008)). Reports also stress Mozambique's limited and poor, even by African standards, transportation system that slows down internal commerce, hinders exports, and impedes the import of fertilizers and insecticides.[14]

Relationship. The framework yields a "reduced-form" log-linear relationship between a locality's income, market access, (land) endowments, productivity, and model parameters.

$$\ln(Y_{o,t}) = \underbrace{\lambda \ln A_{o,t}}_{\substack{\textbf{Productivity} \\ \textbf{[Local Hazards]}}} + \underbrace{\mu \ln MA_{o,t}}_{\substack{\textbf{Market Access} \\ \textbf{[Transport-Blocking Hazards]}}} + \underbrace{\gamma_o}_{\textbf{Endowments}} + \underbrace{\gamma_{p,t}}_{\substack{\textbf{Utility,} \\ \textbf{Int. Rate, Wage}}} \tag{1}$$

Productivity. The first term suggests a log-log relationship between a locality's income and (time-varying) productivity. The community of practitioners, donor agencies, and international organizations often stress the direct economic benefits of local hazard clearance (with the main focus being on health). Although empirical evidence is scant, clearance is thought to increase (agricultural) productivity through a lower risk of incapaci-

[14]The World Food Program's analysis of local markets in Central Mozambique gives many cases. For example, maize in the Northern parts of Tete is sold not only in nearby localities and other districts but also in Manica, Zambezia, and Nampula. Maize produced in the North is shipped to the big markets in central provinces and Tete. Cowpeas in Gaza supply Maputo and the North. Rice produced in Xai-Xai gets shipped to Gaza's and Manica's interior. The World Bank (2008) writes, *"partly as a result of improved security and road network conditions, domestic market integration has improved significantly, domestic trade is growing, and prices are converging across subregions."*.

tation and casualties, land release, and improved livestock survival (significantly positive λ).

Market Access. The second term gives the income-market access relationship with a constant elasticity, μ, which captures the strength of comparative advantage and the share of labor and land in the production function. The (origin) locality's market access, MA_o, is approximately the sum of the population and income/luminosity of all destination localities, $N_{d,t}$, discounted by the bilateral transportation costs ($\tau_{o,d} > 1$), in turn, shaped by the clearance of transportation-blocking hazards *across all Mozambique* and also new road-railroads, and improvements of the transportation network, in each period t. Transportation costs captured by travel time, are scaled by a "trade elasticity" parameter, θ, which inversely maps into localities' comparative advantage:

$$MA_{o,t} \approx \sum_{d \neq o} \tau_{o,d,t}^{-\theta} N_{d,t}. \tag{2}$$

MA reflects effective proximity to populous (or developed) destinations, d. Hence, beyond the intensity of the flow of imported and exported goods, it may also reflect accessibility to government and aid services, commuting, and internal migration. It is challenging to distinguish between these correlated aspects, so *MA* might also reflect these forces.

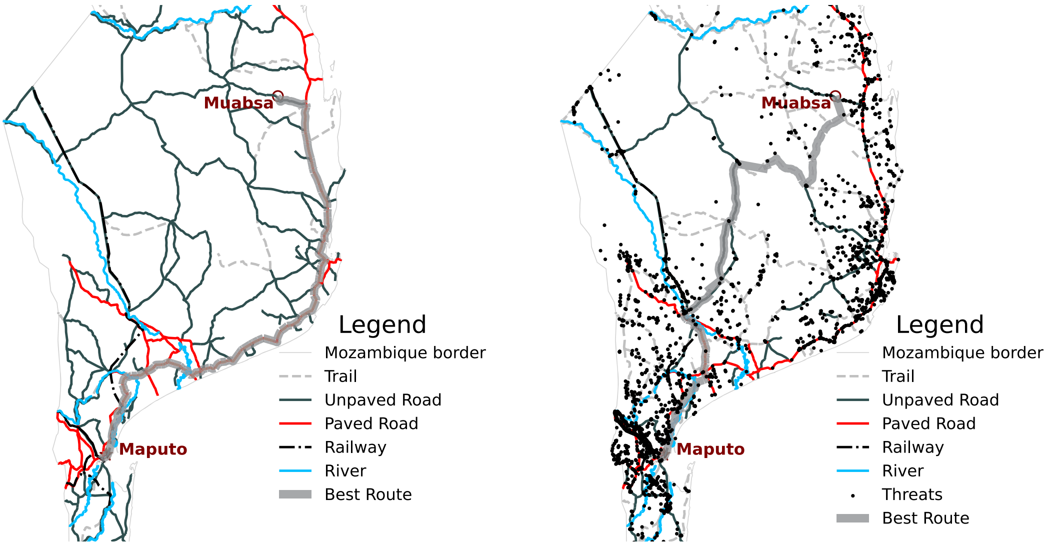
Endowments and Time-Varying Common Factors. Locality-fixed effects, γ_o, collect time-invariant (land) endowments (shaping absolute advantage) related in our setting to geographical attributes, which may permanently affect income. Period-province constants, $\gamma_{p,t}$, absorb factors common to all localities in a given period-province linked in the theoretical framework to the utility, the interest rate, and wages, which are all endogenously evolving as localities become more interconnected and grow richer.

4.2. *Market Access Across Mozambican Localities*

4.2.1. *Construction of Market-Access Statistics*

Along with population (and luminosity), the construction of the *MA* statistics (equation (2)) requires estimating locality-pair transportation costs, factoring in the extent of landmine contamination, the transportation network, and the trade elasticity.

Transportation Costs. The construction of bilateral costs, $\tau_{o,d}$, involves five steps. First, we create the transportation network composed of railroads, paved and unpaved roads, trails, and navigable rivers for each of the three main periods of demining using the 1999, 2003, and 2011 network elements, respectively. For the pre-clearance network, we use the at-independence one. We connect the localities' centroids to the closest transportation element and allow for straight-line connection on foot among localities' centroids (there is no within-locality trade). Second, we parameterize the relative cost of the network's elements. Following studies on transportation in Africa and Mozambique (Kim, Molini, and Monchuk (2012), and Alemu and Van Schalkwyk (2008)), we assume the following. Railway is the most efficient (trade) technology, and its cost is normalized to 1. We set the relative price of paved roads to 2 and unpaved roads to 4. The relative cost of trails is 10, as they are in poor conditions and not used during the rainy season. The relative cost of walking is 20. For navigable rivers, we assign a cost of 15. Third, following our



Panel A: Optimal Route in 2017 **Panel B: Optimal Route in 1992**

FIGURE 5.—Least-Cost/Time Route, Dijkstra's Algorithm. Panels A and B give the optimal route from Maputo to Muabsa (Inhambane Province) in 2017, without any minefields, and in 1992, when minefields/hazards (dots) block access to paved roads, unpaved roads, trails, and rivers.

interviews with deminers, reports, and surveys, we impose that a CHA within 100 meters of a transportation segment blocks its usage. The buffer aims to account for errors in the clearance reports and the network. Fourth, we approximate the transport cost by the product of bilateral distance via the transportation network and the relative costs of the respective modes. This is equivalent to using travel time, which factors the speed of going from origin to destination (e.g., Jedwab and Storeygard (2022), Alder et al. (2022)). Finally, we solve for the least-cost path between two localities' centroids using Dijkstra's algorithm.

Example. Figure 5 illustrates the algorithm-derived optimal route between Maputo and the town of Muabsa in Inhambane province, $700km$ north of the capital. Panel A shows the path in 2017. As all hazards have been cleared, the algorithm employs the most efficient network elements, which yields a cost of 1552. The route for 1992, in Panel B, is very different. As dozens of minefields block the highway $N1$, linking Maputo to the Central districts along the Indian Ocean, and the secondary road linking Muabsa to $N1$, the algorithm relies on unpaved roads and trails, resulting in a significantly more expensive (lengthier) route. The shortest path is more than a four-fold increase in travel time.

Trade Elasticity. A key parameter is the trade elasticity, θ, reflecting (inversely) the strength of comparative advantage (or variety differentiation). As a benchmark, we use a value of 3.8, which is in the middle of the estimates that Simonovska and Waugh (2014) produce in their careful work of the trade elasticity in comparative advantage settings (see also Jedwab and Storeygard (2022) and Alder et al. (2022)). Below, we explore the sensitivity of our estimates to alternative values of the trade elasticity and the network elements' parameterization costs.

4.2.2. *Market-Access Measures*

First, we compile yearly contemporaneous MA statistics using the transportation network available in each period, the yearly extent of contamination that evolves as clearance progresses, and the yearly population derived by interpolating across the four censuses. We then compute the period averages. Second, we use the transportation network at independence using localities' population in 1980, ($MA_{o,\text{init}}$); this MA statistic isolates the role of landmine removal from subsequent endogenous changes in population, new roads, and improvements in the network. Figure 6 maps the changes between the last and the first period in contemporaneous (log) market access (Panel A) and the analogous difference using the pre-clearance transportation network and 1980 population ($MA_{o,\text{initial}}$, Panel B). The correlation between the two measures is 0.67.

Three features are important for our analysis. First, there is considerable local variation in changes in market access, as province constants explain only 4% of the variation, and admin-2 fixed effects about 23%. Second, changes in log MA are (very) weakly correlated with geographic, location, and early development proxies (SM Figure D5), reflecting the colonial legacy of railroads and roads connecting the ports with the interior instead of linking the main cities (see also Jedwab and Moradi (2016)).

Third, changes in a locality's market access, which reflect clearance in localities connected via the transportation network, are only weakly correlated (between 0.15–0.20) with the evolution of clearance in the locality itself [see SM Table D3], allowing us to explore the two mechanisms reflected in equation (1) both separately and jointly. This low correlation is not surprising as less than 15% of clearance interventions (1241/8436) involved elements of the transportation network.

