Economic Studies 202

Adrian Poignant

Gold, Coal and Iron

Essays on Industrialization and Economic Development

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ECONOMICS AT UPPSALA UNIVERSITY

The Department of Economics at Uppsala University has a long history. The first chair in Economics in the Nordic countries was instituted at Uppsala University in 1741.

The main focus of research at the department has varied over the years but has typically been oriented towards policy-relevant applied economics, including both theoretical and empirical studies. The currently most active areas of research can be grouped into six categories:

* Labour economics
* Public economics
* Macroeconomics
* Microeconometrics
* Environmental economics
* Housing and urban economics

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UNIVERSITET

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Abstract

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Essay I: How does electricity provision affect female employment? In theory, electrical household appliances can save labor in domestic production and divert it to the market. However, the empirical evidence has been inconclusive. Many studies from contemporary rural electrification projects face difficulties with bundled infrastructure, and cannot account for variation in the quality of supply. In this paper, I study how Tajik women responded to a five-year-long energy crisis resulting from the breakdown of Tajik-Uzbek electricity trade in late 2009, that reduced winter-time electricity access to a few hours per day. I produce reduced-form evidence that an intensive margin reduction in electricity access leads to lower female employment as women exit the labor force to become homemakers. The effect is specific to women and does not appear to be driven by changes in labor demand, involuntary unemployment, labor migration or fertility. However, the employment effect is accompanied by lower adoption of labor-saving electrical appliances. These results suggest that electricity provision plays an important role in facilitating the release of female labor from unpaid domestic work. Furthermore, the findings emphasize that the quality of electricity supply is critical for unlocking the full benefits of electrification in developing countries.

Essay II: The relationship between rural industries and agriculture during the early stages of economic development is not well understood, despite its potentially central role in economic transformations. I investigate the expansion of small-scale gold mining and processing in north-western Tanzania between 2008 and 2012, and find that small-scale mining causes nearby households to allocate fewer resources to agricultural production and reduce their agricultural output. My findings thus contradict the hypothesis that rural non-farm sector activities generate positive spillover effects for smallholder agriculture in Sub-Saharan Africa by mobilizing agricultural investments. Instead, Tanzanian households appear to substitute away from agricultural activities when outside options improve. The results of this paper confirm that small-scale gold mining increases the consumption levels of nearby households, while having no overall negative effects on school attendance or health outcomes of children. Therefore, while the emergence of small-scale mining does not appear to initiate leaps in agricultural development, it can play an important role in alleviating rural poverty in the short- to medium run.

Essay III (with Niklas Bengtsson and Raoul van Maarseveen): The transition from artisanal to industrial production is an important step in economic development, but the impact on the artisanal workers remains poorly understood. In the latter half of the 19th century, technological advances in Swedish iron production initiated a wave of industrialization that caused artisanal finery forges and blast furnaces to close down as production moved to large-scale ironworks. Using linked census data and a unique dataset covering the universe of iron producers between 1860 and 1890, we investigate the effect of the site closures on worker outcomes. We find that workers displaced by the industrial transformation became 23 percentage points more likely to exit the iron industry, 25 percentage points more likely to migrate to another parish, and experienced a 10 percent decline in earnings relative to other groups of workers. While we find that the transition from artisanal to industrial production had persistent adverse consequences for workers, these effects do not appear to carry over to the next generation. To our knowledge, this paper is the first to quantify the effects of worker displacement during the second industrial revolution.

Keywords: electricity, female employment, labor supply, artisanal mining, agriculture, displacement, industrialization, industrial revolution

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Till Vera

Acknowledgments

A few days ago, still late March, I walked the botanical gardens in Uppsala and saw a two-hundred-year-old tree coming out of its winter dormancy. Watching its heavy branches (one might have thought it was planted by Linné himself), I came to think of my soon-to-be-submitted doctoral dissertation. The association is not as far-fetched as it might seem, since that old tree in the botanical gardens actually shares some resemblance with the text you hold in your hand. Not because it is enclosed in cellulose fibers and can produce a pleasant heat if treated unkindly, but because it's development from seed to adult is the result of the collective care of many gardeners over the years. These are my colleagues and friends, without whose contributions this dissertation might never have materialized.

First, I am deeply indebted to my principal supervisor Niklas Bengtsson for believing in my abilities many years ago and encouraging me to pursue a career in research. Since the first time I peeked my head into his office (and probably soon had it brimming with the philosophies of Karl Popper), he has been an endless source of inspiration, confidence and wisdom. I cannot emphasize enough how much this thesis owes to him.

Next, I would like to extend my sincere gratitude to Mounir Karadja for providing invaluable guidance as my assistant supervisor. He also helped me arrange a research visit to UC Berkeley - a visit that still would not have been possible without the kind invitation of Supreet Kaur and generous financial assistance from the Jan Wallander and Tom Hedelius Foundation - for which I am forever grateful.

Moreover, I would like to express my deepest appreciation to my licentiate and final seminar discussants Annika Lindskog and Anna Tompsett. Their many suggestions, and occasional calls for pruning, have immensely improved almost every aspect of this thesis. So much so, that it can be appreciated from the cover page.

My dissertation has also benefited from the input of many faculty members of the economics department at Uppsala University. I would like to extend special thanks in this regard to Mikael Elinder for offering indispensable advice during my final year. I also thank Oscar Erixon for his contagious enthusiasm and Daniel Spiro for his encouragement throughout. Likewise, I am grateful to Eva Mörk for being a superb department head and assisting me in the job market process, and to Torben Mideksa, Per-Anders Edin, Yoko Okuyama, and all members of the UCFS study group for helping me improve my work.

Furthermore, I wish to recognize the assistance of some outstanding colleagues at other institutions, including the Uppsala Urban Lab and the Department of Economic History. In particular, I am deeply grateful to Matz Dahlberg, Jakob Molinder and Göran Rydén for their feedback and constructive criticism. I also wish to thank all the people, too numerous to mention individually, who have provided generous comments and suggestions at conferences and meetings organized by the Association of Swedish Development Economists, the Urban Economics Association, the American Economic Association, the Economic History Society, and the Nordic Conference of Development Economics.

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I also wish to express my deepest appreciation to my comrades Scott, Martin, Måns, Rebecka, Varen Barbaren och den Vilda Västen. Even if they did not contribute directly to this thesis (although some did in their own ways), spending almost half a decade penning it down would certainly have been miserable if it were not for the unwavering support of my friends outside the university.

However, the greatest source of love and encouragement has been my family. One chapter of this dissertation was born when we visited the Hagelsrum blast furnace, and most of its pages have grown out of the attic of our station house in Rosenfors, a place of many wonderful beginnings. Therefore, I want to end by thanking my brothers Oliver and Villiam, and my parents, Christian and Gunilla. You are my pillars of strength.

Stockholm, 5 April 2022
Adrian Poignant

Contents

Introduction

We live in a world of constant economic change. At least since the industrial revolution and the start of the current "era of modern economic growth" (Kuznets, 1971), the conditions of economic life have been subject to seemingly endless transformations. For example, in 1850 more than 70% of Swedish workers were employed in agriculture and only around 10% of the population lived in cities (Krantz and Schön, 2007). One and a half century later, a brief time in human history, agricultural employment had declined to a negligible 3% through improvements in labor productivity, and the majority of workers had moved to urban manufacturing and services industries. Over the same time period, Swedish real GDP per capita increased by a factor of 25, and the average life expectancy increased by around 40 years.

It is sometimes possible to ascribe such profound economic changes to specific technological breakthroughs. For instance, the expansion of railroad networks in the 19th century is often considered an unequivocal symbol of human achievement that has contributed to economic growth and industrialization around the world (see e.g. Fogel, 1962; Donaldson and Hornbeck, 2016; Berger and Enflo, 2017). In other cases, the diffusion of a new technology can have long-run consequences that are difficult to anticipate. For example, in the first chapter of this dissertation, I use evidence from rare events in contemporary Tajikistan to argue that the provision of household electricity can release women from unpaid domestic work, much in the same way that the mechanization of agriculture released labor from the fields. Therefore, the introduction of electricity may have contributed to the unprecedented rise in female employment that nearly doubled the labor force in countries like Sweden over the last century, and will likely continue to shape the emerging labor markets of countries that are currently building up their infrastructure.

The value of railways and electricity are just some examples of why the history of modern economic growth is generally considered an unambiguous success story. In fact, the average human being on this planet has never been richer, longer-lived, or better educated. But, as we stand on top of years upon years of marginal improvements, it is easy to overlook how the transformations that brought us here might have been perceived by their contemporaries. In fact, it is only in hindsight that the path of economic development appears smooth and always directed toward a better future. Like an observer from afar, we are prone to overlook many obstacles and uncertainties along the way, which could make a would-be traveler question whether they are making any progress at all. For instance, when Dickens described the "monstrous serpents

of smoke trailing themselves over Coketown", he was criticizing the oppressive reality of industrial life as he saw it, where a grand narrative of social progress, measured in figures and averages, disguised the inhumane conditions of factory work. Writing in the midst of intensive railway constructions, a Russian novelist evoked a similar sentiment when he had one of his characters suggest that the railroad was "a poison poured upon the earth to corrupt the springs of life". Such skeptical voices can be heard up to the present day, and their prevalence serve as a reminder that economic development sometimes has a steep price.

In developing countries today, the first stages of industrialization often come at the cost of increased pollution and other types of environmental damage, and workers employed in early industries frequently suffer from hazardous working conditions (Grossman and Krueger, 1995; Dinda, 2004; Blattman and Dercon, 2018). These issues create important challenges for present-day decision makers across the developing world, who do not have the luxury of hindsight when called upon to regulate the new types of industries and activities that emerge on their economic landscape. In the second chapter of this dissertation, I study the local economic impact of one such controversial industry in northwestern Tanzania. The rapid expansion of small-scale gold mining across West, Central, and East Africa has been criticized for posing serious risks to worker health and for its potentially harmful effects on the local environment (quite literally threatening to pour poison upon the earth), while simultaneously promising to raise the living standards of some of the poorest people in the world.

Still, the most ubiquitous costs of economic development are not negative externalities emanating from the of birth of new industries, but the disruptions caused by the death of old ones. The notion that technological innovations carry the seeds of destruction was famously encapsulated in Schumpeter's (1942) concept of "creative destruction". However, the idea itself was exceedingly well-understood centuries earlier, as evidenced by the revolts of disaffected British textile workers who, in the words of Lord Byron, were "sacrificed to improvements in mechanism". The modern-day anxieties about widespread job-loss from artificial intelligence and automation are thus far from historically unprecedented, and instead appear to be an intrinsic characteristic of the ever-changing modern economy. In the final chapter of this dissertation, we study the individual worker consequences of the destruction of hundreds of blast furnaces and forges in 19th century Sweden, which followed from the rapid industrialization of the Swedish iron industry.

In conclusion, this dissertation, which I have named *Gold, Coal and Iron*, consists of three independent essays that are widely separated by time, space and topics, but which all relate to central and reoccurring features of industrialization and economic development. Next, I provide a short summary of each essay in sequence.

The Essays

I.

In the first essay entitled *The Effects of Electricity on Female Employment: Evidence from Tajikistan's Winter Energy Crisis*, I study the labor supply effects of electricity provision using a natural experiment in Tajikistan. The paper investigates the century-old hypothesis that electrification can release female labor from unpaid domestic work by facilitating technological change in home production. I produce reduced-form evidence that the loss of electricity access on the intensive margin leads to lower female employment, as women exit the labor force to become homemakers. Furthermore, I find that the employment effect is accompanied by lower adoption of labor-saving electrical appliances. These results suggest that electricity provision plays an important role in facilitating the release of female labor from unpaid domestic work, and emphasize that the quality of electricity supply is critical for unlocking the full benefits of electrification.

II.

In the second essay entitled *Small-scale Gold Mining and Agricultural Development: evidence from north-western Tanzania*, I study the effects of small-scale gold mining on agriculture in rural Tanzania. In this paper, I investigate the expansion of small-scale gold mining and processing in north-western Tanzania between 2008 and 2012, and find that small-scale mining causes nearby farmers to allocate fewer household resources to agricultural production and reduce their agricultural output. However, the results confirm an earlier finding that small-scale gold mining has positive consumption effects. Therefore, while small-scale mining activities do not appear to contribute to agricultural development, the results of this paper suggest that they can play a short- to medium run role in alleviating rural poverty.

III.

In the third essay entitled *The Social Cost of Industrialization: Evidence from the 19th Century Swedish Iron Industry*, I work together with Niklas Bengtsson and Raoul Van Maarseveen to study how the industrial revolution in Swedish iron production affected the labor market outcomes of artisanal workers. We study the individual worker consequences of the rapid industrialization of the Swedish iron sector in the 19th century, which caused hundreds of artisanal forges and blast furnaces to close down as production moved to large-scale ironworks. We find that workers displaced by the industrial transformation became significantly more likely to migrate to another parish, and experienced a ten percent decline in earnings relative to other groups of workers.