4.3. *Estimating Equation and Identification*

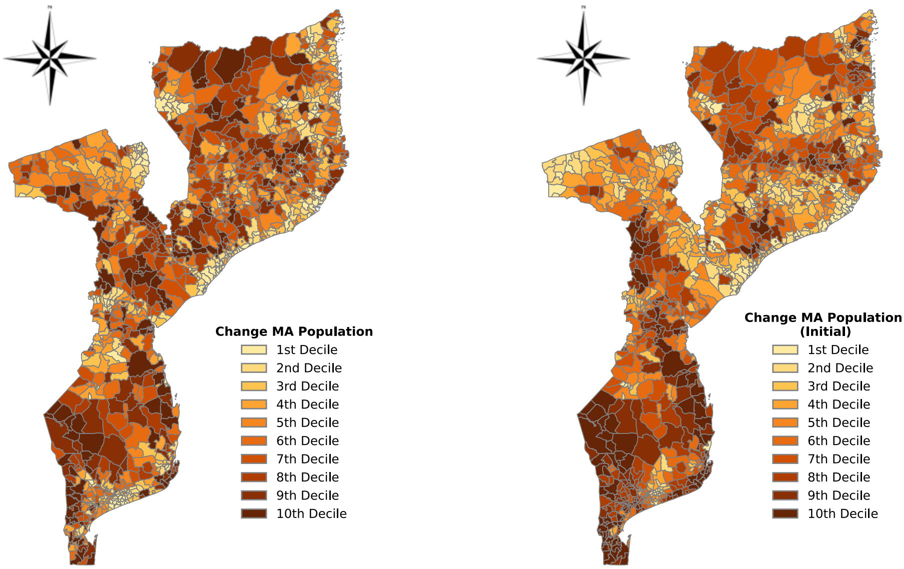
Armed with measures of market access and cleared hazards, we estimate variants of equation (1) across the 1184 localities over the 1992–2017 period.

$$\text{Lit}_{o,t} = \lambda\, \text{Haz}_{o,t} + \mu \ln MA_{o,t} + \mathbf{X}'_{i,t}\Gamma + \gamma_o + \gamma_{p,t} + \zeta_{o,t} \tag{3}$$

Landmine removal affects income, proxied by luminosity, $\text{Lit}_{o,t}$, by reducing the number of hazards (increasing productivity) in a given origin and time, $\text{Haz}_{o,t}$, and through market access, $MA_{o,t}$, by lowering transportation costs. This treatment spillover framework cannot quantify common-to-all-locality shocks absorbed by the province period-specific constants, $\gamma_{p,t}$, which also account for differential changes in the socioeconomic environment across provinces, policies, and provincial shocks.

Estimation proceeds in two steps. First, in the next section, we run variants of the estimating equation focusing on the "direct" productivity-enhancing role of clearance using "event-study" designs with yearly data. This allows us to test for pre-trends and explore short-, medium-, and longer-term dynamics. Second, in Section 6, we jointly assess the productivity and the market access role of landmine removal over the three phases of demining.

There are four identification challenges. The first concern regards the potential strategic clearance of landmines in areas with growth potential. Although the history of clearance in Mozambique suggests that this was not the case, we explore in the event-study analysis below whether luminosity increases before the commencement of clearance operations. In addition for the joint estimation of the two mechanisms, we develop an identification design that isolates clearance of hazards not pinpointed as potentially contaminated in the previous surveys, which therefore could not have been part of any central



Panel A: Change in Log MA Population Contemporaneous **Panel B: Change in Log MA Population Pre-clearance Network and Population**

FIGURE 6.—Change in Population Market Access. Panel *A* plots the change in the log of the population-weighted market access between the third (2009–2017) and the first phase of demining (1992–2000). Panel *B* plots the change in the log of population market access using the pre-clearance transportation network and the 1980 population.

strategic prioritization or targeting. [We do not implement this strategy in the event study analysis as the literature on the staggered adoption of multiple treatments is evolving.]

Second, time-varying local factors may be correlated both with clearance and productivity. To better capture the former, besides the province period-specific constants, we add a time-varying third-order latitude-longitude polynomial and interactions of geographic and locational characteristics with the year/period constants, $\mathbf{X}'_{i,t}\Gamma$.[15] Moreover, in some specifications, we replace the province-period constants with more granular district (admin-2)-period ones.

Third, the evolution of market access reflects the changing population and transportation costs, which are, in turn, driven by localities' income (and related development factors). The population evolves jointly with income in the underlying theoretical setup, reflecting changes in transportation, local productivity, and labor movements. Thus, we mainly work with market access statistics using destination localities' populations in 1980.

A fourth issue is measurement error. Despite our efforts to identify the exact location and year of clearance, the information is arguably noisy. To the extent that the error is uncorrelated with a locality's growth potential, a reasonable description of the context in which demining took place, the coefficient on λ will be attenuated. There is also measurement error in the market access statistic, stemming not only from noise in the exact location of minefields (needed to infer whether they block roads and railroads) but also

[15]The location and geographic features include log distance from Swaziland, South Africa, Zimbabwe, Zambia, Malawi, or Tanzania, elevation, malaria, and suitability for agriculture.

from the projection error in the transportation network and the parameterization of bilateral costs (equation (2)). We experiment with alternative parameter values and relax the assumption of landmines blocking the network to assess the stability of our results. As the MA statistics may not accurately capture effective proximity to agricultural markets or export hubs, we also explore sensitivity using measures putting more weight on proximity to the main (port) cities.

5. LANDMINE CLEARANCE AND LOCAL DEVELOPMENT

We first lay down the event-study specification, discuss estimation, and explore pre-trends. Second, we report the estimates. Third, we use the cancellations of SHA as a placebo. Fourth, we conduct a preliminary exploration of the mechanisms. SM Section C and the AA Section W1.5 give further evidence.

5.1. *Empirical Framework*

5.1.1. *Event-Study Design*

To explore the dynamics of local development, when clearance operations start and complete, we set aside potential MA effects (motivated by the low correlation between local clearance and MA) and rewrite the estimating equation (3) as follows:

$$\text{Lit}_{i,t} = \mu_i + \mu_{t,p} + \beta^{I,F} CLEAR^{I,F}_{i,t} + \mathbf{X}'_{i,t}\Gamma + \zeta_{i,t}. \tag{4}$$

$\text{Lit}_{i,t}$ denotes economic activity in locality i, in year, t, proxied by nighttime lights between 1992–2017. 1992 is the first year of the lights series and the end of the civil war; 2017 is the year of the last intervention. As many localities registered zero light (especially in the early years), we focus on the extensive margin with an indicator that equals one if any pixel in the locality is lit. To examine the dynamics of development around clearance, we transpose the number of (cleared) hazards ($\text{Haz}_{i,t}$) and employ as explanatory variables an indicator that switches to one either in the year of *initial* clearance and all subsequent years ($CLEAR^{I}_{i,t}$) or when the locality gets *fully* cleared ($CLEAR^{F}_{i,t}$), and all subsequent years. We distinguish between initial and full clearance, as interventions spanned several years in the heavily mined localities.

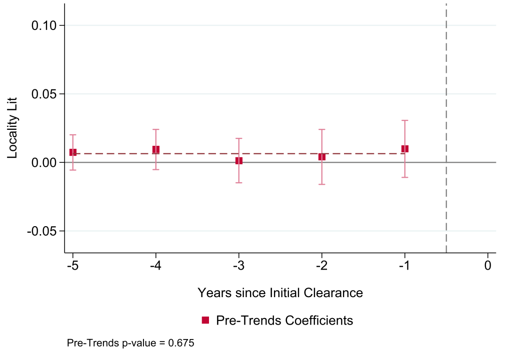
The dynamic specification reads

$$\text{Lit}_{i,t} = \mu_i + \mu_{t,p} + \sum_{h=-a}^{b} \beta^{I,F}_h \mathbf{1}\left[CLEAR^{I,F}_{i,t} = h\right] + \mathbf{X}'_{i,t}\Gamma + \zeta_{i,t}. \tag{5}$$

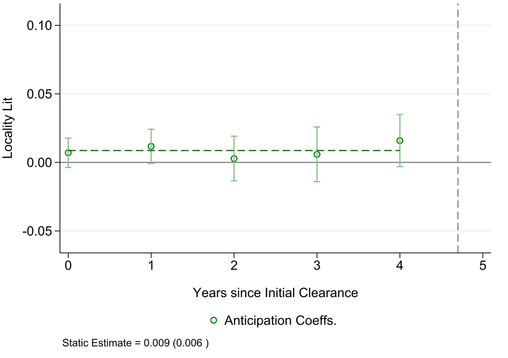
The estimates on the lead indicators allow for detecting differential dynamics between noncontaminated and mined localities before clearance ("pre-trends"). The coefficients of the lags capture the dynamic path of luminosity following the initiation/completion of demining.

5.1.2. *Estimation*

Recent works demonstrate that least squares (LS) estimation of difference-in-difference designs with a staggered "event," like ours (as demining starts/completes in different years across contaminated localities), may fail to produce unbiased estimates of the average treatment effect when the effects change over time, or there is treatment



Panel A: Pre-trends

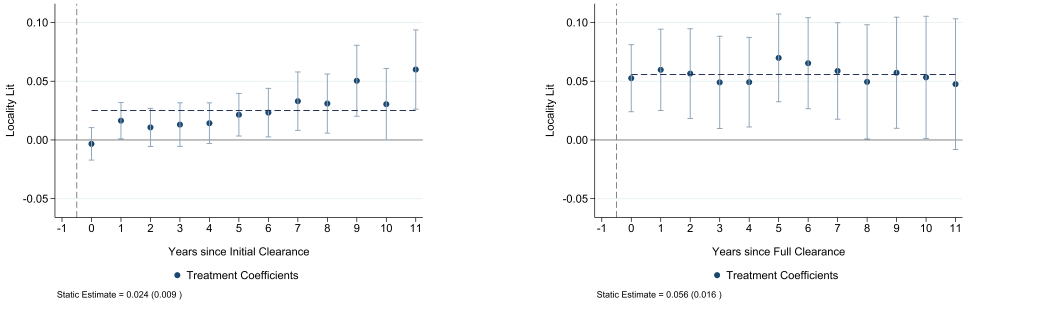


Panel B: Anticipation

FIGURE 7.—The outcome variable is an indicator that equals one if the locality is lit and zero otherwise. Panel A reports a pre-trend test. The squares report the coefficients of lead indicators in the dynamic event-study specification, testing for common trends between not-yet-cleared and noncontaminated localities in the 5 years before clearance commences. The figure also reports the p-value of an F-test of the null hypothesis of no differences in the outcomes between the two groups of localities. Panel B reports a test of anticipation effects, where the initial clearance is moved 5 years before the actual year in contaminated localities. The hollow dots give the "placebo" imputation estimates of (hypothetical) initial clearance indicators, estimates with the imputation estimator. The legends give the static estimands (and standard errors) for the "placebo" years. All specifications include province-year fixed effects and locality constants. 95% confidence intervals based on standard errors clustered at the district level are given alongside the five pre-clearance indicators' simple (unweighted) mean (in dashed lines).

heterogeneity across localities (Callaway and Sant'Anna (2021), de Chaisemartin and D'Haultfoeuille (2020)). The problem emerges because LS with staggered rollout not only leverages comparisons between cleared units and "pure" control observations (noncontaminated localities and those where no intervention has occurred) but also compares cleared units to those cleared earlier. These, often referred to as "forbidden," comparisons, are problematic when the dynamic correlations are not constant. Various diagnostics indicate time heterogeneity when considering initial, though not full, clearance.[16] We, thus, estimate the static and dynamic association between clearance and luminosity using the "imputation" method of Borusyak, Jaravel, and Spiess (2024), well suited to our setting. First, the locality and the year-province constants (and the coefficients on controls) are estimated using *only untreated* observations, that is, all yearly observations of nonmined localities and the pre-clearance years of contaminated ones. Second, the estimate is the average post-clearance luminosity minus the imputed value from the locality and the province-year constants (and the controls) computed in the first step. We compute both the mean of all post-clearance years (static) and of each year separately (dynamic).