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I. The Effects of Electricity on Female Employment: Evidence from Tajikistan's Winter Energy Crisis

I am indebted to Niklas Bengtsson and Mounir Karadja for their support throughout this project, and to Anna Tompsett for invaluable feedback on earlier drafts of this paper. I would also like to thank Mikael Elinder, Alice Hallman, Annika Lindskog, Raoul van Maarseven, Eva Mörk, Marco Sanfilippo, Daniel Spiro, as well as participants at the 2021 NCDE conference and the 2022 ASSA annual meeting for helpful comments and suggestions.

I.1 Introduction

The era of rapid technological growth that began with the industrial revolution took long to reach the large informal sector of the economy that is concerned with the production of domestic goods and services. Significant technological change in the domestic sector emerged only with the general introduction of household electricity in the 20th century, and came in the embodiment of new types of domestic capital goods and devices. These electrical machines, commonly known as "household appliances" or "consumer durable goods", now permeate the homes of industrialized countries and greatly reduce the labor costs associated with many domestic tasks. Some economists, notably Greenwood et al. (2005), have argued that these technological improvements contributed significantly to the rise in female labor force participation that occurred in the United States and Europe over the last century.[1] Today, whether electricity infrastructure plays a role in the transfer of labor from the home to the market remains a highly relevant question, as more than 700 million people across the developing world still lack electricity connections, and many more suffer from poor supply reliability. In this paper, I shed new light on the relationship between electricity provision and female employment using evidence from a large-scale natural experiment in Tajikistan, and find that intensive margin reductions in electricity access lead to lower female employment.

In late 2009 a diplomatic conflict between Tajikistan and Uzbekistan resulted in the sudden interruption of Tajikistan's external electricity trade, causing winter-time electricity supply to rapidly deteriorate. This event gave rise to a half-decade-long period of electricity scarcity known as "Tajikistan's Winter Energy Crisis", during which most Tajik households were subjected to winter-time electricity rationing, and many received only a few hours of electricity per day. In this paper, I use spatial variation in exposure to electricity restrictions during the winter energy crisis to estimate how the marginal loss of electricity access affected the labor market outcomes of Tajik men and women. I use data from the LSMS and DHS household survey programs to construct a repeated cross-sectional dataset of roughly 31,000 women spanning between 2003 and 2017, as well as a smaller panel dataset of roughly 1,200 men and 1,300 women spanning between 2007 and 2011. Using spatial variation in electricity restriction as identifying variation, I show that a reduction in access to electricity significantly decrease the employment rate of women, but has no effect on the employment rate for men. Using an instrumental variables approach to interpret the reduced form effects, I find that a woman who expe-

[1] Greenwood et al. (2005) introduce a dynamic general equilibrium model inspired by Becker (1965) to decompose the change in female labor force participation. Within the framework of their model, new technologies introduced as a result of electrification can explain more than half of the increase in female labor market participation observed in the United States since 1900. Subsequently, this hypothesis has been supported by empirical studies using long-run data from the United States (Cavalcanti and Tavares, 2008) and other industrialized countries (Coen-Pirani et al., 2010; Heisig, 2011).

rienced the median blackout period of approximately 16 hours per day would have become 12 percentage points less likely to be employed as a result of the electricity restrictions (on a baseline employment rate of 25 percent).

The estimated effect appears to be mainly driven by women exiting the labor force to become homemakers, and is increasing with the number of children. I explore a number of potential mechanisms and find that the results do not appear to be caused by changes in the labor demand of firms, changing job search behavior, changes in male migration patterns, or changes in fertility. The negative employment effect appears in two independent datasets, is visible across several definitions of treatment (including the preferred ex-ante measure of potential exposure and ex-post measures of observed blackouts), and can be discerned across both the extensive and intensive margin of employment. Furthermore, I find household-level evidence that exposure to electricity restrictions decreases the adoption rate of labor-saving electrical appliances. These findings are consistent with the hypothesis that electricity provision promotes female employment by facilitating the adoption of labor-saving electrical appliances that release women from unpaid domestic labor.

Previous papers have studied the effects of electricity provision on labor-supply using evidence from contemporary rural electrification programs. In a seminal paper, Dinkelman (2011) uses land gradient to instrument for electricity grid expansions in rural South Africa, and finds that electrification increased female employment by roughly 9 percentage points, which appears to be driven by an increased uptake of labor-saving household appliances.[2] Similar evidence of positive labor-supply effects specific to women has been found by Grogan and Sadanand (2013) in Nicaragua, Khandker et al. (2014) in India, Dasso and Fernandez (2015) in Peru, and Grogan (2018) in Guatemala (all using instrumental variables approaches). On the other hand, papers by Burlig and Preonas (2021) and Van de Walle et al. (2017) find that electricity grid expansions in rural India had no significant effects on the labor supply of men or women. Similarly, a paper by Salmon and Tanguy (2016) uses an instrumental variables approach in rural Nigeria to find that electrification had very small positive labor supply effects on men, but no effect on women. Finally, a recent randomized experiment by Lee et al. (2020b) in rural Kenya found no economically meaningful effects of electrification on male or female labor supply.

The conflicting evidence produced by the previous literature may be due to contextual differences as well as methodological issues. For instance, Bensch et al. (2020) and Lee et al. (2020a) have recently expressed concerns that the geographic variables used to instrument for infrastructure construction in

[2] An earlier paper by Ilahi and Grimard (2000) makes a similar argument regarding water infrastructure in rural Pakistan. They find that improved public water provision caused women to spend in less time collecting water and more time in income generating activities. In a related paper, using data from Tajikistan, Meurs and Slavchevska (2014) finds that access to central heating is positively correlated with female employment.

the earlier papers of this literature (following Dinkelman, 2011) may violate the exclusion restriction. In particular, different infrastructure projects like electricity and road networks tend to be bundled together, making it difficult to reliably separate the effect of electricity provision from other confounding factors.[3] My paper avoids this issue by using variation in electricity access derived from a negative electricity supply shock, rather than temporal variation in grid expansions. However, the effects of electricity provision on labor supply may also vary by context. For instance, the viability of labor-saving electrical appliances may depend on income levels, access to credit, interactions between electricity and other types of infrastructure, and the quality of electricity supply, which could explain null effects in some settings. During the aforementioned 14-month experiment conducted by Lee et al. (2020b) in Kenya, about 19% of the transformers in the study area suffered long-term blackouts, with the average of these blackouts lasting 4 months. In the Nigerian context studied by Salmon and Tanguy (2016), most urban households experience daily blackouts, and rural households generally have access to less than four hours of electricity per day.[4] In this paper, I argue that such intensive margin variation in electricity access plays an important intermediary role in unlocking the benefits of electrification.

The remainder of the paper continues as follows. Section I.2 provides an overview of the historical background and institutional setting, section I.3 describes the data. Section I.4 discusses the empirical approach, section I.5 presents the main results, section I.6 discusses mechanisms, and section I.7 concludes.

I.2 Historical Background and Institutional Setting

I.2.1 The Disintegration of the Central Asian Power System

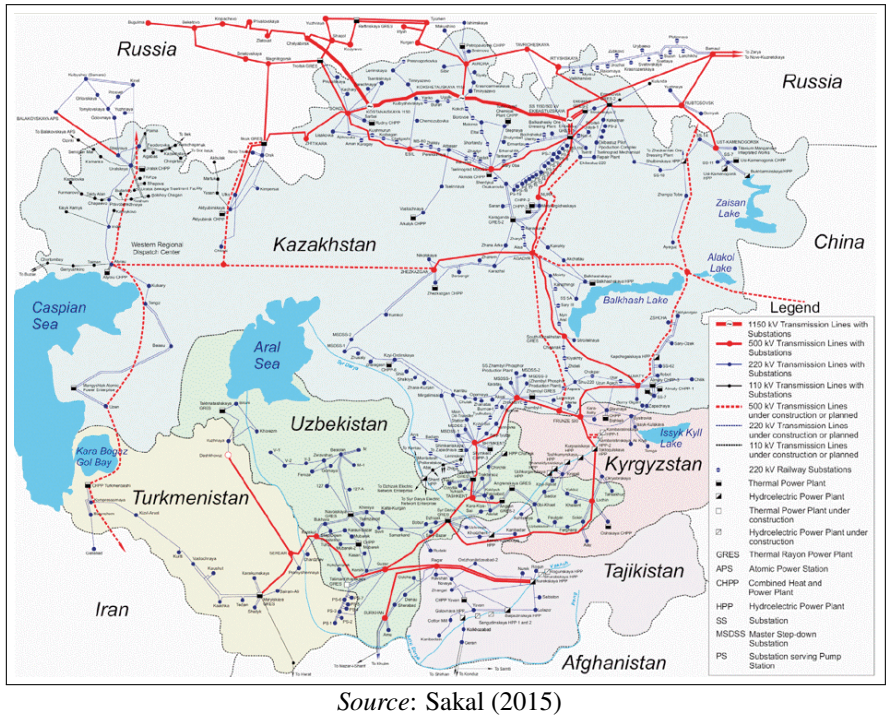
The prolonged energy crisis that affected Tajikistan in the early 2010s can appear puzzling at first glance. Tajikistan is richly endowed with energy resources and possesses a relatively well-developed power system due to massive infrastructure investments undertaken by the Soviet Union. As a consequence, the population of Tajikistan enjoys almost universal access to electricity according to standard definitions, with an electrification rate of 99.5% in 2010 (IEA and World Bank, 2021). This sets Tajikistan apart from most countries with similar levels of per capita income, such as Bangladesh with an electrification rate of 55.3%, Kenya with 19.2% and Tanzania with 14.8%.

[3] The tendency for infrastructure to be bundled also raises important questions regarding the existence of complementarities. For instance, Vanden Eynde and Wren-Lewis (2021) find that electrification significantly increased dry-season agricultural output of Indian villages when combined with improved road infrastructure, but not when provided in isolation.

[4] See Barros et al. (2014) and Olatomiwa et al. (2015)

Tajikistan's vulnerabilities in the energy sphere instead follow from its inherited position within a large regional infrastructure network known as the Central Asian Power System (CAPS), which was constructed by the Soviet Union in the 1970s when Tajikistan, along with Kyrgyzstan, Turkmenistan, Uzbekistan and Kazakhstan were constituent Soviet Socialist Republics (SSRs). The CAPS united most of Soviet Central Asia into a single electricity production and transmission network that connected producers and consumers across the region. Similarly to most Soviet-era infrastructure projects, the CAPS was not designed to accommodate the national borders that would later emerge. This meant that after the dissolution of the Soviet Union, large sections of the population in the newly independent successor states came to depend on electricity produced abroad and transported on transmission lines intersecting several national jurisdictions. Figure I.1 depicts the Central Asian Power System around the year 1990, with Tajikistan located in the Southeastern corner of the map.

Figure I.1: *CAPS circa 1990*



Source: Sakal (2015)

While former Soviet Central Asia is richly endowed with a diverse range of energy resources, the different types of resources are not evenly distributed across the region. In particular, large deposits of oil and natural gas are located in the western plains belonging to Turkmenistan, Uzbekistan and Kazakhstan, while there is significant hydropower potential concentrated in the mountainous southeast belonging to Tajikistan and Kyrgyzstan. Within the scope of the

unified power system, this variation in energy sources gave rise to a relatively diversified and reliable energy supply environment that took advantage of the comparative advantages of different parts of the network. In practice, this meant that areas with abundant hydropower resources (such as the Tajik SSR) would supply the CAPS with excess electricity at low cost during seasons of high water flow, and import fossil-fuel based power from other regions when the river flow rates subside.

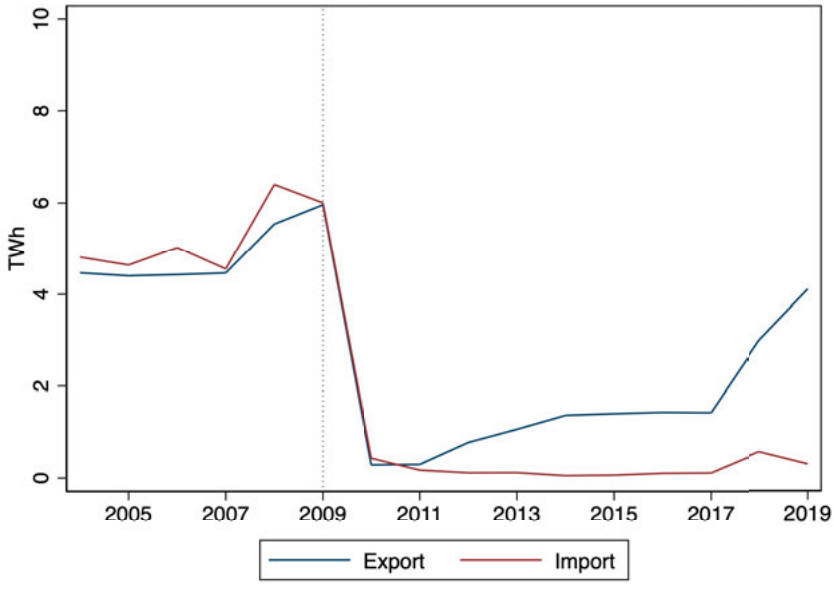
After the dissolution of the Soviet Union, the Central Asian successor states inherited the CAPS and continued to operate it jointly for several years. However, the regional energy cooperation eventually began to deteriorate as a series of diplomatic conflicts arose over shared resources. One of these disputes arose between Tajikistan and Uzbekistan over dam constructions that threatened to divert water from Uzbekistan's state-owned cotton industry. Simultaneously, Tajikistan accused Uzbekistan of abusing its monopoly over fossil-fuel deliveries by charging exorbitant prices. The diplomatic conflict intensified in 2007 and 2008 when a sequence of particularly harsh winters strained the power systems across the region, and in November 2009 Uzbekistan decided to cut all transmission lines connecting Tajikistan to the rest of the CAPS. This put an immediate stop to Tajikistan's electricity exchange with Uzbekistan, but also meant that Tajikistan could no longer trade electricity with Turkmenistan, Kyrgyzstan and Kazakhstan. As a consequence, Tajikistan became effectively isolated from the unified Central Asian electricity grid and entered a period of virtual energy autarky.

The immediate effect of the disintegration of the CAPS is visible in figure I.2, which plots Tajikistan's yearly electricity imports and exports as reported by the Statistical Agency of Tajikistan (TAJSTAT). While the aggregate output of electricity remained unchanged, the cessation of the seasonal electricity trade created a temporal mismatch between supply and demand. In particular, the Tajik power system began to suffer from excess demand in the winter, as the energy that could be stored in existing dams was not sufficient to satisfy demand until the resumption of river flows in the spring. Simultaneously, the power system produced an excess supply of electricity in the summer when the river flow rates are high, as smaller dams and run-of-river plants would fill up quickly and need to be discharged. This seasonal imbalance had severe effects on the wintertime electricity access for many Tajik households.

I.2.2 Tajikistan's Winter Energy Crisis

The disruption of the electricity trade plunged Tajikistan into a "winter energy crisis" that lasted for roughly five years. This period featured significant and reoccurring electricity shortages that left large parts of Tajikistan's population without electricity for extended periods in the winter. The national power company Barqi Tojik managed for the most part to guarantee sufficient sup-

Figure I.2: *Tajikistan's electricity trade*



Source: TAJSTAT (2021)

ply of electricity to important institutions like hospitals, schools, government buildings, and some nationally important industries. However, to conserve electricity, strict restrictions were imposed on household consumers. A system of rationing was introduced based on a three-step procedure. First, the central government in Dushanbe issued monthly decrees determining the distribution of disposable energy (in kilowatt-hours) between Tajikistan's regions (oblast), major cities, and larger industrial entities. In the second step, regional administrations divided their power budgets between districts (rayon) based on populations size, the locations of important facilities, and other local considerations. Finally, each district was responsible for maintaining its monthly energy budget by adjusting the amount of electricity distributed to consumers on a daily basis, which was generally done through scheduled blackouts. The timing and duration of district-wide blackouts could thus differ from day to day depending on variable supply and demand factors, but in general they were planned and announced in advance.

Throughout the crisis, the Tajik government never abandoned its policy of "socially oriented tariffs", which meant that it was not possible to use price

instruments to regulate demand.[5] Instead, according to official statements, the three-step rationing system was used to ensure approximately equal access to electricity across different parts of the country. In practice, however, the electricity restrictions differed significantly between districts. The capital city of Dushanbe was largely spared from blackouts, and it appears that geographical factors such as proximity to major Uzbek or Tajik power stations become important determinants of electricity access. For example, in the month of December 2014 the longest average blackout period (18 hours and 24 minutes per day amounting to around 24 days of continuous blackout) was observed in the district of Zafarobod, which is located next to Uzbekistan's largest power station (the Syrdarya Power Plant). In the same month, the district containing Tajikistan's largest hydropower station (the Nurek Power Plant), did not experience a single minute of blackout (see figure I.3 for a map). The region of Gorno-Badakhshan Autonomous Oblast (GBAO) operates a separate power system, and, since it was never part of the CAPS, it was not directly affected by the winter energy crisis. The GBAO thus falls outside the scope of the natural experiment studied in this paper and is consequently excluded from the analysis.[6]

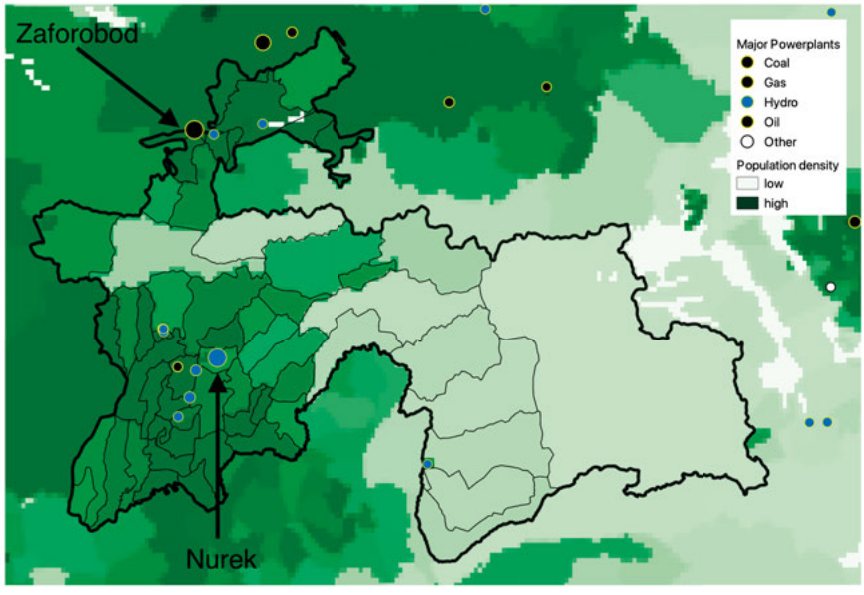
The social impact of the winter energy crisis has been extensively covered by Tajik and foreign media and is documented in several government fact-finding missions and NGO reports. Concerns about the humanitarian consequences of the crisis prompted both the UNDP (2011) and the World Bank (2014) to issue in-depth investigations of the costs of energy poverty in Tajikistan. A study by Fields et al. (2013) estimated the annual economic losses to over US$200 million, which would correspond to about 3% of GDP. However, the true economic and social costs of the crisis are elusive. On the household side, the best data describing the extent of the electricity restrictions comes from the Consumer's Union of Tajikistan (CU), which began to record the daily electricity availability in Tajik districts in 2012. This data collection effort revealed that, contrary to the official government position at the time, there were large differences in electricity access between districts.[7] The CU data is described in more detail in section I.3. Figure I.4 plots daily electricity availability at the district level for Tajik districts (excluding GBAO) in the winter of 2012/2013, with a red line representing the average across districts.

[5]The government of Tajikistan continued to set household electricity prices below the cost of production as an implicit government subsidy. A similar subsidy applied to the state-owned Tajik Aluminum Company (TALCO), the department of agriculture, and to government institutions.

[6]In appendix I.A I show that this restriction has no material bearing on the results, which are robust to the inclusion of GBAO. However, while the GBAO suffered severe electricity supply issues both before and during the study period, the physical separation of the two grids means that the methodology of this paper does not apply there. The autonomous region represents roughly half of Tajikistan by area, but contains less than 3% of the population.

[7]The data collection itself began as a response to perceived discrepancies between official statements and the experiences of household consumers regarding the distribution of electricity.

Figure I.3: *Map of Tajikistan, including major power plants*



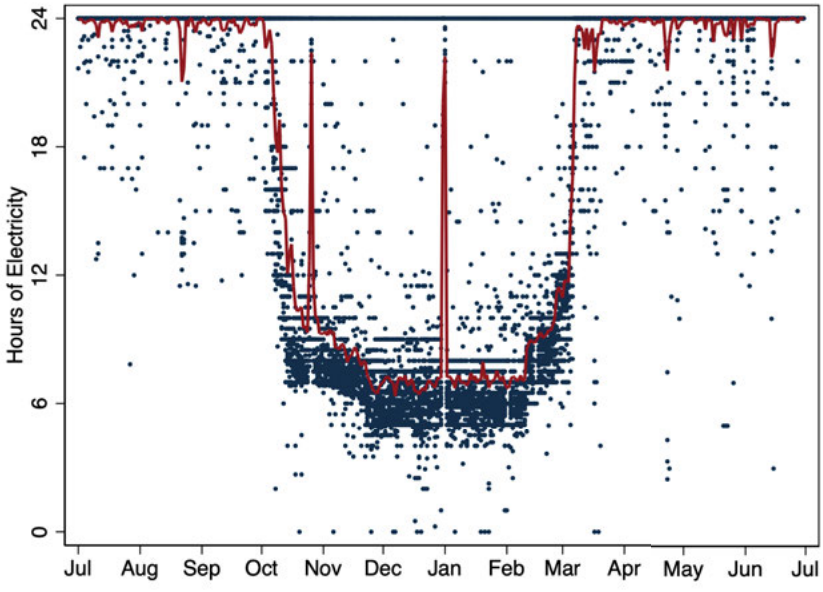
Sources: Byers et al. (2018) and CIESIN (2016)

The figure illustrates the strong seasonal variability in electricity access that characterized the winter energy crisis. Most districts provide 24 hours of electricity in the summer months, while access in winter-months becomes limited to about 6 hours of electricity per day. In table I.17 in appendix I.B I present corresponding figures for each year between 2012 and 2018.

Since the electricity restrictions were confined to the winter-months, they also coincided with peak energy demand for heating. The local climate in Tajikistan varies greatly due to differences in elevation and other factors, but most of Tajikistan's population are exposed to cold winters with temperatures below zero for more than three months in an average year. The winter energy crisis forced many households to replace grid electricity with alternatives energy sources for heating and cooking. The main alternatives include coal, firewood, agricultural byproducts (such as cotton stalks) and dried fuel bricks made from animal manure. Households generally absorbed these costs though increased monetary expenses or increased time devoted to activities such as the collection of firewood or the production of fuel bricks.[8] A report by the

[8]The responsibility to provide fuel sometimes extended beyond the household. Tajik media reported that in some rural schools, students were required to bring fuel bricks at the start of the day to heat the classrooms. Part of the costs may also have taken the form of negative externalities. The increased extraction of firewood in Tajikistan may also have contributed to ecological damage through deforestation (see e.g. Robic et al., 2010; S. Alam, 2019).

Figure I.4: *Daily winter time electricity availability (July 2012 to July 2013)*



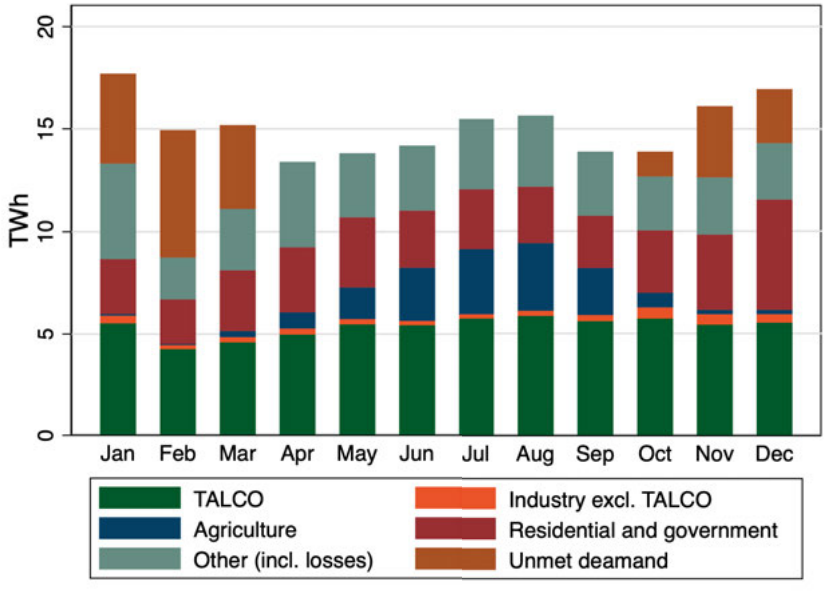
Source: daily district-level data collected by the Consumers Union of Tajikistan

Asian Development Bank (2016) found that Tajik women often contributed considerably to the household budget through the collection and processing of fuel. Time spent securing energy resources add to the shadow costs of energy that are born by households and are difficult to quantify. A survey conducted by the World Bank (2014) suggest that high winter energy costs in this period tended disproportionately to affect lower income households that lack the necessary liquidity or credit to purchase fuel stocks in advance, and were thus forced to pay the higher winter-time prices. Poor households may also lack the means to undertake initially costly investments, for example in improved insulation, that can increase energy efficiency. The same survey finds that in a sample of rural respondents, households spent around 1800 Somoni (roughly US$ 380) on coal per year, corresponding to approximately 10% of the average household income. However, as noted by Robic et al. (2010), energy poor households in rural areas of Tajikistan tend to rely on the fuels that they can collect and produce themselves, which means that the true energy costs may be higher.