[16]The decomposition of Goodman-Bacon (2021) that splits the LS estimate into all possible $2x2$ comparisons shows that with the initial clearance indicator, half of the LS coefficient (52.3%) stems from "forbidden" comparisons. When we look at full clearance, "forbidden comparisons" get a 26% weight. In the AA Section W1.4, we show that a similar picture emerges when we perform the intuitive tests of Jakiela (2021) to detect the observations with "negative weights" and check the homogeneity of the coefficients. Negative weights emerge late for localities cleared early, especially with the initial clearance indicator that switches to one much earlier than the full clearance indicator. The coefficient homogeneity assumption is rejected with the initial but not with the full clearance indicators.



Panel A: Initial Clearance **Panel B: Full Clearance. Excl. Inter. Clearance**

FIGURE 8.—The figure reports event study coefficients (in circles) with the Borusyak, Jaravel, and Spiess (2024) imputation method that estimates the response of luminosity in the year of clearance and 11 years after. In Panel A, $T = 0$ corresponds to the initial year of clearance. In Panel B, $T = 0$ corresponds to the year when the locality is completely clear of all contamination. Panel B drops years of partial clearance, that is, locality-year observations where clearance has commenced but not completed. The outcome variable is an indicator that takes the value of one if the locality is lit and zero otherwise. All specifications include province-year fixed effects and locality-specific constants. The legends give the static estimands (and standard errors) for the twelve post-clearance years (including the event year). 95% confidence intervals based on standard errors clustered at the district level are given alongside the simple (unweighted) mean (in dashed lines) of the twelve post-pre-clearance indicators.

Pre-Trends. It is instructive to examine pre-trends in development between contaminated and non-mined localities *before any clearance takes place*, as this sheds light on the potential targeting of growing areas. Borusyak, Jaravel, and Spiess (2024) suggest comparing the LS coefficients on the leads of equation (5) that capture differences in the dynamics of luminosity between not-yet-cleared, on the one hand, and noncontaminated localities, on the other hand, before clearance begins.[17] Figure 7, Panel A plots the estimates. All lead indicators enter with small and statistically insignificant coefficients. The F-test fails to reject the null hypothesis of no differences in luminosity between the noncontaminated localities and the mined localities before clearance starts. We also checked for "anticipation" effects; assuming that clearance begins 5 years earlier, we estimate placebo "treatments" with the imputation estimator (Liu, Wang, and Xu (2022)). As Figure 7, Panel B shows, there is no evidence, as the placebo clearance does not correlate with luminosity. These results square well with the fragmented, ad hoc, noncentrally coordinated, and based on imprecise information process of clearance in the 1990s and early 2000s. It is also in line with our interviews with deminers and officials that prioritizing high-growth (potential) areas was neither logistically feasible nor part of the contracts nor applied by operators.

5.2. *Baseline Event Study Estimates*

Dynamic Estimates. Figure 8 plots the imputation estimates from the dynamic specification (equation (5)). Standard errors are clustered at the admin-2 (district) level, which accounts for serial correlation and spatial (within-district) interdependencies. Panel A

[17]The test (i) avoids the pre-testing problem in OLS blending post and pre-event observations by restricting estimation of the leads to "untreated" observations (Roth (2022)); (ii) is robust to treatment heterogeneity; and (iii) is conceptually appealing as it separates the estimation of landmines' role in development from pre-clearance dynamics.

plots the coefficients of the twelve post-clearance indicators (including the year of initial clearance, $T = 0$). Luminosity increases gradually after the operations start. The coefficients on the post-1 to post-5 indicators suggest an increase in the likelihood of lit of about 1 percentage points (pp). The coefficients rise and turn significant 5 to 6 years after the initial operations when the median mined locality gets cleared of all hazards. Panel B focuses on *full* clearance, excluding years with partial clearance. Dropping the years with demining teams on the ground, conducting technical surveys, drafting action plans, and completing their tasks addresses concerns that the coefficients somehow mechanically pick up their presence. These estimates compare development in never-mined localities and contaminated ones before any clearance and after removing all hazards. The likelihood that the locality is lit after demining teams have cleared all hazards is about 5.6 pp; for comparison, 13% of localities are lit in 2005.

Static Estimates. Table II gives the static estimates of equation (4) The coefficient in column (1) suggests an average increase of about 5 pp in the likelihood that the locality will be lit after clearance commences, compared to noncontaminated and not-yet-cleared localities. The coefficient, estimated across the entire sample, is higher than when we focus on the twelve post-clearance years (Figure 8, Panel A), as estimation leverages all post observations. In column (2), we focus on the years following the final intervention, omitting observations when clearance has started but not completed. Clearing a locality from all hazardous areas increases the likelihood of being lit by roughly 6.2 pp compared to the period of full contamination. The estimates with the imputation method are comparable to the LS ones when omitting "forbidden" comparisons between cleared early and late localities (Goodman-Bacon (2021)), 0.036 with the initial and 0.047 with the full clearance indicator. As the median (mean) number of CHA in contaminated localities is 5 (9.3), the estimates imply that clearing a single hazard increases luminosity by about 0.005 pp, on average (see Borusyak, Jaravel, and Spiess (2024)). To better understand magnitudes, we estimated the elasticity between lights and development proxies using 139 georeferenced DHS surveys in 34 countries and all Mozambican Censuses (1997, 2007, and 2017) [SM Section B]. The DHS analysis implies an increase of about 0.10 standard deviations in the standardized composite wealth index when a locality turns from unlit to lit. The Mozambican censuses suggest an increase in schooling by about 0.40 years when a locality turns from unlit to lit.

Sensitivity. Columns (3)–(5) explore different measures of luminosity and clearance. In (3), we dropped 1026 interventions before 2007 with limited information in the reports. Those entries mainly come from the IMSMA database, which becomes precise after 2007. In (4)–(5), we stop the analysis in 2013 and use nighttime data only from the DMSP satellites with and without any adjustment for top-coding, sensor calibration, and blooming. In (6), we control for annual rainfall, which is crucial for agricultural economies and may affect clearance. In (7), in a restrictive test, we replace the province-year with district-year fixed effects to account for unobserved features at a fine level. The estimates across all perturbations are similar to the baseline, and precision often improves. In addition, SM Table C1 shows that the imputation estimator coefficients, when we condition on market access, are very similar to those reported in Table II.

5.3. *SHA Cancellations as Placebos*

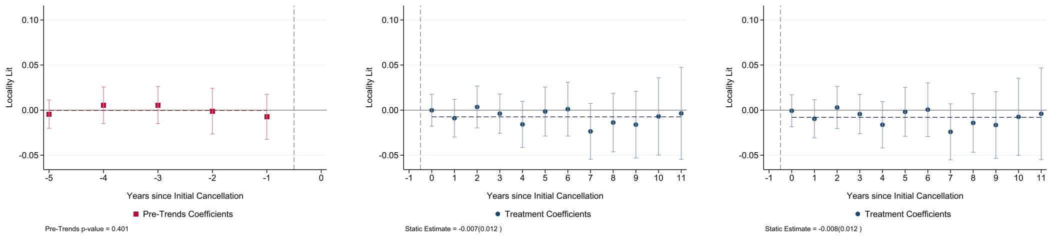
As described earlier, our database records instances when the demining teams visited a SHA to verify the contamination only to find out that it was *"landmine-free,"* as either the community was using the suspected area already or no one could confirm the

TABLE II

LANDMINES REMOVAL AND LOCAL DEVELOPMENT.

	Initial Clearance	Full Clearance					
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Clearance	0.050	0.062	0.059	0.056	0.048	0.062	0.065
	(0.013)	(0.017)	(0.018)	(0.014)	(0.015)	(0.017)	(0.022)
Estimate per Cleared SHA	0.00522	0.00649	0.00614	0.00586	0.00507	0.00648	0.00683
Number of Localities	1184	1184	1184	1184	1184	1184	1184
Specification	Unconditional	Excluding Interm. Clearance	Drop Limited Info Operations	DMSP Only Stop 2013	DMSP Unadjusted Stop 2013	Controlling Rain (Log)	District X Year FE
Locality FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year x Province FE	Yes	Yes	Yes	Yes	Yes	Yes	No
Loc and Geo X Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
# Treated Observations	15,270	8990	8646	5492	5492	8990	7125
Observations	30,784	24,504	24,964	19,814	19,814	24,504	22,639

Note: The table reports difference-in-difference estimates using the imputation estimator associating luminosity with landmine clearance. The dependent variable is an indicator that equals one if the locality is lit and zero otherwise. The main independent variable in column (1) is an indicator that takes the value of one when clearance operations start in a locality and all subsequent years; the indicator equals zero when clearance has not started. In columns (2)–(7), the main independent variable takes the value of one when the locality is fully cleared of all hazards and all subsequent years; these specifications omit locality-year observations in contaminated localities where clearance has started but not yet completed. Column (3) uses data on 7410 clearance interventions with detailed completion reports; in column (4), the analysis uses the luminosity series only from the DMSP-OLS satellites that stop in 2013; column (5) uses the unadjusted ("raw") luminosity series from DMSP-OLS from 1992 to 2013, taking the average in years of multiple observations from different DMSP satellites; column (6) controls for the log of yearly rainfall. The specifications in (1)–(6) include province-year fixed effects, while specification (7) includes district-year fixed effects. All specifications include interactions between year indicators and location (third-order polynomial of latitude and longitude) and geographic controls (log distance from Swaziland, South Africa, Zimbabwe, Zambia, Malawi, or Tanzania, elevation, malaria, suitability for agriculture). Standard errors (in parentheses) are clustered at the district (admin 2) level.