In contrast with the vivid qualitative descriptions that exist regarding household consequences of the winter energy crisis, detailed descriptions of the consequences for businesses and other consumers are more elusive. In general, it is likely that the winter energy would affect smaller firms in particular, as these tend to rely on the residential electricity grid and often cannot make

efficient use of self-generation (see e.g. Alby et al., 2012). During the winter energy crisis, Tajik authorities gave explicit priority to some large industrial firms that were considered particularly important to the national economy. The most salient example is the state-owned Tajik Aluminum Company (TALCO) in Tursunzoda, which accounts for roughly 30-40 % of Tajikistan's total electricity demand (the residential and government sectors by comparison together account for roughly 20 % of total demand). Other firms were able to avoid the electricity restrictions by relying on their own generator capacity, or due to favorable seasonal patterns in electricity use. The agricultural sector, which is Tajikistan's second-largest consumer of electricity overall, was almost completely unaffected by the winter shortages. The extensive irrigation system powered by electrical pumps only operates from spring to early fall, which means that agricultural demand for electricity was confined to the months of surplus. Figure I.5 shows the monthly composition of electricity demand in 2009 according to Fields et al. (2013), and illustrates the seasonality of demand for electricity in agriculture. The data used to produce this graph coincides with the regional electricity shortages that began in the winter of 2008 and eventually led to the disruption of the Tajik-Uzbek electricity in November 2009, which marks the beginning of the winter energy crisis.

Figure I.5: *Monthly electricity demand by sector in 2009*



Note: The graph is reproduced using data from Fields et al. (2013).

The Business Environment and Enterprise Performance Surveys (BEEPS) conducted by the European Bank of Reconstruction and Development (EBRD)

provide some evidence of firm responses to the winter energy crisis.[9] Table I.1 reports the mean number of monthly power outages, and the rate of generator ownership for manufacturing firms in each of the five survey rounds between 2002 and 2019. The frequency of power outages start to increase in 2008, which marks the onset of the regional electricity shortages that eventually led to the disconnection of Tajikistan from the CAPS in November 2009, and reach a peak in 2013, at the height of Tajikistan's winter energy crisis. By 2019, the frequency of power outages had declined to below the level in 2002 and 2005. Generator ownership increases between 2008 and 2013, and then appears to persist at a high level after the return of regular electricity supply. This pattern is consistent with earlier findings on firm-level responses to unreliable electricity environments that suggest firms make investments in self-generation capacity that can be difficult to reverse (see Reinikka and Svensson, 2002; M. M. Alam, 2014; Allcott et al., 2016).

Table I.1: *Firm outcomes*

Survey year	2002	2005	2008	2013	2019
Monthly power outages					
Mean	2.73	2.74	4.37	6.52	1.59
SD	4.10	3.90	11.15	10.45	6.57
Observations	176	200	345	336	329
Has generator					
Mean			0.13	0.23	0.22
SD			0.34	0.42	0.41
Observations	0	0	115	122	159

Note: the firm-level data is from the Business Environment and Enterprise Performance Surveys conducted by the European Bank of Reconstruction and Development.

I.2.3 Recovery from the Crisis

The winter energy crisis lasted roughly five years before it was eventually mitigated by improvements in electricity supply. The government of Tajikistan responded to the crisis by massive investments in infrastructure construction and rehabilitation. A report issued by Tajikistan's Ministry of Economic Development and Trade (MEDT) notes that in 2012 the Government of Tajikistan directed roughly 15% of the total national budget toward electricity infrastructure (Fakirov, 2012). The results of these efforts include the commissioning of the Sangtuda 2 Hydroelectric Power Plant in 2011 and the Dushanbinskaya 2 natural gas powered Thermal Power Plant in 2014, which represent

[9] In this reoccurring survey, a small sample of businesses is asked to describe various aspects of their operations and the business environment. Some firms appear in several surveys, but the sample is replenished in each iteration, creating an unbalanced panel.

a combined capacity of over 600 MW. In addition, Tajikistan commissioned 11 smaller hydroelectric plants between 2010 and 2013, and expanded and upgraded transmission networks.[10] Tajikistan also officially resumed the construction of the massive Rogun dam in 2016 which, when completed, is expected to have a capacity of 3.6 TW. The disruption of the electricity trade in 2009 also led the Tajik government to seek deeper cooperation with other neighbors, mainly Afghanistan and Kyrgyzstan, and to expand the capacity of the transmission infrastructure leading into these countries. While the expansion of trade with other countries did little to alleviate Tajikistan's winter electricity shortages, it allowed Tajikistan to resume exporting some of its summer surplus (the gradual increase in exports is visible in figure I.2).

Over time, the deficits were gradually alleviated, until universal and regular winter supply was fully restored in 2017. Therefore, when Tajikistan and Uzbekistan in 2018 reached an agreement to resume the electricity trade, the Tajikistan's winter crisis was effectively already over. Tajikistan's recovery from the winter energy crisis can be seen in the table I.2, which presents the average daily hours of household electricity access between November and February by season. The data used to construct this table was collected by Tajikistan's Consumers Union beginning in 2012, and thus cannot capture the initial stages of the winter energy crisis. However, it shows a noticeable improvement in winter-time electricity access after 2015 that eventually led to the restoration of full year-round access to electricity in all parts of Tajikistan.

Table I.2: *Daily Hours of winter-time electricity (average for November-February)*

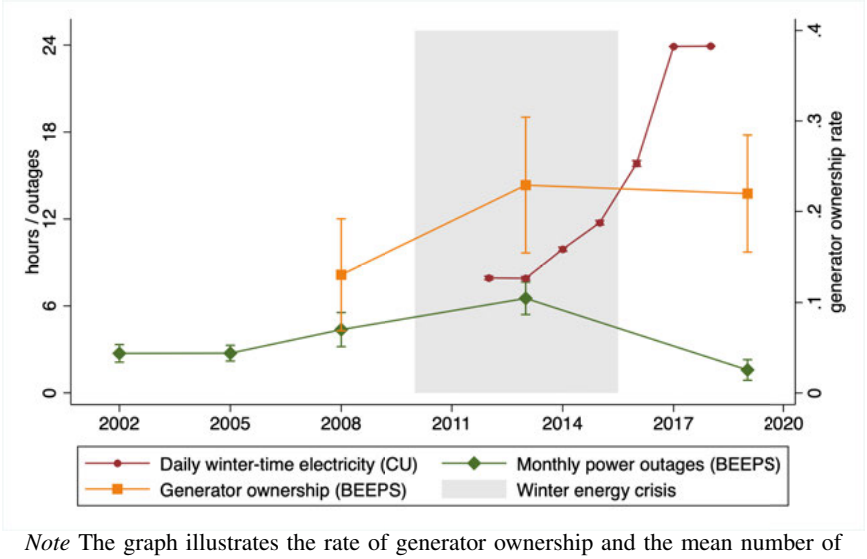
Winter	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19
Mean	7.93	7.91	9.92	11.75	15.84	23.9	23.93
Median	6.5	6.33	8	9.13	17	24	24
SD	4.36	4.82	5.72	6.05	7.92	0.86	1.15

Note: the summary statistics presented in this table are based on daily district level electricity availability data collected by the Consumers' Union of Tajikistan (CU) starting in February 2012. It presents daily averages based on observations from the months of November, December, January and February in each corresponding season.

Figure I.6 illustrates the means presented in tables I.1 and I.2 in a single graph. It shows the rate of generator ownership and mean number of monthly power outages reported by Tajik firms in the BEEPS surveys, as well as the mean daily winter-time electricity availability of households reported in the CU data.

[10]This information was obtained from the website of Barqi Tojik (the national power company of Tajikistan) accessed in 8 April 2021: `http://www.barqitojik.tj/about/dependents/generation/`

Figure I.6: *Generator ownership, power outages and hours of household electricity*



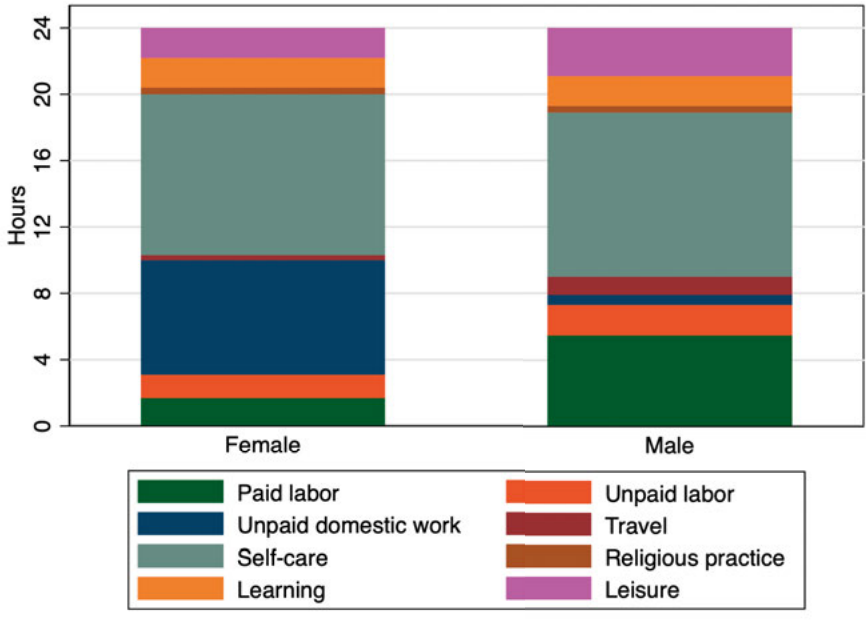
Note The graph illustrates the rate of generator ownership and the mean number of monthly power outages reported by Tajik firms in the BEEPS data, as well as households' mean daily winter-time electricity availability as indicated by district-level electricity supply data from Tajikistan's Consumers Union.

I.2.4 Female Employment in Tajikistan

In order to understand how the electricity restrictions might have affected female employment in Tajikistan, it is useful to also discuss some characteristics of the Tajik labor market (see e.g. Asian Development Bank, 2016; Asian Development Bank, 2020). The Tajik labor market reflects traditional gender roles that Tajikistan shares with many other predominantly agrarian economies, but is also shaped by the institutional legacy of the Soviet Union and the turbulent period of economic transition and civil conflict that followed independence. Under the Soviet system, women were formally guaranteed the right to employment and equal pay for equal work, and female employment was supported through publicly provided health-care and child services (Falkingham, 2000). The quality of these services have declined since independence, but the legacy of formal institutional support for female employment can still be discerned in cross-country comparisons, and Tajik women make up between 35 and 40% of the total labor force (see appendix I.B.1). Female workers are mainly concentrated in agriculture, social services, health care and education, and tend to be under-represented in professional and technical occupations. Furthermore, women tend to occupy lower positions in employment hierarchies, and are more likely to engage in informal and part-time work. However, the largest difference between male and female employment patterns relates to labor migration. Since the conclusion of the Tajik civil

war in 1997, large numbers of male workers have sought seasonal employment abroad (predominantly in Russia). A World Bank report by Strokova and Ajwad (2017) notes that in 2015 about one million Tajik workers, including about one third of men aged 20–39, worked abroad at some point during the year. Tajik migrant workers are almost exclusively male and typically married. Between 2006 and 2019 remittances from migrant workers represented about one third of Tajikistan's GDP according to World Bank (2021b), which makes Tajikistan one of the most remittance-dependent countries in the world. The high male migration rate has shifted the labor force composition of some sectors. For example, the agricultural sector has become increasingly populated by women, to the extent that in 2015 Mukhamedova and Wegerich (2018) notes that around three out of four agricultural workers were female. The Asian Development Bank (2016) reports that the average monthly wage rate of women is about 60% of the male rate. While this wage gap can be partly accounted for by other observable characteristics, the persistence of large unexplained differences suggests the existence of gender-based wage discrimination in the Tajik labor market (see World Bank, 2013; Asian Development Bank, 2016).

Figure I.7: *Time-use of Tajik women and men (on weekdays)*



Source: Asian Development Bank (2020)

Another important difference between men and women relates to informal work. The general division of responsibilities within Tajik households tasks

women with most of the domestic unpaid labor, whereas men carry the main responsibility for income generation. This is a feature that Tajikistan shares with many countries across the world. Figure I.7 shows the results of a recent time-use survey conducted by the Asian Development Bank (2020).[11] On average, Tajik women spend about 1 hour and 40 minutes per day performing paid labor, compared to about 5 hours and 30 minutes for men. However, Tajik women spend about 7 hours per day on average in unpaid care and domestic work, compared to 40 minutes for Tajik men. According to the time-use survey, the domestic work performed by women is mainly divided between cooking (2 hours and 15 minutes per day), caring for children (2 hours and 12 minutes per day), cleaning (1 hour and 12 minutes per day), and washing clothes (1 hour per day). The large amount of time spent in domestic work means that Tajik households devote considerable resources to the production of domestic goods and services, which may imply a significant opportunity cost in terms of time diverted from market employment. However, time spent in domestic activities can also directly substitute for market goods. As noted by the Asian Development Bank (2016), Tajik women often contribute considerably to the household budget through the collection of firewood and the production of fuel bricks from animal manure that are used in heating and cooking. While fuel collection may be a particularly important category of unpaid housework in Tajikistan due to its climate, it is a significant time-use category for rural households in many developing countries.