Panel A: Cancellation. Pre-trends **Panel B: Cancellation** **Panel C: Cancellation Control for Clearance**

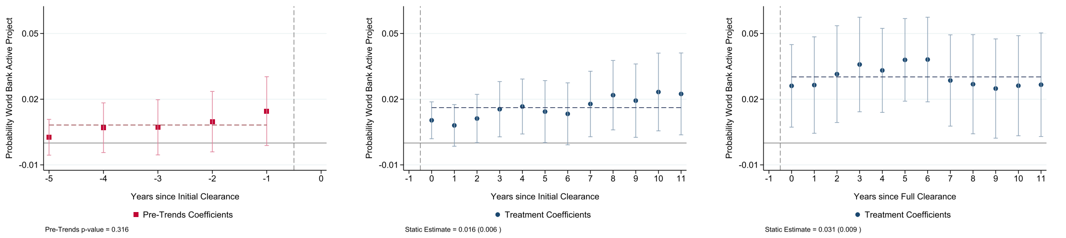
FIGURE 9.—The figure reports difference-in-difference coefficients (in circles) with the imputation method that estimates the response of luminosity in the year of cancellation and 11 years after. $T = 0$ corresponds to the year when the first SHA that was erroneously classified is canceled in a given locality. Panel B plots the unconditional estimates. As clearance and cancellation can happen in the same locality, Panel C controls for actual clearance in the locality. The outcome variable is an indicator equal to one if the locality is lit. All specifications include province-year and locality-specific constants. The legends give the static estimands (and standard errors) for the 12 post-cancellation years (including the event year). The squares in Panel A report coefficients of lead indicators, testing for common trends in the 5 years before cancellation occurs for the first time between not-yet-canceled localities and localities without cancellations. The panel legends report the p-value of an F-test of the null hypothesis of no outcome differences between the two groups of localities. 95% confidence intervals based on standard errors clustered at the district level are given alongside the simple (unweighted) mean (in dashed lines) of the twelve post- and the five pre-cancellation indicators.

presence of a hazard. We examined the dynamics of luminosity when operators reclassify SHAs as canceled or nonaffected by landmines to shed light on two issues. First, if operators, donors, or the National Institute of Demining target areas with growth potential, we should observe luminosity increase before or shortly after the arrival of demining teams, even when no contamination is present. Second, if the mere presence of deminers boosts activity, luminosity should spike around the year of reclassification. Figure 9 plots the coefficients of the imputation estimator.[18] Three results emerge. First, as with actual clearance, there is no evidence of differential trends in luminosity between localities to be visited by clearance squads and localities without cancellations, that is, nonmined and contaminated ones with no cancellations (Panel A). Second, there is no jump in luminosity in the year or around the cancellation (Panels B–C). Third, development does not respond dynamically to the cancellation. SM Table C2 provides further evidence of luminosity's nonresponse to cancellations.

5.4. *A Primer on the Mechanisms*

Aid. Landmine clearance may spur local economic activity by allowing much-needed aid and development projects. In Figure 10, we examine the evolution of World Bank projects around clearance from 1992 to 2017. Roughly half of the 234 projects (in 108 localities) cover water supplies, sanitation, flood protection, and irrigation, directly linked to agricultural productivity (equation (1)). The other half mainly consists of improvements in local roads, new paths, electrification, and public administration projects. There

[18]Several reports explicitly state that deminers reclassify SHA as canceled while removing mines from nearby minefields. Therefore, we omit instances where actual clearance occurs simultaneously in a $2km$ radius to avoid capturing the impact of removing landmines. There are 1573 reclassifications of SHA as not contaminated in 682 localities. In 523 localities, cancellations occur once, whereas in 159 localities, cancellations occur over multiple years. For the latter, we take the first cancellation as the event year.



Panel A: Pre-trends **Panel B: Initial Clearance** **Panel C: Full Clearance. Exclud. Interm. Clearance**

FIGURE 10.—The figure reports difference-in-difference coefficients with the imputation estimator associating the presence of a World Bank-funded project in the locality 12 years after clearance operations commence (Panel B) and complete (Panel C). Panel C drops observations with partial landmine clearance. The outcome variable is an indicator that takes the value one if there is at least one active World Bank-funded project in the locality in a given year and zero otherwise. All specifications include province-year and locality-fixed effects. Panel *B* and *C* legends also give the static estimands (and standard error) for the 12 post-clearance years. Panel A reports LS coefficients testing for parallel (common) trends between not-yet-cleared localities and noncontaminated localities 5 years before clearance commences; the legend gives the p-value of an F-test of the null hypothesis, indicating that there are no differences in active WB projects between the two groups of localities before the clearance. 95% confidence intervals based on standard errors clustered at the district level are also shown, alongside the simple (unweighted) mean (in dashed lines) of the 12 post and the 5 pre-clearance indicators.

is little evidence that aid increases before clearance operations start (Panel *A*). The coefficients of the imputation estimator (Panels B–C) imply a roughly 3 (1.5) pp increase in the likelihood of an active WB project after full (initial) clearance, suggesting that landmine removal opens the road for irrigation, electrification, and transportation investments, revealing a plausible mechanism. However, although donor support appears to react to clearance, the correlation between luminosity and clearance retains its economic and statistical significance when accounting for WB projects and when we drop all localities with WB projects (SM Table C3).

Roads and Population Density. We then examined the within-locality correlation between clearance and changes in the road network. Since we do not have yearly information, we run panel specifications associating indicators for new road construction and improvements (e.g., unpaved to paved) in the 1973 networks and clearance at the four points where we have transportation information. The LS estimates (in SM Table C4) show that landmine removal correlates with improvements in the at-independence road network, revealing another mechanism. Clearance does not seem to spur urbanization unless the interventions take place along the transportation network.

Heterogeneity. Lastly, as a preliminary step in looking at the landmines' role in facilitating flows, we distinguish between interventions along the transportation network and elsewhere. When we run the imputation estimator separately for the two sets of interventions, we find much stronger correlations with luminosity when looking at the clearance of mines blocking roads and railroads, suggesting landmines' role in hindering trade (SM Figure C1).

6. LANDMINES AND DEVELOPMENT. PRODUCTIVITY AND MARKET-ACCESS

After detailing the short-, medium-, and long-run link between local clearance and economic activity, we jointly explore the role of local and nationwide clearance on productivity and market access (framework equation (1)). First, we report the baseline estimates. Second, we implement an identification design that isolates clearance of hazards not pinpointed as potentially contaminated in earlier surveys, which could not have been centrally prioritized. SM Section D gives summary statistics, descriptives, and additional results.

6.1. *Baseline Results*

Table III gives the baseline estimates of equation (3) that links luminosity with the removal of hazards and market access within Mozambican localities across the three main phases of demining, which we match to the transportation network [period 1: 1992–2000; period 2: 2001–2008; period 3: 2009–2017].

Contemporaneous. Cleared hazards ($\text{Haz}_{o,t}$) enter with a highly significant coefficient in column (1), implying a per-hazard increase in the likelihood the locality is lit by half a percentage point, similar to the "imputation estimator" with annual data in Table II. The development-MA elasticity is positive and highly significant with both the baseline population market access and the luminosity-weighted measure (columns (2) and (4)). A one-standard-deviation increase in MA (around 2.5 log points) raises the likelihood the locality is lit by 7.8 pp. Columns (3) and (5) capture both the direct [λ] and market access [μ] effects of clearance. The coefficient on $\text{Haz}_{o,t}$ suggests an increase in the light likelihood of 3.5% when the average locality gets fully cleared. To put these numbers in context, 6.8% and 34.9% of the contaminated localities were lit in 1992 and 2017, respectively. The coefficient on market access retains statistical and economic significance, as the correlation with cleared hazards is small-to-modest (SM Table D3).

Isolating Landmines' Role. The market access estimates in (2)–(5) do not only capture the role of landmine removal, as localities' market access also increases due to the expansion/improvement of transportation networks and increases in their trading partners' population (luminosity). In columns (6)–(7), we isolate the component of market access from landmine removal, using the pre-clearance transportation and population [Figure 6, Panel *B*]. The coefficient in $MA_{o,\text{initial}}$ in (6) is highly significant. In (7), we use an initial MA statistic that excludes adjacent localities to account for localized shocks. Omitting neighboring localities may also account for spatially correlated error-in-variables. Swings in market access from removing landmines along the pre-civil-war transportation network of nonadjacent localities boost luminosity. The comparison of the standardized coefficients on market access and the cleared hazards suggests that the former, working via the unblocking of the network, is roughly three to five times as important as the role of local clearance.

IV. Columns (8)–(11) report IV estimates where the MA measure capturing initial conditions [pre-clearance transportation network and 1980 population] serves as the instrument for contemporaneous MA. In (10)–(11), we use the initial MA, excluding neighboring localities. So, specification (7) is the corresponding "reduced form" for the IV estimates in (10)–(11), while column (6) denotes the "reduced form" for the IVs in (8)–(9). The first-stage fit is strong, as changes in market access over 1992–2017 reflect, to a significant extent, landmine clearance along the colonial network.[19] The estimate in (8) suggests

[19]The first-stage coefficients of the population-weighted MA are 0.87 (0.06) (standard error clustered at the district level) in column (8), and 0.49 (0.05) in column (10), with the initial MA measure that drops adjacent

that a one-standard-deviation increase in contemporaneous MA increases the likelihood a locality is lit by 20.8 pp. As in other market access studies, the 2SLS estimates are (approximately) three times as large as the LS ones.[20] The difference may stem from a reduction in measurement error that the 2SLS deals with. First, officials of the National Institute of Statistics and foreign specialists consider the 1980 population census of much higher quality than the 1997 one and around the same as the one in 2017 (National Institute of Statistics (2019)). Second, the 1973 network consists of the road segments and rail lines that Mozambicans have been using for decades. Third, the 1998 and 2003 mappings appear noisier, as there are some erratic changes; for example, segments initially classified as paved are subsequently reclassified as unpaved before reappearing in 2011 as paved. Fourth, while one would have expected the country to expand transportation in more developed areas with higher potential, the few new roads post-1993 were mainly built far from the coast. Transportation improvements do not correlate with proximity to big cities or province capitals (see Jedwab and Storeygard (2022) for similar patterns in Sub-Saharan Africa).

Alternative Parameterizations. Figure 11 explores sensitivity to the parameterization of the trade elasticity, θ, and the relative costs of the transportation modes. Both panels report 2SLS estimates, analogous to specification (8) of Table III. Circles give standardized coefficients with the baseline relative transportation costs, while the specifications in diamonds use the corresponding values from Jedwab and Storeygard (2022). The main difference between the two is the somewhat higher costs of railroads than paved roads, the authors assume, and the absence of rivers.[21] The first row gives 2SLS estimates using a trade elasticity value of one, a helpful benchmark, corresponding to proportional-to-distance trade costs (Harris (1954) “market potential”). The market access-development nexus strengthens. Then we experiment with the low (2.74) and high (5.4) estimates of Simonovska and Waugh (2014). The latter is close to the median value from Head and Mayer (2014) meta-analysis (5.03). The 2SLS coefficients are quite similar to the estimates with the baseline value. Finally, we use θ equal to 8.22.[22] The MA coefficient is significantly positive and stable. The main reason the relative parameterization of primary roads versus rails appears quantitatively less important is related to the unusual nature of the Mozambique network. Very few railroads, all going East-West, and the country’s North-South orientation render the road network the key transportation element; see, for example, the Maputo-Muabsa example in Figure 5.

Sensitivity Analysis. We performed various robustness checks that we report in SM Section D. First, we used the unadjusted DSMP data to explore how the corrections for

localities. The first-stage coefficients of the luminosity MA are 0.84 (0.07) [column (9)] and 0.62 (0.07) [column (11)].

[20]In SM Table D4, we replace luminosity with log population. We estimate an elasticity of log market access and log population between 0.07 and 0.12. This is very similar to the 30-year elasticity [0.08–0.13] of city population to market access in Jedwab and Storeygard (2022) for 39 countries in Africa.

[21]In Jedwab and Storeygard (2022), highways are the most efficient mode, normalized to 1 (speed: 80 km/h). The relative cost for railroads and paved roads is 1.33 (60 km/h) and for unpaved roads is 2 (40 km/h); for trails is 6.66 (12 km/h), and for walking to places with no roads/trails is 13.33 (6 km/h). As river transportation is not considered, we assign it our baseline relative cost of 15.

[22]Buys, Deichmann, and Wheeler (2010) report travel-based trade elasticities across Sub-Saharan African countries between 2.05 and 3.84. Donaldson (2018) estimates somewhat larger trade elasticities of 7.80 in colonial India. Donaldson and Hornbeck (2016) use a value of 8.22, based, however, on iceberg trade costs rather than travel-time/distance.

TABLE III

LANDMINE CLEARANCE, MARKET ACCESS, AND SPATIAL DEVELOPMENT.

	OLS					Reduced Form		2SLS			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Log MA Population		0.031	0.024					0.083		0.102	
		(0.011)	(0.011)					(0.028)		(0.036)	
		[0.179]	[0.139]					[0.476]		[0.589]	
Log MA Light				0.037	0.034				0.086		0.082
				(0.009)	(0.009)				(0.028)		(0.027)
				[0.298]	[0.275]				[0.696]		[0.659]
Log MA Population (Initial)						0.072					
						(0.025)					
						[0.378]					
Log MA Population (Initial) Doughnut							0.051				
							(0.018)				
							[0.257]				
Cleared Hazards	0.006		0.005		0.005	0.004	0.005	0.004	0.004	0.004	0.004
	(0.002)		(0.002)		(0.002)	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)
	[0.099]		[0.090]		[0.089]	[0.076]	[0.082]	[0.069]	[0.075]	[0.062]	[0.076]
Number of localities	1184	1184	1184	1184	1184	1184	1184	1184	1184	1184	1184
Locality FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time x Province FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time x Loc and Geo	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Kleibergen-Paap F-test	.	.	.	.	.	.	.	251	149	93.1	74.2
Observations	3552	3552	3552	3552	3552	3552	3552	3552	3552	3552	3552

Note: The table reports panel fixed effects estimates associating luminosity with market access across a balanced sample of 1184 localities. The dependent variable is an indicator that takes the value of one if the locality is lit and zero otherwise. Estimation is across the three periods of landmine clearance: 1992–2000, 2001–2008, and 2009–2017. Log MA Population denotes the logarithm of the contemporaneous population-weighted market access. Log MA Light denotes the logarithm of the contemporaneous luminosity-weighted market access. Log MA Population (Initial) is the logarithm of the population-weighted market access using the pre-civil-war transportation network (in 1973) and localities' populations in 1980. Log MA Population (Initial) Doughnut is similar to the Log MA Population (Initial) but drops neighboring localities in the calculation. Cleared Hazards denote the cumulative number of cleared CHA. Columns (1)–(7) report OLS estimates. Columns (8)–(9) report 2SLS coefficients, instrumenting the contemporaneous MA with Log MA Population (Initial). Columns (10)–(11) report 2SLS coefficients, instrumenting contemporaneous MA with the Log MA Population (Initial) Doughnut. All specifications include locality-fixed effects, province-period fixed effects, and period-specific cubic polynomials in latitude and longitude and period-specific geographic controls (log distance from Swaziland, South Africa, Zimbabwe, Zambia, Malawi, or Tanzania, elevation, malaria, suitability of agriculture). Standard errors in parenthesis are clustered at the district (admin 2) level. The table gives standardized "beta" coefficients [in brackets].

top coding, blooming, and sensor calibration influence our results. Second, we stopped in 2013 using the harmonized nighttime data from the DMSP satellites. Third, we replaced the province-period constants with district-period ones to account for time-varying unobservables at a finer level. Fourth, we dropped pre-2007 CHA, where information is limited. Fifth, given the importance of Maputo-Matola, Beira, and Nampula-Nacala for trade, we inflated the population/luminosity of these cities, adding the values of Johannesburg, Harare, and Lilongwe, respectively. Sixth, we run weighted OLS and 2SLS specifications using localities population in 1980 as weights. Seventh, we double the passage costs rather than assuming that minefields block the corresponding segments. Eighth, we use the log of Cleared Hazards to reduce the role of outliers. Ninth, we used the log

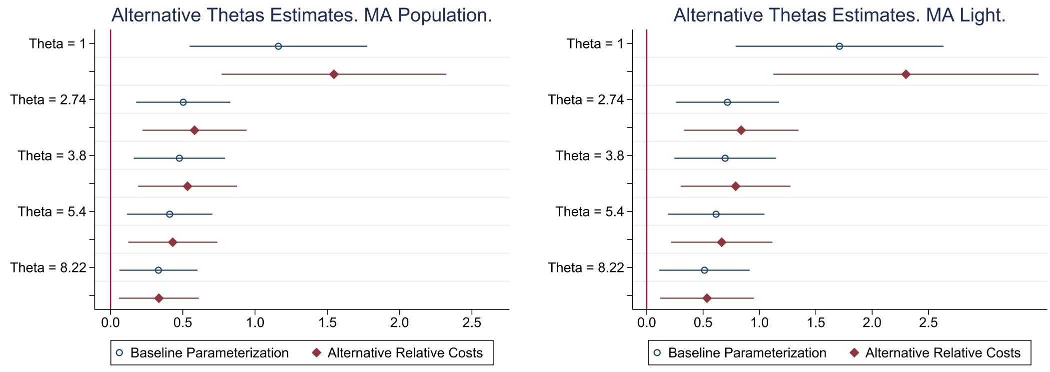


FIGURE 11.—Alternative Parameterization. The figures plot the standardized beta 2sls coefficients associating the lit indicator with the logarithm of the population-weighted MA (Panel A) and the luminosity-weighted MA (Panel B). The instrument is the logarithm of the population-weighted MA initial in all specifications. The hollow circles give 2SLS estimates with the baseline parameterization of relative transportation costs, while the diamonds give the corresponding 2SLS estimates with the parameterization of Jedwab and Storeygard (2022). All specifications control for the cumulative number of cleared CHA, locality fixed effects, province-period fixed effects, and interactions of period indicators with a third-order polynomial of latitude and longitude and geographic controls (log distance from Swaziland, South Africa, Zimbabwe, Zambia, Malawi, or Tanzania, elevation, malaria, suitability of agriculture). Standard errors are clustered at the admin-2 level.

of luminosity plus a small number as the outcome. Tenth, we repeated estimation at the annual frequency (although error-in-variables may be magnified). Eleventh, to minimize concerns that the estimates pick up the return of the refugees and the internally displaced people (IDPs), we rerun the annual specifications, dropping the initial five years. Almost all displaced had returned to their birthplaces or settled elsewhere by the October 1994 elections (see AA Table W5). Lastly, we removed the period interactions with geographic and location attributes and focused on the 1043 localities with available population data across all four censuses.

6.2. *Isolating the "Not-in-Surveys" Component of Clearance*

6.2.1. *Approach*

We now exploit the fact that more than half of the clearance operations were minefields that the three nationwide surveys, which guided demining in each phase, missed; see Section 3. Out of the 8436 clearances, 5097 were in contaminated areas that were neither identified as SHA in preceding surveys nor located within a two-kilometer radius.

We first construct MA statistics that reflect the clearance of areas correctly identified as contaminated in previous nationwide surveys (*in-surveys*), assuming the other contaminants remain on the ground. To isolate the role of clearance from new roads and population movements, we compile the "in-surveys" MA measures using the pre-clearance network and localities' 1980 population. We then subtract the "in-surveys" initial MA from the overall initial MA. The difference captures the component of the initial MA driven by the clearance of mines unaccounted for by the national surveys.

Borusyak and Hull (2025) point out that even when examining the role of exogenous transportation investments, the estimates may suffer from omitted-variables bias, as they may propagate more strongly in central areas. By taking the difference between the two MA measures, we account for the inherent correlation between market access and a locality's centrality. Nevertheless, due to the peculiar structure of Mozambique's transportation network, which does not connect its main cities much, even the baseline market access statistics are weakly correlated with geography, location, and early development proxies. Hence, it is not surprising that the "recentered" (residualized) MA is not a significant correlate of these features (see SM Figure D5).

6.2.2. *Results*

One way to isolate the component of market access from the clearance of "in-survey" hazards is to include on the RHS of equation (3) both the MA initial and the corresponding statistic that only reflects the removal of landmines correctly identified as SHA, "in-surveys" MA initial. Columns (1) and (2) of Table IV report the LS estimates. The coefficient on initial MA is stable and highly significant. As the "in-survey" MA captures any potential central coordination and localities' centrality, these results suggest that the luminosity-MA link is strong even when we exploit variation only from the clearance of hazardous areas that could not have been part of concerted prioritization and accounting for a location's centrality in the network.

Columns (3)–(5) associate luminosity with the "recentered" MA that eliminates the variation from "in-survey" interventions. The coefficient on the recentered MA is highly significant and close to the one estimated with the baseline initial MA (Table III, column (5)). $ClearHaz_{o,t}$ also enters with a significantly positive estimate in (4). This also applies when we only use "not-in-surveys" Cleared Hazards in (5). Columns (6)–(8) report 2SLS estimates using the initial MA recentered as an instrument for the contemporaneous MA. Specification (8) also instruments $ClearHaz_{o,t}$ with not-in-surveys cleared hazards.[23] These specifications, our preferred ones, illustrate the dual role of landmine removal on development. First, the direct productivity effect implies that the full clearance of the average mined locality leads to a 3.1 pp increase in the lit likelihood [$0.0033 * 9.5$ CHA]. Second, clearance boosts economic activity by stimulating market access. A one log point increase in MA, from removing hazards that the surveyors missed, increases the likelihood of light by about 9.2 *pp*. The comparison of the standardized "beta" coefficients tells of clearance's much larger role via MA considerations. The "beta" coefficients on the MA are about 0.50, comparable to Donaldson and Hornbeck (2016) on the railroad-driven increases in market access on land values in the US and in the middle of the range of the Jedwab and Storeygard (2022) estimates of road building driven changes in market access on African urbanization.