I.3 Data

I.3.1 Labor Market and Household-Level Outcomes

The empirical analysis of this paper uses data on individual and household level outcomes, including current employment status, from a number of household surveys conducted between 2003 and 2017. In particular, this data comprises two surveys conducted within the World Bank's Living Standards Measurement Study program (LSMS 2003 & 2007), two surveys conducted within the USAID's Demographic and Health Surveys program (DHS 2012 & 2017), and one survey conducted by the Regensburg Institute for East- and Southeast European Studies (THPS 2011). Each of the surveys, except for the THPS 2011 which forms a panel with the LSMS 2007, rely on independent stratified random sampling procedures and are representative on the national and regional (oblast) level. The household surveys are combined into two distinct datasets which span the study period, and make it possible to observe the evolution of key outcome variables over time.

[11] It should be noted that the time-use survey performed by Asian Development Bank, 2020 uses a small sample of 72 households randomly selected from the Khatlon region. While this appears to be the best evidence on time use in Tajikistan that is available to this date, it may thus not be representative for the country at large.

First, four cross-sectional surveys (LSMS 2003, LSMS 2007, DHS 2012 and DHS 2017) are combined into a repeated cross-sectional dataset of working-age women spanning the period 2003 to 2017. This dataset comprises 30 931 women distributed across 18 115 households. I restrict the sample to women aged 15-49 to match the age composition of the DHS 2012 and DHS 2017 samples, thus ensuring that the demographic characteristics of each constituent cross-section are consistent over time.[12] The timing of these surveys makes it possible to compare the labor market outcomes of Tajik women observed before, during and after Tajikistan's winter energy crisis. Table I.3 describes the data in more detail, and table I.21 in appendix I.C provides additional descriptive statistics for relevant variables.

Second, two surveys (LSMS 2007 and THPS 2011) are combined into a two-period panel dataset spanning the period 2007 and 2011. In addition to the LSMS 2007 and THPS 2011 there exists an intermediary survey (LSMS 2009), which could be used to bridge the panel dataset into a three-period panel with observations from 2007, 2009 and 2011. However, since data-collection for the intermediate survey took place mainly in November 2009 it is unclear to which extent these observations may be affected by the winter energy crisis. The Uzbek decision to disconnect from the Tajik grid was officially announced on November 24, 2009, but Tajikistan's national power company Barqi Tojik reported already on November 11 that it had begun operating independently of the CAPS (relying solely on domestically produced electricity), and was already rationing electricity in certain districts (RFE/RL, 2009). These ambiguities make it difficult to clearly define the treatment status of observations from the LSMS 2009. Furthermore, in light of intense media coverage of the Tajik-Uzbek dispute at the time, it is possible that respondent interviewed earlier in November 2009 might have anticipated developments in the Tajik-Uzbek dispute, and thus internalized some exposure to the treatment. Therefore, to avoid this ambiguity, it is preferable to exclude the LSMS 2009 and instead rely on the two-period panel of individuals observed in 2007 (before the crisis) and 2011 (during the crisis). To make the panel data more comparable to the repeated cross-sectional data, the panel-data sample is also restricted to individuals aged 15 to 49 when first observed in the LSMS 2007. The resulting dataset consists of 1295 women and 1232 men distributed across 1194 households. Table I.3 describes the survey data in more detail.

The panel dataset contains fewer observations but complements the repeated cross-sectional data in several ways. First, the panel structure adds the ability to follow the same respondents over time and control for unobserved heterogeneity at the individual or household level. This offers an advantage over repeated-cross sections if regional migration or differential demographic trends causes compositional changes in the underlying population that cannot

[12] I also exclude observations belonging to the GBAO region. The motivation for this exclusion, and its influence on the results, is discussed I.A.

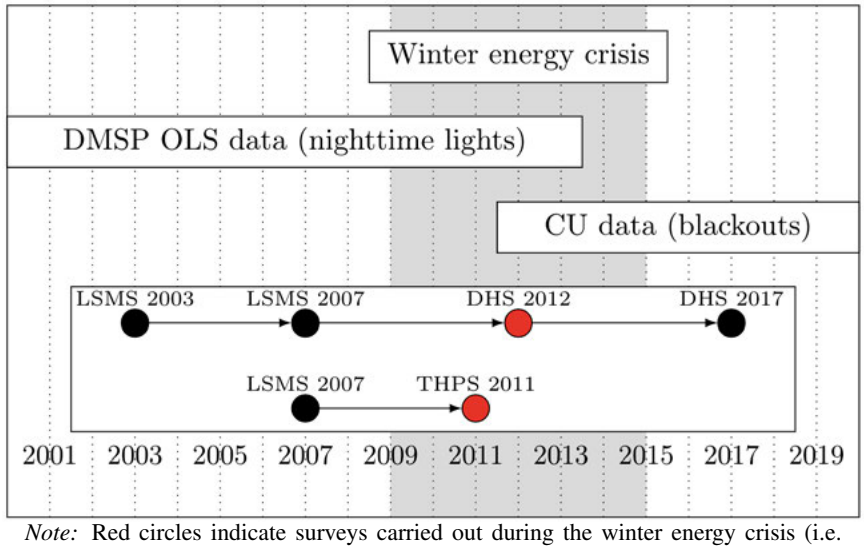
be accounted for by district or municipality-level fixed effects. On the other hand, the results of a panel-data analysis can be influenced by endogenous spatial sorting that affects the probability of being identified in subsequent surveys. However, the attrition rate of the 2011 THPS survey was very low, with approximately 97% of the target sample of original households being successfully located (Danzer et al., 2013). Second, the panel dataset makes it possible to expand the analysis to also include male respondents. This is not possible with the repeated cross-sectional data, since the two DHS surveys conducted in Tajikistan only targeted women. Third, the panel dataset makes it possible to study some outcomes that are not consistently observed in the LSMS and DHS questionnaires, but which were present in both the 2007 LSMS and the 2011 THPS. Finally, the panel data offers a valuable opportunity to cross-validate results using two independent datasets for outcomes that are observable in both datasets. Figure I.8 provides an overview of the data sources and the timing of the data collection.

Table I.3: *Household survey data*

Survey name:	LSMS03	LSMS07	THPS11	DHS12	DHS17	Total
Timing	Before		During		After	
Original datasets:						
households	4 160	4 633	1 503	5 726	6 812	21 342
individuals	26 141	28 957	9 608	9 656	10 718	75 472
women	13 087	14 831	5 018	9 656	10 718	53 310
men	13 054	14 126	4 590	0	0	31 770
Repeated cross-section dataset:						
households	3 294	3903		4 834	6 084	18 115
individuals	5 709	7 341		8 172	9 709	30 931
women	5 709	7 341		8 172	9 709	30 931
men	0	0		0	0	0
Panel dataset:						
households		1 194	1 194			2 388
individuals		2 527	2 527			5 054
women		1 295	1 295			2 590
men		1 232	1 232			2 464

The household surveys used in this paper all collect information about the respondent's current employment status. However, since the exact wording used in the questionnaires differ slightly between surveys, there is some variation in the definition of employment over time. Table I.4 presents the questions used in each survey to ascertain the respondent's current employment status.

Figure I.8: *Overview of data sources and their relative timing*



Note: Red circles indicate surveys carried out during the winter energy crisis (i.e. within the treatment window). Black circles indicate surveys carried out before or after the winter energy crisis (i.e. outside the treatment window).

The respondent is considered to be employed (currently working) if he or she provides an affirmative answer to any of the questions listed under the corresponding survey. One notable difference is that the LSMS definition refers to work performed in the last 14 days, whereas the DHS definition refers to work performed in the last 7 days. However, these minor differences are not likely to materially affect the results. It is also possible to avoid this discrepancy entirely by instead studying employment over the last 12 months, for which there exist consistent survey questions across all surveys. As shown in appendix I.D.5, the 12-month measure produces nearly identical results to the 7-14 day measure used in the main specifications. This likely follows from the fact that more than 90 percent of Tajik women who worked at any point in the last year also worked in the last 7 or 14 days. Therefore, the 7-14 day measure is preferred, as it corresponds better with standard definitions of employment.

I.3.2 Data on Electricity Access and Exposure to Blackouts

To identify spatial and temporal differences in the supply of household electricity across districts of Tajikistan, two sources of data are used. First, I use electricity availability data from Tajikistan's Consumers' Union (CU). This data has been collected by the CU since 2012, and contains daily observations on household electricity access at the district level. The data covers most of Tajikistan's 58 districts, and is continually updated by a network of volunteers organized by the Consumers' Union. The data collection was performed

Table I.4: *Survey questions on employment*

Definition:	LSMS definition	DHS definition
Surveys:	LSMS 2003, LSMS 2007, THPS 2011	DHS 2012, DHS 2017
Q1	During the past 14 days, have you worked for someone who is not a member of your household, for example, a public or private enterprise or company, an NGO or any other individual?	Aside from your own housework, have you done any work in the last seven days?
Q2	During the past 14 days, have you worked on a farm owned or rented by you or a member of your household, whether in cultivating crops or in other farm maintenance tasks, or have you cared for livestock belonging to you or a member of your household?	As you know, some women take up jobs for which they are paid in cash or kind. Others sell things, have a small business or work on the family farm or in the family business. In the last seven days, have you done any of these things or any other work?
Q3	During the past 14 days, have you worked on your own account or in a business enterprise belonging to you or someone in your household, for example, as a trader, shop-keeper, barber, dressmaker, carpenter, taxi driver, car wash, etc.?	

The definition of employment status differs slightly depending on the wording used by the LSMS and DHS. An affirmative answer to any of the questions listed under each definition classifies the respondent as "currently working", while negative answers to all questions classifies the respondent as "not currently working".

though an online application developed by the CU, where members of a monitoring network would report the daily duration of electricity access (measured in hours and minutes) provided to households in their respective districts. The resulting database contains daily district-level data on electricity availability from 2012 and onward. This data makes is possible to calculate the average blackout period in different districts, which reveals the extent to which different parts of Tajikistan suffered from electricity supply restrictions during the winter energy crisis and provides a direct measure of differences in exposure across districts.

However, I also measure blackout exposure using remotely sensed nighttime lights data. For this purpose, I use satellite imagery from the US Defense Meteorological Satellite Program's Operational Linescan System (DMSP-OLS V.4). The nighttime light data was collected by the US Air Force Weather Agency and is provided by the National Oceanic and Atmospheric Administration (NOAA). The data consists of yearly composite images compiled from cloud-free observations collected by DMSP-OLS sensors over multiple individual orbits. The images have been processed by the NOAA Geophysical Data Center to remove background noise and ephemeral lights. The final dataset contains information on the intensity of stable light emanating from human habitations and other locations with persistent lighting at a 30-arc-second grid resolution. Nighttime light emissions tend to be strongly correlated with electricity use, and have been shown to provide a useful proxy for changes in electricity consumption in low and middle income countries (see e.g. Falchetta and Noussan, 2019; Xiao et al., 2018; Shi et al., 2019; Fehrer and Krarti, 2018).

I.4 Empirical Strategy

I.4.1 Specifications

The empirical strategy of this paper uses variation in electricity supply caused by Tajikistan's winter energy crisis to identify the effect of residential electricity access on female employment. In particular, the quasi-experimental setting allows me to employ a generalized difference-in-differences framework to compare changes in the outcomes of women who experienced different levels of exposure to the electricity restrictions. The main empirical specification uses the repeated cross-sectional data on women aged 14-49 (described in I.3.1), which spans between 2003 and 2017. The estimation framework is described by the following equation:

$$y_{i,d,t} = \beta_0 + \beta\,(timing_t \times intensity_d) + \gamma_d + \delta_t + \varepsilon_{i,d,t} \tag{I.1}$$

where $y_{i,d,t}$ is the outcome of unit i (an individual or household) in time t at district d; $timing_t$ is an indicator variable for observations occurring within

the window of treatment (roughly 2010-2015; see figure I.8); $intensity_d$ is a continuous variable that captures the district-specific level of exposure to electricity restrictions (further discussed in section I.4.2); and γ_d and δ_t are district fixed and year fixed effects. If $intensity_d$ is uncorrelated with other location-specific and time-varying factors that could affect the outcomes (i.e. if more and less exposed units would have experienced similar trends in the outcomes in the absence of treatment), then the estimated parameter β can be used to capture a causal relationship between access to electricity and female employment.

The panel data described in section I.3.1 provides an alternative estimation approach. This specification is identical to equation I.1, except that it takes advantage of the panel structure of the LSMS 2007 and THPS 2011 by including unit fixed effects at either the individual or the household level, depending on the level at which the outcome is measured. The panel-data approach is described by the following equation:

$$y_{i,d,t} = \beta_0 + \beta(timing_t \times intensity_d) + \gamma_i + \delta_t + \varepsilon_{i,d,t} \tag{I.2}$$

where the only difference from equation I.1 is the indexation of γ_i. The panel data thus allows me to control for unobserved heterogeneity at the individual and household level rather than at the district level. Since treatment is spatially assigned, I adjust standard errors in all specifications for clustering at the level of treatment, which is the district or the municipality depending on specification. In robustness tests presented in appendix I.E, I also account for more arbitrary forms of spatial correlation.

I.4.2 Defining the Intensity of Exposure

In order to complete the description of the empirical strategy outlined by equations I.1 and I.2 the treatment variable $intensity_d$ must be defined. First, I construct a simple measure of the intensity of exposure to electricity restrictions using observed blackouts. In particular, I use electricity availability data collected by the Consumer's Union of Tajikistan (CU) to calculate the daily average winter-time blackout period in the months of November, December, January and February for each district during the winter energy crisis (i.e. from the start of CU data collection until February 2015). The resulting variable ($blackouts_d$) has a theoretical range between 0 and 24, but effectively ranges between 0 and 17.3. This implies that the longest average blackout period observed in the data over this time period is 17 hours and 18 minutes per day, which corresponds to around three months of continuous blackout between November and February each year of the crisis. The mean blackout period is 15.3 (15 hours and 18 minutes) and the standard deviation is 3.7 (3 hours and 41 minutes). By replacing $intensity_d$ with $blackouts_d$ in equations I.1 and I.2, the estimated treatment effect (β) can then be interpreted as the

effect of one additional hour of winter-time blackouts per day during the crisis. However, this interpretation depends on the crucial assumption that the duration of winter-time blackouts are exogenous.[13] While observed blackouts from the CU data provides a straightforward measure of treatment intensity, it is likely that exposure to blackouts is correlated with other simultaneous events (e.g. plant closures or infrastructure construction) that can have independent effects on labor market outcomes. It is also possible that realized blackouts are endogenous with respect to contemporaneous political decisions that affect employment, since electricity quotas were distributed and rationed out though a nontransparent process involving national, regional and district-level authorities.[14]

One way to avoid the potential endogeneity issues associated with observed blackouts would be to instead use variation in pre-crisis electricity infrastructure as a measure of treatment intensity. As discussed in section I.2.2, the autarkical conditions caused by the winter energy crisis tended to favor locations with central positions in the Tajik national network. This means that pre-crisis proximity to major Tajik power stations and transmission network nodes could play an important role in determining future exposure.[15] Therefore, it should be possible to use spatial differences in physical integration with central Tajik power systems before the crisis to predict subsequent differences in exposure. This would produce a measure of treatment intensity that is robust to contemporaneous shocks during the winter crisis. However, to create a useful measure of treatment intensity based only on physical infrastructure, one would require access to detailed data on Tajik energy systems, including the locations and dates of construction for generation and transmission infrastructure. Unfortunately, such data on transmission infrastructure is not publicly available, and generation infrastructure alone provides a very crude measure of power system integration. Still, in appendix I.F I present a noisy measure of

[13] It also assumes that households had full access to electricity outside the window of treatment (i.e. in 2003, 2007 and 2017), which is not strictly true as many Tajik households experienced power shortages both before and after the winter energy crisis. However, the magnitude of these events are small compared with the extended periods without electricity experienced during the winter energy crisis. For instance, in the winter of 2017 the CU data reports a daily average winter-time blackout period of about 6 minutes, which is insignificant compared to the average of 15.3 hours witnessed in the period 2012-2015.

[14] Several papers have found that political, ethnic, and regional favoritism may affect the distribution of infrastructure provision, as well as economic development in general. See e.g. Burgess et al. (2015), Ahlerup and Isaksson (2015), Hodler and Raschky (2014), and De Luca et al. (2018).

[15] When the regional transmission networks were severed, some parts of Tajikistan ended up occupying a central position in the Tajik national network, while other parts occupied a more peripheral position. The degree of integration with the main Tajik sections of the Central Asian Power System appears to have influenced the degree to which electricity supply problems emerged in different parts of Tajikistan, until the Tajik power systems could be adjusted to the new situation.

treatment intensity based on pre-crisis proximity to Tajik power plants (which thus ignores potentially important variation in transmission infrastructure).

For the main specifications, I instead rely on a measure of pre-crisis integration with Tajik electricity infrastructure that is derived from spatial correlations in nighttime light emissions. This approach builds on the assumption that locations whose power systems were closely integrated before the energy crisis, i.e. shared strong electricity infrastructure connections, are likely to be highly correlated in pre-crisis electricity use, and thus also exhibit strong correlations in pre-crisis observable nighttime light emissions. This makes it possible to identify locations whose power systems were more and less integrated with domestic Tajik power systems prior to the energy crisis, without requiring access to detailed data on electricity transmission infrastructure. Drawing on this notion, I use pre-crisis DMSP-OLS nighttime lights data from the period 2000-2008 and define a pre-crisis nighttime lights index:

$$Z_d = 1 - (\text{corr}(\text{light}_{d,t}, \text{light}_{capital,t}))^2 \tag{I.3}$$

where $\text{light}_{d,t}$ is the mean nighttime light emissions of district d in year t, and $\text{light}_{capital,t}$ is the mean nighttime light emissions of the Tajik capital city Dushanbe in year t.[16] The pre-crisis nighttime lights index specified by equation I.3 thus ranges between zero and one, and depends solely on the share of pre-2009 nighttime light variation that cannot be explained by the capital city of Dushanbe. A high value ($Z_d \approx 1$) indicates that only a small proportion of pre-crisis variation in light emissions can be explained. Such locations are interpreted as being exposed to a "high intensity of treatment", as they were weakly integrated with core Tajik power systems prior to the winter energy crisis and therefore would have suffered more severely from the disruption of electricity trade. Conversely, locations assigned with a low value ($Z_d \approx 0$) are considered to have been strongly integrated with core Tajik power systems prior to the winter energy crisis, and are thus interpreted to have been exposed to a "low intensity of treatment". While nighttime lights may be correlated with several outcomes in addition to electricity use (including economic activity in general), the nighttime lights index has a significant advantage over other measures of exposure in being both pre-determined, and thus robust to contemporaneous shocks, and flexible enough to account for the variation in infrastructure connections that cannot be deduced from the coarse physical infrastructure data.

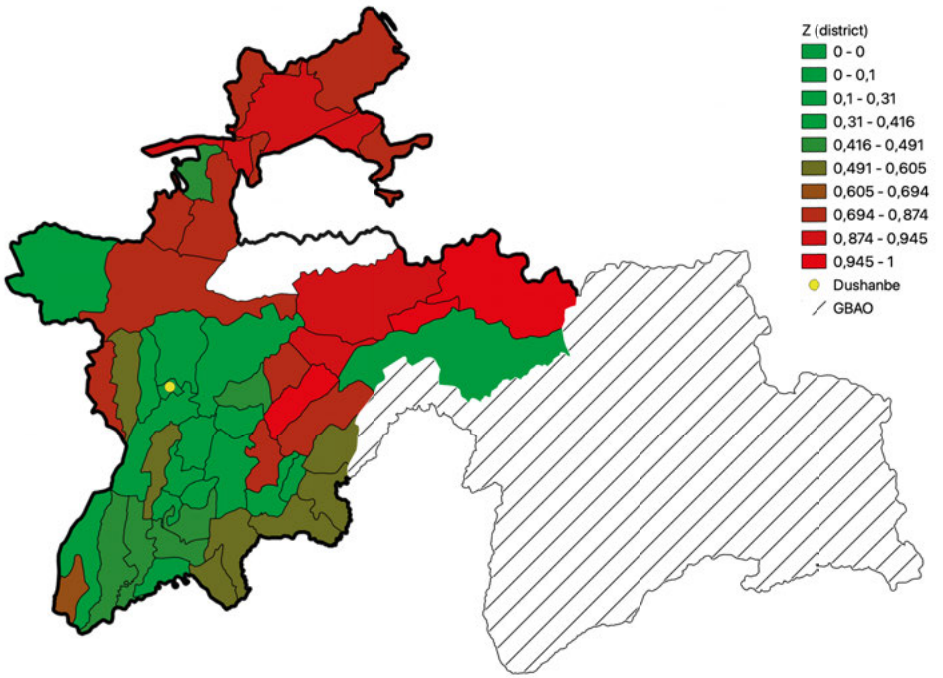
The pre-crisis nighttime lights index is predictive of exposure to observed blackouts (the coefficient of correlation between Z_d and $blackouts_d$ is 0.6578), and is generally well-balanced with respect to spatial differences in female employment before the crisis, as well as other relevant pre-crisis outcomes, such

[16]The definition provided in equation I.3 is equivalent to defining $Z_d = 1 - R_d^2$, where R_d^2 is the R-squared statistic produced by regressing the light emissions of each district on the light emissions of Dushanbe separately for each district by OLS.

as the employment rate, mean wages, and manufacturing output per capita at the district level (see appendix I.G.2). The pre-crisis nighttime lights index can be constructed at any spatial resolution supported by the 30 arc second DMSP-OLS data. Therefore, I construct the index at both the district level (roughly 50 geographical units) and at the municipality level (roughly 270 geographical units).[17]. The district-level definition is preferred over the municipality-level definition for reasons related to the institutional setting and measurement, but I use both measures for robustness when possible. In appendix I.G.1 I discuss potential trade-offs between the two in more detail. The pre-crisis nighttime lights index Z_d provides a method for estimating the relationship between home electricity and female employment that is less likely to suffer from simultaneity bias, as compared to using ex-post observable blackouts. The estimates produced through this approach are "reduced form" and thus convey information only about the direction and statistical significance of the relationship. However, it is possible to use instrumental variables techniques to translate the reduced form results into more comprehensible units of measurement at the cost of additional assumptions (see appendix I.D.2). Figure I.9 illustrates the geographical distribution of the district-level nighttime lights index, while figure I.10 illustrates the geographical distribution of the municipality-level index.

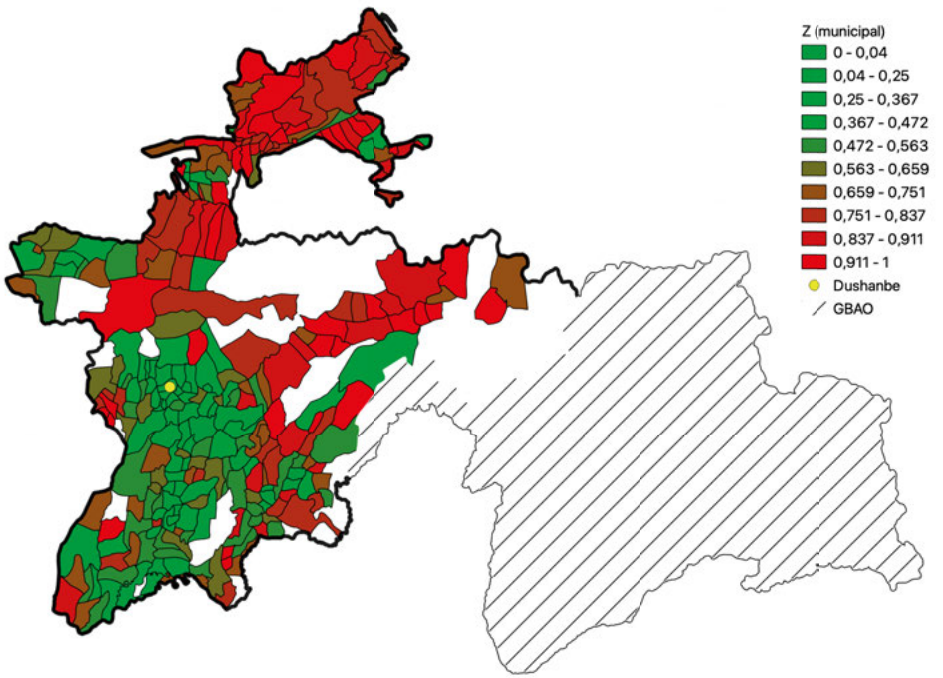
[17] When using the municipality level definition of treatment, I also replace the district fixed effects specified in equations I.1 and I.2 with municipality fixed effects and adjust standard errors for clustering at the municipality rather than the district level.

Figure I.9: *Spatial distribution of the pre-crisis nighttime lights index (district level)*



Note: Some mountainous and sparsely populated locations (e.g. Kuhistoni Mastchoh) drop out due to insufficient data in the DMSP-OLS satellite imagery (i.e. insufficient light emissions on cloud-free days to be reliably separated from background noise. Also indicated is the capital city of Dushanbe, and the Gorno-Badakhshan Autonomous Oblast (GBAO).

Figure I.10: *Spatial distribution of the pre-crisis nighttime lights index (municipality level)*



Note: Some mountainous and sparsely populated locations drop out due to insufficient data in the DMSP-OLS satellite imagery (i.e. insufficient light emissions on cloud-free days to be reliably separated from background noise. Also indicated is the capital city of Dushanbe, and the Gorno-Badakhshan Autonomous Oblast (GBAO).

I.5 Results

I.5.1 A First Look Using Observed Blackouts

Before proceeding to the main results, I estimate equations I.1 and I.2 using observable daily blackout periods from the CU data to signify the intensity of exposure to treatment. This approach is not appropriate for the estimation of causal effects due to the potential endogeneity of blackouts (which is confirmed by robustness tests presented in appendix I.D.1). However, despite the evident drawbacks in terms of causal inference, the correlational evidence offered by ex-post observed blackouts provide a useful starting point for a more in-depth investigation into the causal relationship between electricity and female employment.