7. POLICY COUNTERFACTUALS

The underlying conceptual framework allows for the comparison of alternative landmine removal scenarios. We first approximate the aggregate effects of clearance to a counterfactual without any demining. Second, we consider a clearance protocol that prioritizes the core attributes of the transportation network, as this sheds light on the ongoing demining planning efforts in Ukraine and elsewhere.

[23]Hence, the specifications in (3)–(5) are the corresponding "reduced forms" for the IVs in (6)–(8). The first-stage fit is strong with an F-statistic of 59, as a sizable part of the variability of contemporaneous MA and cleared hazards stems from the clearance of mines not identified as SHA. See AA Table W4 for the first-stage regressions of the 2SLS in Tables III and IV.

TABLE IV

LANDMINE CLEARANCE, MARKET ACCESS, AND SPATIAL DEVELOPMENT ISOLATING THE "NOT-IN-SURVEY" LANDMINE REMOVALS.

	Control for Expected MA		Reduced Form			2SLS		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Log MA Population						0.109 (0.033) [0.626]	0.089 (0.035) [0.513]	0.092 (0.035) [0.530]
Log MA Population (Initial)	0.090 (0.026) [0.471]	0.072 (0.027) [0.375]						
Log MA Population (Initial) In-Survey Only	−0.007 (0.054) [−0.038]	0.002 (0.055) [0.010]						
Recentered MA Population (Initial)			0.089 (0.026) [0.106]	0.069 (0.027) [0.083]	0.076 (0.027) [0.091]			
Cleared Hazards		0.004 (0.002) [0.076]		0.005 (0.002) [0.080]			0.004 (0.002) [0.066]	0.003 (0.001) [0.057]
Not-In-Survey Cleared Hazards					0.005 (0.002) [0.058]			
Number of localities	1184	1184	1184	1184	1184	1184	1184	1184
Locality FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time x Province FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time x Loc and Geo	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Kleibergen-Paap F-test	.	.	.	.	.	167	127	59
Observations	3552	3552	3552	3552	3552	3552	3552	3552

Note: The table reports panel fixed effects LS (in columns (1)–(5)) and 2SLS estimates (in columns (6)–(8)) across the three main phases of landmine clearance in Mozambique, 1992–2000, 2001–2008, and 2009–2017. The dependent variable is an indicator that takes the value of one if the locality is lit and zero otherwise. Log MA Population is the logarithm of the population-weighted contemporaneous market access. Log MA Population (Initial) is the logarithm of the population-weighted market access with the at-independence transportation network and localities' population in 1980. The Recentered Log MA Population (Initial) is the difference between Log MA Population (Initial) and an otherwise similarly constructed MA measure that reflects only the removal of "in-survey" hazards. Cleared Hazards denotes the cumulative number of cleared CHA in a locality. Not-In-Survey Cleared Hazards denote the cumulative number of cleared CHA not identified as SHA in preceding surveys. The 2SLS specifications in columns (6), (7), and (8), instrument the contemporaneous Log MA Population with the "Recentered" Log MA Population (Initial). Column (8) also instruments Cleared Hazards with Not-In-Survey Cleared Hazards. The Sanderson–Windmeijer F-test is 119 for the Log MA Population and 597 for Cleared Hazards. All specifications include locality fixed effects, province-period fixed effects, and a cubic polynomial of latitude and longitude and geographic controls (log distance from Swaziland, South Africa, Zimbabwe, Zambia, Malawi, or Tanzania, and elevation, malaria, suitability of agriculture) interacted with period constants. Standard errors in parentheses are clustered at the district (admin 2) level and standardized "beta" coefficients [in brackets].

7.1. *A Mozambique Without Demining*

What would have been Mozambique's aggregate economic activity in 2017, had the international community, donor agencies, and the government left the contamination problem unresolved? To answer this question, we compare a landmine-free to a landmine-ridden Mozambique in three counterfactual scenarios regarding the evolution of the transportation network. Table V gives the estimates of three counterfactuals in terms of market access in column (1) and luminosity in columns (2)–(3c). In rows (1) to (3), we fix the aggregate Mozambican population at the 2017 level and reallocate across localities using the population shares in 1980 for both the actual and the counterfactual market access. In row (4), we use localities' population count in 2017 for the construction of the actual MA. We quantify the probability that a locality is lit in 2017, factoring in the role of landmines on development only via market access (column (2)) and also taking into account the direct effects of clearance (columns (3a–3c)). For the counterfactuals in column (2), we use the IV estimates from specification (6) in Table IV; for those in (3a) to (3c), we use the IV estimates from specification (8) in Table IV.[24] See AA Section W3 for the model-based counterfactual estimates.

At-Independence Transportation Network. In row (1), we calculate *both* actual and counterfactual market access in 2017 using the pre-clearance transportation network, voiding the role of new roads and improvements. Market access is, on average, 36.3% lower than the realized (median 29.4%). Lower market access decreases the likelihood that the average locality is lit in 2017 by 6.8%; that is, 80–81 fewer lit localities ($0.068 * 1184$). As a share of the lit localities in 2017, 21% would remain dark in this counterfactual (81/381). However, as removing landmines also has a direct effect, captured by the λ estimate on $\text{Haz}_{o,p}$ in equation (3), in (3a)–(3c), we consider both mechanisms. As the luminosity-MA elasticity drops somewhat when we account for cleared hazards, this counterfactual yields a lower likelihood of light from the decline in market access of 5.8%, that is, about 69 localities. Factoring in the productivity channel yields a decline in the probability of observing a lit locality of 2.3%. Considering both effects of demining suggests that in the absence of clearance, about 97 lit localities in 2017 would not have been lit; this is about one-fifth of lit localities in 2017.

Contemporaneous Transportation Network. For row (2), we calculate the counterfactual and the realized MA using the 2011 transportation network, effectively assuming that Mozambique would have been able to build new roads and rails and improve the late colonial transportation network without tackling contamination. The comparison suggests a decline in market access by 59.7%; the larger magnitude stems from landmines blocking an upgraded and expanded transportation network. Nonclearance yields a decline in the mean likelihood of lit of about 13.5%; 160 localities would not have been lit in 2017.

Allowing the Transportation Network to Evolve. For the counterfactual in row (3), we assume that the absence of clearance would have prevented the expansion and improvements of the transportation network (as in row (1)), while clearance would have resulted in the expanded and improved network of 2011. This scenario is motivated by the observation that the rehabilitation and extension of the colonial network moved in tandem with clearance (SM Table C4). Market access decreases by 81% because mines not only obstruct the initial network but also hinder its improvement. The average decrease in the lit probability of 20.6% translates into 244 localities not being lit, approximately half of the lit ones in 2017. The counterfactuals yield similar aggregate losses, as the unconditional MA-driven decline in column (2) is quantitatively similar to the sum of the direct and indirect losses (in (3a) and (3b)).

[24]The change in the probability a locality is lit is computed as: $\sum((\exp(\widehat{\beta}_{2SLS} * (\log \text{MA counterfactual}_{2017}\text{-}\log \text{MA actual}_{2017}) - 1)/1184)$. The unconditional β_{iv} on MA is 0.109, and the conditional is 0.092. As shown in SM Figure D2, the relationship between luminosity and log market access (and cleared hazards) is approximately linear.

In row (4), we keep the counterfactual the same as in row (3), but for the actual MA, instead of using the 1980 population shares, we use the 2017 ones, allowing clearance to influence the evolution of the population distribution. Localities' market access in 2017 would have declined by 79.8% had landmines remained on the ground, and the population would not have been reallocated as in reality.[25] The standard deviation of this decline is 29%, while the 5th and 95th percentiles are 31.4%, and 98.9%. These considerable counterfactual MA costs are almost identical to Donaldson and Hornbeck (2016), who estimate an MA decline of 80% should railways not materialize in the late 19th century US.

Cost-Benefit Approximation. We conclude this section by approximating the aggregate costs and benefits of landmine clearance. Chiovelli et al. (2023a) estimate a GDP-lights elasticity of around 0.30 (mean) and 0.21 (median). Combining these estimates with the counterfactual losses estimated in the third counterfactual and Mozambique's GDP in 2017 of $17.18 billion (in 2015 USD), we estimate the demining benefits to be between $743 and $1061 million.[26] When we use the most conservative counterfactual in row (1), we get a dividend of between 295 and 423 million $[17.18 * 0.082 * 0.21(0.30)]$. Mozambique's growth has been strong, adding 14 billion in GDP since the end of the civil ($3.115 in 1993).[27] So, the benefits from demining are about 4% of this sizable increase; 5.3%–7.5% for counterfactual (3). Turning now to the clearance costs, the data is scant, sporadic, and of low quality. We reviewed all reports of the *Landmine Monitor*, which collects funding information from major donors and local authorities. The numbers of the Mozambican Ministry of Foreign Affairs and Cooperation (in the 1990s) and the National Institute of Demining (after 2001) are (inflated) estimates. The information covers not only clearance activities (removal of hazards, surveys, materials, and training), but also victim assistance, mine awareness, even military aid. After cleaning the data, our calculations suggest that total aid for mine action accounts for about 365–400 million (constant 2015 USD). Assuming that 20% went to other-than clearance-related activities, the totals are about 290–320 million.

Policy. While there is ambiguity about the actual costs, their comparison with the benefits reveals a noteworthy result, which to us, appears not very sensitive to the underlying assumptions. Comparing the costs to the direct economic benefits of landmine removal

[25]The across-locality correlation between the actual population in 2017 and the one using the total population of 2017 reallocated according to the population share of each locality in the 1980 census is above 80%.

[26]Conservatively, we assume that when a locality turns lit, its luminosity level matches the average across all localities in 2017. This assumption means that the 20.6% decline in the lit probability calculated in the counterfactual scenario translates into a similar percentage decrease in nationwide luminosity. This is not an innocuous assumption because, together with the luminosity-GDP elasticity, it pins down the estimated benefits. Alternatively, if we assume that when a locality gets lit, it achieves the average luminosity of already lit localities, the benefits of demining would be larger. However, a consistent pattern emerges regardless of the assumed GDP-luminosity elasticity or the luminosity values assigned to newly illuminated localities. The direct (productivity) effects of demining locally are a fraction (between one-third and one-ninth) of the market access effects. This conclusion is supported by the model-imputed counterfactuals of output, which bypass the luminosity-related transformations (see AA Section W3).

[27]In per capita terms, GDP grew by about 7% per year, from $219.3 in 1993 to $601.3 in 2017. About 4% of the 2017 GDP comes from off-shore natural gas, developed in the mid-late 2000s. Mozambique has been relying heavily on foreign aid. Official Development Assistance (ODA) hovered around 50% of GNI in the 1990s and about 25% in the 2000s and 2010s. Data come from the World Bank's World Development Indicators Database.

shows that the former are larger than the latter; this might explain the focus of the UN, specialized agencies, donors, and operators on the humanitarian aspects, deaths, injuries, psychological trauma, and exclusion rather than on the economic impact on local productivity. However, the cost-benefit analysis yields an entirely different picture when considering the market access gains from removing landmines, even with the most conservative counterfactual. The benefits considerably outweigh the costs.

Model-Based Counterfactuals. The regression-based counterfactuals detailed above do not capture general equilibrium effects present in the underlying theoretical framework. In the AA Section W3, we complement the analysis by conducting model-based counterfactuals of the aggregate effects of nonclearance. Following Donaldson and Hornbeck (2016), we calculate two extreme sets of counterfactuals. First, we keep the utility constant and allow the population to adjust in the nonlandmine removal counterfactual. Second, we keep the population at the 2017 level and allow the utility to fall. The model's quantitative exploration yields considerable declines in the population (of 50–70%), or utility (of about 20%) had Mozambique not proceeded with clearance. Although these are arguably high costs,[28] they are similar to the ones of Donaldson and Hornbeck (2016); so the model-based counterfactuals reveal that the aggregate benefits of Mozambique from landmine clearing are not dissimilar from the impact of railroads on the US economy during the Gilded Age. Most importantly, both the regression and the model-based analysis show that the "market-access" channel rather than productivity drives the overall impact of landmines on aggregate economic activity (captured by luminosity, income, population, and utility). This result, which arises naturally from the model parameterization and the distribution of mines (Figure 1), further highlights the need to consider the role of landmines in preventing commerce when designing demining and conducting cost-benefit analyses.

7.2. *Coordination and Prioritization*

We now ask how market access would have evolved had demining operators followed a coordinated strategy (perhaps under the UN or the government) that prioritized clearance of the transportation network. By focusing on changes in market access, one does not need to make assumptions about the lights-related transformations or the costs of clearance.

Counterfactual. We consider the following protocol based on the clearance history and Mozambique's economic geography. In the first period (1992/3–2000/1), operators prioritize the three "development" corridors, where primary roads and railroads connect Maputo, Beira, and Nampula to the interior. During the second period (2002–2008), clearance continues across the three corridors and then targets the highway ($N1$) connecting the South to the Central coastal areas and the North. Operators clear all remaining hazards in the third period (2009–2017). Consistent with the at-the-time constraints, the number of cleared localities is the same in the counterfactual, and in reality, every period: 55, 453, and 358 localities are cleared in the first, second, and third phases, respectively.

[28]In reality, manufacturing, mining, and services, which are absent from the model, could have absorbed some of the population, leaving agriculture in the no-clearance counterfactual.

TABLE V

COUNTERFACTUALS. ABSENCE OF LANDMINE CLEARANCE.

		Decline in the Probability of a Lit Locality due to:			
	Percent Decline in MA No demining (1)	Only MA Unconditional (2)	MA. Control Removal CHAs (3a)	Nmbr of Removed CHas (3b)	Total Effect (3c)
Pre-clearance Network	−0.363	−0.068	−0.058	−0.023	−0.082
		(0.019)	(0.021)	(0.010)	(0.019)
Contemporary Network	−0.597	−0.129	−0.111	−0.023	−0.135
		(0.035)	(0.038)	(0.010)	(0.036)
Pre-clearance vs. Contemporary Network	−0.810	−0.211	−0.182	−0.023	−0.206
		(0.055)	(0.061)	(0.010)	(0.058)
Pre-clearance vs. Contemporary Network	−0.798	−0.215	−0.186	−0.023	−0.209
Population Shares Change		(0.055)	(0.062)	(0.010)	(0.059)

Note: Each row reports the counterfactual impact on market access and luminosity assuming nonclearance of contamination in 2017. In row (1), we calculate actual and counterfactual market access using the pre-clearance transportation network. Row (2) compares actual and counterfactual market access using the most recent transportation network (as of 2011). Row (3) assumes that the absence of landmine clearance would have prevented the expansion and improvements of the pre-clearance transportation network. Row (4) mirrors row (3) but compares a counterfactual where the population in 2017 has been reallocated according to the shares of the population of 1980 versus with the actual market access using the 2017 population count as observed in the 2017 census. Column (1) reports the percent drop in market access. Column (2) tabulates the average decline in the probability of a locality being lit only through market access. Columns (3a), (3b), and (3c) disaggregate the total effect of nonclearance into market access (3a), direct effect (3b), and the total effect (3c). For all counterfactuals, we reallocate the total Mozambican population in 2017 to reflect localities' population shares in 1980.

Results. Figure 12 plots the increase in market access using the at-independence network and 1980 population between 1992 and 2009 when half of the mined localities were cleared. The realized MA changes are depicted in the left bars, and the counterfactual changes are depicted in the right bars. The difference reveals the losses of nonprioritizing "central" areas. Market access for the average locality would have increased by 22 log points if operators had coordinated the clearance of minefields close to the main transportation segments. To better understand how these losses are distributed, Figure 12 further distinguishes between four groups. Let us start with the 362 localities that were neither cleared in reality [$Actual = 0$] nor in the counterfactual [$Simulated = 0$]. In reality, log market access increased by 0.19; while no clearance occurred locally, market access rose due to clearance in other areas. Had clearance targeted the central nodes of the transportation system, log market access would have increased significantly more by 0.31. For the 194 fully cleared localities in reality and the counterfactual, the average increase in actual log market access is 0.55. The counterfactual increase is 0.73, since the simulated market access gets a boost from the clearance of other central localities. The mean increase in actual log-market access in the 314 localities, which were cleared but not prioritized in our counterfactual, is 0.27, while the change in the counterfactual log MA is lower 0.16. The "mirror" image of this difference is the 314 localities that were not cleared in reality but targeted in the counterfactual. The average increase of realized log market access is 0.65. Market access increased despite the absence of clearance, as these localities benefited from landmine removal elsewhere. However, the counterfactual increase in log MA is significantly larger, 1.32.

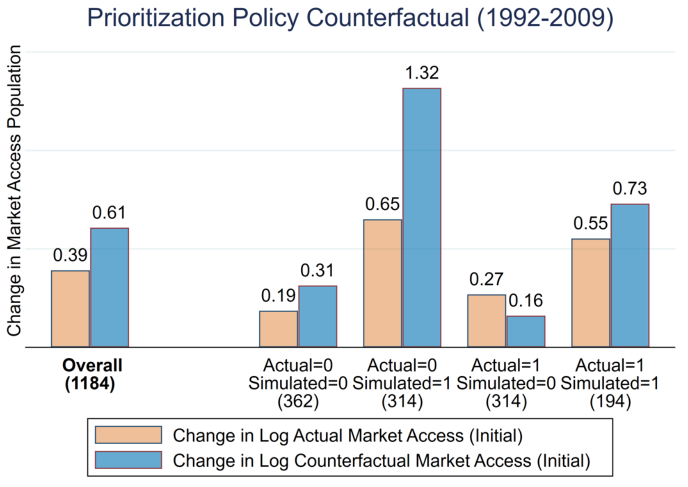


FIGURE 12.—Prioritization Counterfactual. The figure plots the mean in 2009 of the realized (left bar) and counterfactual (right bar) change in (log) market access, fixing population and transportation to the pre-clearance levels across 5 groups: (*i*) all 1184 localities. (*ii*) 362 localities neither cleared by 2009 nor in the counterfactual simulation. (*iii*) 314 contaminated localities cleared in the simulation but not in reality. (*iv*) 314 cleared in reality localities but not in the counterfactual; (*v*) 194 localities cleared both in reality and the counterfactual.

Policy. This simple counterfactual illustrates the sizable losses from the lack of prioritization. It further shows that operators, the UN, and governments should recognize the substantial spillover effects of clearing areas near roads and railways. While more evidence from additional countries is necessary, the underlying conceptual market access framework allows for some (cautious) extrapolation. Yet, a word of caution is in order. Our counterfactual analysis does not consider humanitarian aspects, at-the-time information, and coordination costs. Hence, it is not meant to supplant prioritization strategies but to complement them. It is worthwhile to emphasize that our economic-potential prioritization aligns with health concerns, as the limited international data suggest that casualties, amputations, and injuries are equally likely in both remote and more connected areas (Landmine Monitor, 2017; Frost et al., (2017)). Nonetheless, the simulations offer an informative, hands-off approach to crafting an informed demining strategy in the presence of economic externalities, which the Mozambican case suggests are sizable, though not much considered by the policy community and practitioners. Finally, the uncovered sizable economic costs of landmines blocking roads offer backing to the international community's efforts to expand the International Mine Ban Treaty on Antipersonnel Landmines of 1999 to antivehicle (antitank) landmines.

8. DISCUSSION

Two to three decades ago, there was hope that the *International Campaign* and the signing of the Antipersonnel Landmine Ban Convention would make landmines a legacy of the past. But landmines still affect the lives of millions around the world. Cheap to obtain and easy to manufacture, their appeal to warring parties, militias, governments, the military, and rebels has not faded. Alarmingly, news, policy briefs, and reports tell of the widespread use of all sorts of contaminants, including cluster munitions, in Ukraine, Syria, and Myanmar. The focus of the media, the UN, international organizations, and policy institutions is on the lives lost, the injured, and the handicapped, who face lasting traumas and social exclusion. Likewise, the few studies take a statistical value of life approach, zooming into the lives and injuries saved by clearance.

Our paper is a first step towards a better understanding of the economic impact of landmines. Focusing on Mozambique, the only heavily contaminated country to be declared landmine-free, we uncover significant, albeit modest, local benefits from clearance. However, we establish that clearing roads and railroads from contaminants confers large aggregate economic dividends due to market access forces. We also estimate considerable losses in Mozambique from the fragmented and noncoordinated demining process. Given recent evidence on the significant benefits of transportation infrastructure, this finding may not come as a surprise. Yet, it stands in contrast to the *modus operandi* of demining operators characterized by limited coordination, often prioritizing remote areas.

Clearly, we need more research on the mechanisms (see, e.g., the subsequent studies of Riaño and Valencia Caicedo (2024), on Laos and Prem, Purroy, and Vargas (2025), in Colombia). Using individual-level data, it will be illuminating to examine how landmines and improvised explosive devices shape poverty, land use, agricultural productivity, commerce, and health. Moreover, as landmines entail sizable environmental costs, future work could assess their role in livestock and wildlife conservation. Landmines are one of the many deleterious facets of (civil) warfare, sadly on the rise; not limited to child soldiering, refugee flows, forced labor, extortion, violence against women, and mutilations. Future research should dig deeper into these aspects, understand their heritage, and examine potential (spatial) interdependencies.