Table I.5: *The effect of blackouts on employment*

Outcome:	Employment (=1 if working)					
Dataset:	Repeated-cross section (women 15-49)			Panel (men & women 15-49)		
Sample:	Women	Married	Unmarried	Women	Men	Both
Column:	(1)	(2)	(3)	(4)	(5)	(6)
timing × blackouts	-0.0035***	-0.0038**	-0.0030**	-0.0055**	0.0011	-0.0023
	(0.0013)	(0.0015)	(0.0012)	(0.0026)	(0.0016)	(0.0017)
R-squared	0.071	0.084	0.061	0.0055	0.032	0.0048
Clusters	52	52	52	43	43	43
Observations	30955	20026	10929	2590	2464	5054

All models include district and year fixed effects. Standard errors in parentheses are clustered at the district level: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Column 1 of table I.5 reports that exposure to blackouts is negatively correlated with female employment, indicating a coefficient of -0.0035 that is statistically significant at the 99% level. This means that, during the winter energy crisis, the predicted probability for a woman to be employed was about 0.35 percentage points lower for every hour of blackout (i.e. for every hour without electricity) experienced per day in the winter months in her district. Taken at face value, this finding indicates that a woman who experienced the median blackout period (16 hours and 20 minutes per day) would be roughly 5 percentage points less likely to participate in the labor force compared to a woman who had continuous access to electricity throughout the crisis. The results presented in columns 2 and 3 indicate a slightly larger point estimate when the sample is restricted to married women, and a slightly smaller point estimate when the sample is restricted to unmarried women (but the difference is not statistically significant). Columns 4, 5 and 6 presents the estimates produced when using the panel data approach. The point estimate presented

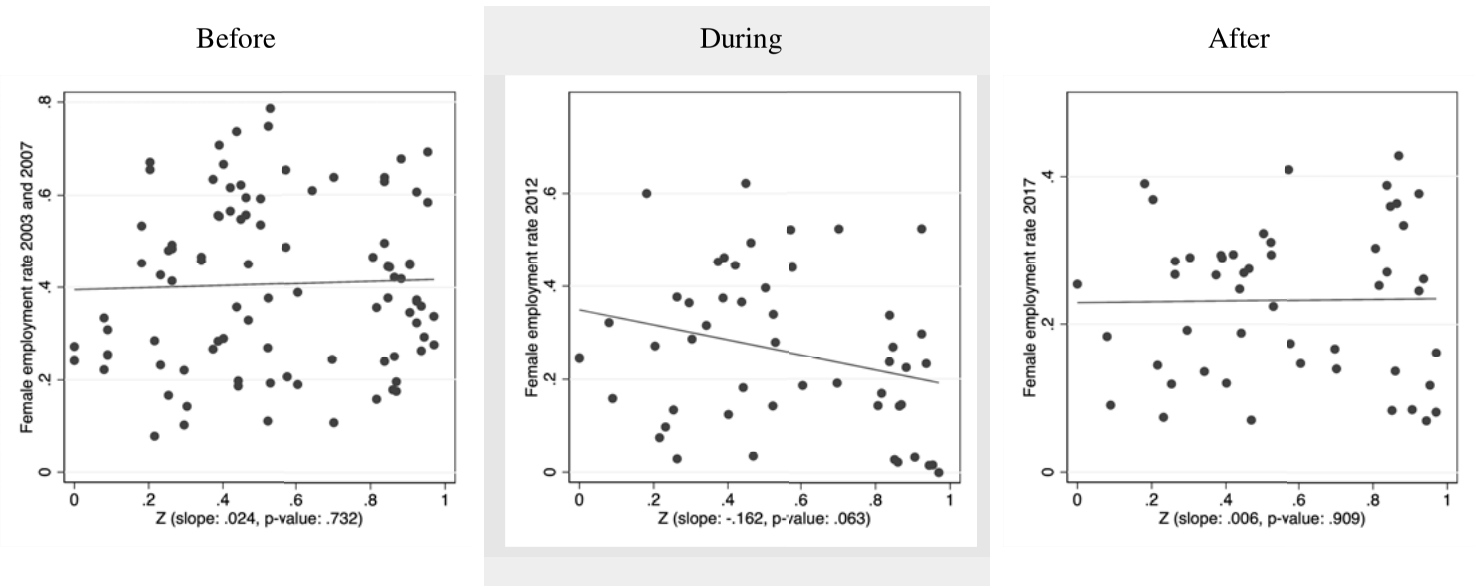
in column 4 (which uses the all female sample) is negative, statistically significant, and larger in magnitude than that obtained from the repeated cross-sectional approach. The panel data also permits the inclusion of male respondents. However, when the sample is restricted to men (column 5), and when it combines both men and women (column 6), the point estimates become small and statistically insignificant.

I.5.2 Electricity Provision and Female Employment

The results presented above suggest a negative relationship between exposure to blackouts and female employment. However, the observed blackouts may be correlated with other factors that also influence female employment over time, which would violate the assumption of parallel trends that is required for a causal interpretation of the estimates. This suspicion is confirmed by placebo tests presented in appendix I.D.1. The central issue with using observed blackouts to measure the intensity of exposure is that the blackouts themselves are endogenous economic outcomes that were realized over the course of the winter crisis, and the severity of the blackouts may be correlated with a variety of shocks that also affect female employment. Therefore, the main analysis of this paper instead relies on the pre-crisis nighttime lights index to estimate the relationship between electricity provision and female employment. Figure I.11 shows the correlation between the pre-crisis nighttime lights index and the observed female employment rate at the district level before, during and after the winter energy crisis. The negative coefficient in the middle panel suggests that districts exposed to a higher intensity of treatment, as indicated by the pre-crisis nighttime lights index Z_d, tended to have lower female employment during the winter energy crisis. However, this relationship is not visible before and after the crisis period, which is consistent with the notion that the index is largely uncorrelated with other factors that affect female labor force participation at the district level (although the identifying assumptions only require that it is uncorrelated with time-dependent factors). These figures also suggests that, already at the district level, there appears to be some evidence of a relationship between female employment and exposure to electricity restrictions.

Figure I.12 illustrates the evolution of the employment rate of Tajik women over the study period, where the sample is split into two categories based on the intensity of treatment. The two lines represent the employment rate of women that, according to the nighttime lights index Z_d, are assigned with an exposure to treatment that is above (red) or below (blue) the median. This binary transformation of the treatment variable discards some variation in exposure, but makes it possible to visualize the main findings of this paper in a simple graph. Figure I.12 reveals a traditional difference-in-differences (DD) estimate of roughly -0.06. This estimate can be read as the difference be-

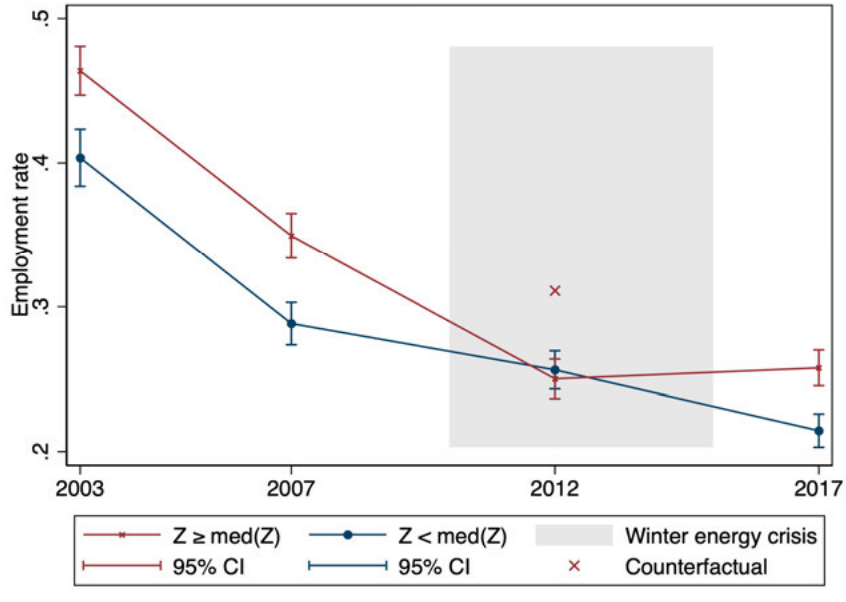
Figure I.11: *Correlations between female employment and exposure in different periods at district level*



Note: The raw employment rates have been aggregated at the district level using the LSMS 2003, LSMS 2007, DHS 2012 and DHS 2017 surveys

tween the observed mean of the "treatment" group in 2012 (represented by the red line) and the counterfactual mean in 2012 (represented by a red marker) that would have been observed if the treatment group had evolved similarly to the control group. The figure visualizes three important findings of this paper. First, higher exposure to electricity restrictions during Tajikistan's winter energy crisis resulted in larger reductions in female employment. Second, the employment rates of women who were more and less exposed evolved similarly prior to treatment. Third, the effect on female employment is reversed after the end of the treatment period, which suggests that the estimated effect is specific to the timing of the crisis.

Figure I.12: *Illustration of the main result: binary treatment version*



The graph shows the unadjusted employment rate of 30 884 women over four survey waves between 2003 and 2017. The lines represent women assigned into higher (Z_d above median) and lower (Z_d below median) exposure to treatment. A binary-treatment analogue of the effect presented in column A1 of I.6 can be discerned in the differential change between the two groups as they enter and exit the winter crisis.

Table I.6 reports the results of estimating the main regression model outlined in equation I.1 on the cross-sectional sample of women aged 15-49, and using the pre-crisis nighttime lights index Z_d to signify the intensity of treatment. The results are reported separately for the district and municipality level treatment definition. Column A1 includes the full sample spanning from 2003 to 2017 and reports a negative treatment effect (-0.097). This result signifies that, for women in districts that received the highest possible intensity of treatment ($Z_d = 1$), the probability of working decreased by roughly 10 percentage

points during of the winter energy crisis, as compared with women in district that received the lowest possible intensity of treatment ($Z_d = 0$). In appendix I.D.2 I use an instrumental variables approach to translate this reduced form result into a more comprehensive unit of measurement for easier comparison with other studies. Using the nighttime lights index to instrument for observed blackouts, I find that each additional hour of winter-time blackouts decreased female employment by roughly 0.0075 percentage points. This means that a woman who experienced the median blackout period (of approximately 16 hours per day) became roughly 12 percentage points less likely to be employed (on a mean of 25 percent baseline female employment).

Columns A2 and A3 split the sample by marital status, and reveal that the estimated effect is stronger among married women than among unmarried women. Columns A4 and A5 show that the point estimates remain negative when the analysis is restricted to observations belonging to the years 2003, 2007 and 2012 (representing the onset of the winter energy crisis) and when the analysis is restricted to observations belonging to the years 2012 and 2017 (representing the period of recovery from the crisis). Columns B1-B5 of table I.6 use the municipality level index. These point estimates are slightly smaller, but are otherwise similar to those presented in columns A1-A5. Overall, the results indicate that exposure to the electricity restrictions had a negative effect on female employment during Tajikistan's winter energy crisis. This effect appears to be generated by opposite changes occurring as individuals enter and exit the time window where treatment takes place, which supports the interpretation that the effect is specifically related to the timing of the winter energy crisis, and was gradually reversed after its resolution.

Table I.7 presents a series of robustness tests using different (incorrect) specifications of the treatment period.[18] If the identifying assumptions are valid, the models should produce significant estimates only if the timing of the treatment is correctly specified, as there should be no large systematic differences in trends between more and less intensely treated individuals outside the treatment window. For the purposes of this exercise, I exclude observations from 2012 (the true period of treatment), and instead define the treatment as occurring in one of the other three time periods. The estimates presented in columns 1 to 6 of table I.7 are thus analogous to the estimates presented in columns A1 and B1 of table I.6, which are again reported in columns 7 and 8 for reference. The results show that the negative effect on female employment only appears when the treatment is correctly specified. This is consistent with the assumption of parallel trends.

Finally, table I.8 reports the results of estimating model I.2 on the panel of individuals aged 15-49 observed in the LSMS 2007 and the THPS 2011 surveys. The panel data regressions reproduce the main results presented in table I.6 using an alternative dataset. Furthermore, since the panel data includes

[18] In appendix I.D.1 I present more extensive results from these tests.