REFERENCES

ALDER, SIMON (2017): *Chinese Roads in India: The Effect of Transport Infrastructure on Economic Development,* Work. Pap., Univ. North Carolina, Chapel Hill. [1743]

ALDER, SIMON, KEVIN CROKE, ALICE DUHAUT, ROBERT MARTY, AND ARIANA VAISEY (2022): "The Impact of Ethiopia's Road Investment Program on Economic Development and Land Use," World Bank Policy Research WP 10000. [1743,1755]

ALEMU, ZERIHUN GUDETA, AND HERMAN DANIEL VAN SCHALKWYK (2008): "Market Integration in Mozambican Maize Markets," African Books Collective. [1754]

ARCAND, JEAN-LOUIS, AUDE-SOPHIE RODELLA-BOITREAUD, AND MATTHIAS RIEGER (2014): "The Impact of Land Mines on Child Health: Evidence From Angola," *Economic Development and Cultural Change*, 63 (2), 249–279. [1742]

ASCHERIO, ALBERTO, ROBIN BIELLIK, ANDY EPSTEIN, GAIL SNETRO, STEVE GLOYD, BARBARA AYOTTE, AND PAUL R. EPSTEIN (1995): "Deaths and Injuries Caused by Land Mines in Mozambique," *Lancet*, 346 (8977), 721–724. [1741]

BLATTMAN, CHRISTOPHER, AND EDWARD MIGUEL (2010): "Civil War," *Journal of Economic Literature*, 48 (1), 3–57. [1742]

BORUSYAK, KIRILL, AND PETER HULL (2025): "Non-Random Exposure to Exogenous Shocks: Theory and Applications," *Econometrica* 91 (6), 2155–2185. [1768]

BORUSYAK, KIRILL, XAVIER JARAVEL, AND JANN SPIESS (2024): "Revisiting Event-Study Designs: Robust and Efficient Estimation," *The Review of Economic Studies*, 91 (4). [1741,1759-1761]

BUYS, PIET, UWE DEICHMANN, AND DAVID WHEELER (2010): "Road Network Upgrading and Overland Trade Expansion in Sub-Saharan Africa," *Journal of African Economies*, 19 (3), 399–432. [1766]

CALLAWAY, BRANTLY, AND PEDRO H.C. SANT'ANNA (2021): "Difference-in-Differences With Multiple Time Periods," *Journal of Econometrics*, 225 (2), 200–230. [1759]

CAMERON, MICHAEL, GIBSON, JOHN, HELMERS, KENT, LIM, STEVEN, TRESSLER, JOHN, VADDANAK, KIEV (2010): "The value of statistical life and cost-benefit evaluations of landmine clearance in Cambodia," *Environment and Development Economics* 15 (4), 395–416. [1741]

CHIOVELLI, GIORGIO, STELIOS MICHALOPOULOS, ELIAS PAPAIOANNOU, AND TANNER REGAN (2023a): "Illuminating the Global South," Working paper, LBS. [1741,1752,1772]

CHIOVELLI, GIORGIO, STELIOS MICHALOPOULOS, ELIAS PAPAIOANNOU, AND SANDRA SEQUEIRA (2023b): "Civil War, Forced Displacement, and Human Capital," Working paper, LBS, LSE and Brown. [1749]

CHIOVELLI, GIORGIO, STELIOS MICHALOPOULOS, AND ELIAS PAPAIOANNOU (2025a): "Supplement to 'Landmines and Spatial Development'," *Econometrica Supplemental Material*, 93, https://doi.org/10.3982/ECTA17951. [1747]

——— (2025b): "Additional Appendix to Landmines and Spatial Development," Working paper, LBS. [1743]

DE CHAISEMARTIN, CLÉMENT, AND XAVIER D'HAULTFOEUILLE (2020): "Two-Way Fixed Effects Estimators With Heterogeneous Treatment Effects," *American Economic Review*, 110 (9), 2964–2996. [1759]

DFID (2014): "Mine Action: Evaluation Report," Tech. rep, Department for International Development. [1741]

DONALDSON, DAVE (2015): "The Gains From Market Integration," *Annual Review of Economics*, 7 (1), 619–647. [1743]

——— (2018): "Railroads of the Raj: Estimating the Impact of Transportation Infrastructure," *American Economic Review*, 108 (4–5), 899–934. [1743,1766]

DONALDSON, DAVE, AND RICHARD HORNBECK (2016): "Railroads and American Economic Growth: A "Market Access" Approach," *The Quarterly Journal of Economics*, 131 (2), 799–858. [1743,1753,1766,1769,1772, 1773]

EASTERLY, WILLIAM, AND TOBIAS PFUTZE (2008): "Where Does the Money go? Best and Worst Practices in Foreign Aid," *Journal of Economic Perspectives*, 22 (2), 29–52. [1742]

EATON, JONATHAN, AND SAMUEL KORTUM (2002): "Technology, Geography, and Trade," *Econometrica*, 70 (5), 1741–1779. [1743,1753]

ELLIOT, GARETH, AND GEOFF HARRIS (2001): "A Cost-Benefit Analysis of Landmine Clearance in Mozambique," *Development Southern Africa*, 18 (5), 625–633. [1741]

ELVIDGE, CHRISTOPHER D., KIMBERLY BAUGH, MIKHAIL ZHIZHIN, FENG CHI HSU, AND TILOTTAMA GHOSH (2017): "VIIRS Night-Time Lights," *International journal of Remote Sensing*, 38 (21), 5860–5879. [1752]

FROST, ALEXANDRA, PETER BOYLE, PHILIPPE AUTIER, COLIN KING, WIM ZWIJNENBURG, DAVID HEWITSON, AND RICHARD SULLIVAN (2017): "The Effect of Explosive Remnants of War on Global Public Health: A Systematic Mixed-Studies Review Using Narrative Synthesis," *The Lancet Public Health*, 2 (6). [1741]

GOODMAN-BACON, ANDREW (2021): "Difference-in-Differences With Variation in Treatment Timing," *Journal of Econometrics*, 225 (2), 254–277. [1759,1761]

GOVERNMENT OF MOZAMBIQUE (2008): "Request for an Extension of the Deadline for Completing the Destruction of Anti-Personnel Mines in Mined Areas," Tech. rep. [1745]

HALO TRUST (1994): "The Halo Trust / UNOHAC Mines Survey of Mozambique," Maputo. [1744]

HARRIS, CHAUNCY D. (1954): "The Market as a Factor in the Localization of Industry in the United States," *Annals of the Association of American Geographers*, 44 (4), 315–348. [1743,1753,1766]

HARRIS, GEOFF (2000): "The Economics of Landmine Clearance: Case Study of Cambodia," *Journal of International Development*, 12 (2), 219–225. [1741]

HEAD, KEITH, AND THIERRY MAYER (2014): "Gravity Equations: Workhorse, Toolkit, and Cookbook," in *Handbook of International Economics*, Vol. 4. Elsevier, 131–195. [1766]

HENDERSON, J. VERNON, ADAM STOREYGARD, AND DAVID N. WEIL (2012): "Measuring Economic Growth From Outer Space," *American Economic Review*, 102 (2), 994–1028. [1752]

HUMAN RIGHTS WATCH (1997): "Still Killing. Landmine in Southern Africa," Tech. rep. [1745]

IMF (2014): *Mozambique Rising: Building a New Tomorrow*. International Monetary Fund. [1746,1753]

JAKIELA, PAMELA (2021): "Simple Diagnostics for Two-Way Fixed-Effects," Report, Williams College. [1759]

JEDWAB, REMI, AND ALEXANDER MORADI (2016): "The Permanent Effects of Transportation Revolutions in Poor Countries: Evidence From Africa," *Review of economics and statistics*, 98 (2), 268–284. [1756]

JEDWAB, REMI, AND ADAM STOREYGARD (2022): "The Average and Heterogeneous Effects of Transportation Investments: Evidence From Sub-Saharan Africa 1960–2010," *Journal of the European Economic Association*, 20 (1), 1–38. [1743,1755,1766,1768,1769]

KIM, YOUNG, VASCO MOLINI, AND DANIEL C. MONCHUK (2012): "Estimating Fair Value of Agricultural Land Based on Potential Agricultural Productivity and Market Access in Mozambique," Tech. rep, World Bank. [1754]

LANDMINE MONITOR (2023): "Landmine Monitor 2023," Discussion paper, International Campaign, to Ban Landmines (ICBL) and the Cluster Munition Coalition (CMC). [1742]

LIU, LICHENG, YE WANG, AND YIQING XU (2022): "A Practical Guide to Counterfactual Estimators for Causal Inference With Time-Series Cross-Sectional Data," *American Political Science Review*, 1, 1–17. [1760]

MERROUCHE, OUARDA (2008): "Landmines and Poverty: IV Evidence From Mozambique," *Peace Economics, Peace Science and Public Policy*, 14 (1). [1742]

NATIONAL GEOPHYSICAL DATA CENTER (2010): "Version 4 DMSP-OLS Nighttime Lights Time Series," Tech. rep, National Oceanic and Atmospheric Administration. [1752]

NATIONAL INSTITUTE OF STATISTICS (2019): "Resultados Definitivos, Censo 2017," Presentation. [1766]

PREM, MOUNU, MIGUEL E. PURROY, AND JUAN F. VARGAS (2025): "Landmines: The Local Effects of Demining," *Journal of Public Economics*, 247 105399. [1742,1776]

REDDING, STEPHEN, AND ANTHONY J. VENABLES (2004): "Economic Geography and International Inequality," *Journal of International Economics*, 62 (1), 53–82. [1743,1753]

RIAÑO, JUAN FELIPE, AND FELIPE VALENCIA CAICEDO (2024): "Collateral Damage: The Legacy of the Secret War in Laos," *The Economic Journal*, 134 (661), 2101–2140. [1776]

ROTH, JONATHAN (2022): "Pretest With Caution: Event-Study Estimates After Testing for Parallel Trends," *American Economic Review-Insights*, 4 (3), 305–322. [1760]

SIMONOVSKA, INA, AND MICHAEL E. WAUGH (2014): "Trade Models, Trade Elasticities, and the Gains From Trade," Tech. rep, National Bureau of Economic Research. [1755,1766]

UNITED NATIONS MINE ACTION SERVICE (2024): "UNMAS Annual Report 2023: Mine Action Cannot Wait," United Nations. [1742]

WFP (2016): "A Market Performance Analysis in Mozambique: Rapid Market Assessment in Tete and Gaza Provinces," Tech. rep, World Food Programme. [1753]

WORLD BANK PUBLICATIONS (2008): "Beating the Odds: Sustaining Inclusion in Mozambique's Growing Economy." World Bank Publications. [1753]

Co-editor Dave Donaldson handled this manuscript.

Manuscript received 19 December, 2019; final version accepted 5 May, 2025; available online 13 June, 2025.

The replication package for this paper is available at https://doi.org/10.5281/zenodo.15242012. The Journal checked the data and codes included in the package for their ability to reproduce the results in the paper and approved online appendices.