Table I.6: *The effect of the winter energy crisis on employment*

Outcome:	Employment (=1 if working)				
Dataset:	Repeated cross section (women aged 15-49)				
Panel:	A				
Resolution:	District				
Years:	All years (2003-2017)			2003-2012	2012-2017
Sample:	Women	Married	Unmarried	Women	Women
Column:	(1)	(2)	(3)	(4)	(5)
timing × Z	-0.097**	-0.11**	-0.074	-0.11*	-0.083
	(0.039)	(0.040)	(0.045)	(0.062)	(0.067)
R-squared	0.069	0.083	0.059	0.086	0.054
Clusters	51	51	51	51	50
Observations	30884	19983	10901	21175	17842
Panel:	B				
Resolution:	Municipality				
Years:	All years (2003-2017)			2003-2012	2012-2017
Sample:	Women	Warried	Unmarried	Women	Women
Column:	(1)	(2)	(3)	(4)	(5)
timing × Z	-0.087**	-0.11**	-0.060	-0.100	-0.078
	(0.039)	(0.042)	(0.049)	(0.062)	(0.052)
R-squared	0.088	0.11	0.087	0.11	0.074
Clusters	212	212	212	190	181
Observations	29860	19365	10495	20353	17527

All models include district/municipality and year fixed effects. Standard errors in parentheses clustered at the district/municipality level (fixed effects and clusters are defined at the level of treatment): *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table I.7: *Testing for differential trends*

Outcome:	Employment (=1 if working)							
Dataset:	Repeated cross section (women aged 15-49)							
Sample:	Excluding 2012 (the period of treatment)						All periods	
Timing:	2003		2007		2017		2012	
Resolution:	Dist.	Mun.	Dist.	Mun.	Dist.	Mun.	Dist.	Mun.
Column:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
timing×Z	0.029	0.014	0.0017	-0.068	-0.023	0.045	-0.097**	-0.087**
	(0.11)	(0.092)	(0.052)	(0.046)	(0.11)	(0.085)	(0.039)	(0.039)
R-squared	0.069	0.092	0.069	0.092	0.069	0.092	0.069	0.088
Clusters	51	190	51	190	51	190	51	212
Observations	22751	21840	22751	21840	22751	21840	30884	29860

All models include district/municipality and year fixed effects. Standard errors in parentheses clustered at the district/municipality level (fixed effects and clusters are defined at the level of treatment): *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

men, it also adds the possibility to compare the effect across genders. Column 1, which restricts the sample to women, reports a negative estimate of -0.16. Column 2, which restricts the sample to men, reports a positive but statistically insignificant estimate of 0.04. Column 3 combines both women and men, and reports a small negative estimate. Columns 4-6 report similar estimates for the municipality-level nighttime lights index. The findings suggest that the negative relationship between electricity access and employment is specific to women.

I.6 Mechanisms

I.6.1 Appliances and Home Production Technology

The results presented so far strongly suggest that electricity restrictions during Tajikistan's winter energy crisis resulted in decreased female employment, which in turn implies the existence of a positive relationship between electricity provision and female employment. In this section, I explore the nature of this relationship in more detail. I begin by examining the labor supply mechanism formulated by Greenwood et al. (2005), whereby access to electricity frees up labor from home production that can be transferred to the market. In the Tajik context, the labor-saving potential of household electricity is twofold. First, the use of electricity for cooking and heating provides an alternative to more labor-intensive methods of acquiring energy, such as the handling of coal, collection of firewood and cotton stalks, and the production of fuel-bricks from animal dung. The share of households' time and resources devoted to the

Table I.8: *The effect of the winter energy crisis on employment (panel data)*

Outcome:	Employment (=1 if working outside home)					
Dataset:	panel (men & women aged 15-49)					
Resolution:	District			Municipality		
Sample:	Women	Men	Both	Women	Men	Both
Column:	(1)	(2)	(3)	(4)	(5)	(6)
timing × Z	-0.16**	0.041	-0.069	-0.15**	0.0015	-0.081
	(0.078)	(0.048)	(0.044)	(0.076)	(0.061)	(0.055)
R-squared	0.010	0.032	0.0060	0.0068	0.039	0.0084
Clusters	43	43	43	84	84	84
Observations	2582	2451	5033	2340	2236	4576

All models include district/municipality and year fixed effects. Standard errors in parentheses clustered at the district/municipality level (fixed effects and clusters are defined at the level of treatment): *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

acquisition of fuels is thus likely to increase in periods of electricity scarcity.[19] Second, electricity is necessary for the use of productivity-increasing technologies, such as electric stoves, washing machines, vacuum cleaners. Tajik women interviewed by the Asian Development Bank (2016) during the winter crisis stated that poor access to electricity increased the difficulty of domestic tasks by precluding the use of labor-saving electrical appliances. A later time-use survey by the Asian Development Bank (2020) (conducted after the crisis) found that Tajik women with access to electrical stoves cook between 4 and 7 hours less per week compared to women that use wood or animal dung as the main cooking fuel, and that that women with access to washing machines spend about 2.5 hours less washing clothes.

In order to evaluate this potential mechanism, I turn next to study outcomes related to households' use of electrical household appliances.[20] Table I.9 reports the $\hat{\beta}$ coefficients obtained from estimating equation I.1, where the outcome variable $y_{i,t}$ indicates household i's ownership of a certain type of appliance in time t. The sample is identical to that used in the main specifications,

[19]The World Bank (2014) "assessment of household energy deprivation in Tajikistan" concluded based on a small survey conducted in 2013 that energy (including own production) accounted roughly 10 of the total consumption of rural Tajik households, which rises to 15 percent in the heating season. The largest share of energy expenditure is agro-fuels (dung and cotton stalks), followed by firewood, coal and electricity. The report notes that male householders are responsible for purchasing wood, while women and children are responsible for collecting it.

[20]The DHS and THPS surveys did unfortunately not collect information on the time spent in various domestic activities, such as firewood collection and bio-fuel production. Therefore, the direct evidence available from the datasets on home production is confined to the ownership of appliances.

presented in table I.6, with the exception that the unit of observation is at the household level rather than the individual level. Column A1 presents a positive and statistically significant effect on the ownership of small electrical generators that is statistically significant at the 99% level. This finding aligns with anecdotal evidence of households purchasing small-scale generators to cope with the lack of electricity, and confirms that the treatment is indeed picking up the effects of electricity restrictions.

Table I.9: *The effect of the winter energy crisis on appliance ownership*

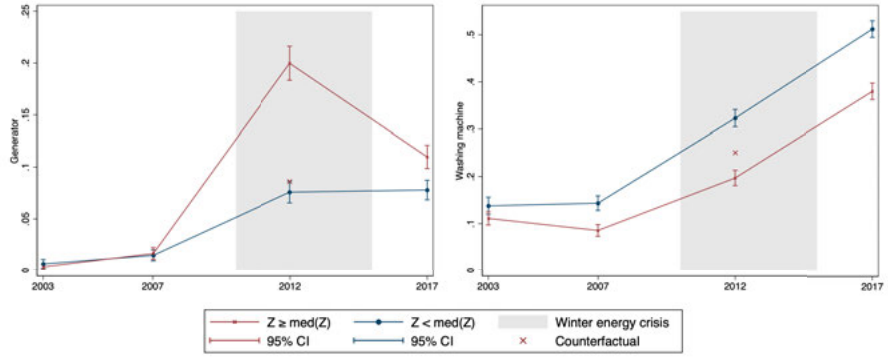
Dataset:	Repeated cross section (households)			
Resolution:	District			
Panel:		A		
Outcome:	Generator	Washing machine	Computer	Refrigerator
Column:	(1)	(2)	(3)	(4)
timing × Z	0.16***	-0.086***	-0.094**	0.031
	(0.027)	(0.032)	(0.035)	(0.063)
R-squared	0.081	0.21	0.14	0.29
Observations	18053	18054	18053	18006
Dep. var. mean	0.072	0.27	0.13	0.53
Panel:		B		
Outcome:	Air conditioner	Television	DVD-player	Satellite dish
Column:	(1)	(2)	(3)	(4)
timing × Z	-0.0046	0.0071	0.0086	0.0096
	(0.019)	(0.018)	(0.067)	(0.076)
R-squared	0.15	0.14	0.43	0.31
Observations	18043	17911	18056	18053
Dep. var. mean	0.16	0.93	0.53	0.34

All models include district and year fixed effects. Standard errors in parentheses are adjusted for clustering at the district level: *** p < 0.01, ** p < 0.05, * p < 0.1.

Column A2 of table I.9 presents a negative effect on the ownership of washing machines. This can be interpreted as a relative reduction in the adoption of labor-saving appliances. I also find a negative effect on the ownership of personal computers (column A3). I find no effect on refrigerators and air conditioners (columns A4 and B1). This is unsurprising, since the winter-time electricity supply restrictions are unlikely to affect the utility of appliances that are used mainly in summer. Furthermore, the ownership of entertainment

devices appears to be largely unaffected, as indicated by small estimated effects for television sets, DVD-players and satellite dishes.[21]

Figure I.13: *Visual illustration of key findings*



The graph shows the unadjusted ownership rate of small-scale electrical generators (dvizhok) and washing machines for 18 123 households between 2003 and 2017. The lines represent households assigned into higher (Z_d above median) and lower (Z_d below median) exposure to treatment. The two figures illustrate the findings presented in columns A1 and A2 of table I.9, but do not provide a true representation of the estimates as they rely on a binary treatment analogue to make the visualization possible.

Figure I.13 illustrates these findings using a binary transformation of the treatment variable. It shows that the ownership of generators increased significantly during the winter energy crisis, and remained relatively high after its conclusion. This suggests that the investment in generator capacity was not fully reversible, and mirrors the descriptive evidence on generator ownership in the firm data presented in table I.1. Furthermore, the figure shows that the ownership rate of washing machines is increasing over the study period, which implies that the negative effect is driven by a slower rate of adoption among more intensely treated households rather than an absolute decline. Table I.27 in appendix I.D.3 repeats this exercise using the municipality-level treatment variable, which produce nearly identical results. Overall, the effects on household appliance ownership suggest that the loss of electricity had a negative effect on the adoption of labor-saving electrical appliances. This evidence is consistent with the notion that electricity releases women from unpaid domestic labor through improvements in home production technology.

[21] Whereas the ownership of television sets is unchanged, there is an (almost significant) negative effect on the ownership of color TVs. In addition to refraining from investing in washing machines and personal computers, some households that are severely affected by electricity restrictions may thus also be refraining from upgrading the quality of some of their entertainment devices. Table I.26 in appendix I.D presents the corresponding results when using observed blackouts for treatment intensity instead of the pre-crisis nighttime lights index.

I.6.2 Demand-Side Effects and Job Search

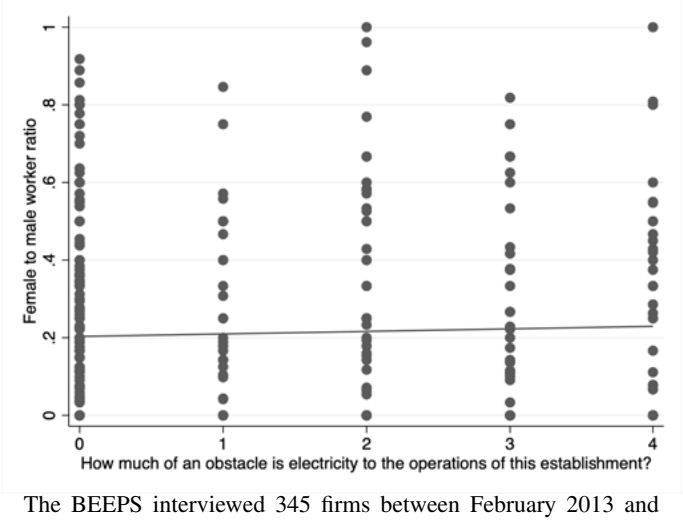
Another important hypothesis is that winter-time electricity restrictions affect female employment through changes in labor demand. For instance, one might worry that electricity scarcity caused some firms to shut down or to postpone the hiring of new workers, resulting in a general labor demand shock that could lead to lower employment. One circumstance that speaks against this hypothesis is that the effect is specific to female respondents. While the elasticity of labor supply may differ between genders, one would expect a negative labor demand shock to affect both men and women to some extent. However, the estimated effect on male employment is small, positive, and statistically insignificant across all specifications (including for unmarried men). In order to rationalize these findings within the framework of a general demand-side shock, male labor supply would have to be almost perfectly inelastic (or even have a negative slope). Therefore, general demand-side effects appears unlikely to explain the main results of this paper.

Another possibility is that demand-side factors impact men and women differently. For instance, a recent paper by Vidart (2021) suggests that electrification in the US tended to complement tasks that favor women in the labor market, which emphasizes the potential demand side effects of electricity on female labor force participation. In the case of Tajikistan, firms that employ large numbers of female workers might be more vulnerable to electricity restrictions compared to other firms, which could explain the heterogeneous effects. However, the sectors identified by the Asian Development Bank (2020) as having relatively large female employment shares (education, social services, health and agriculture), are not likely to be among those that were more exposed to the winter-time electricity restrictions. Therefore, there is little ex-ante reason to suspect female-dominated firms were particularly affected. Furthermore, firm data from the 2013 BEEPS survey (which was conducted during the winter energy crisis) reveal that the female employment share is largely uncorrelated with firms' perceptions about the obstacle posed by electricity. Firms that reported electricity to be the biggest obstacle to their business had an average female employment share of 19.8 %, while other firms had an average female employment share of 21.3 %.[22] Figure I.14 uses the BEEPS data to plot the female employment share of Tajik manufacturing and service sector firms against the perceived severity of electricity as an obstacle to business (on an ordinal scale from zero to four). This evidence suggests that firms with different shares of female workers were similarly affected by the electricity shortages.

Another way to address the potential demand-side factors is to consider job search behavior. The LSMS 2007 and THPS 2011 surveys include information on the job search activities of non-employed respondents, while the DHS

[22]The 2013 BEEPS includes 360 firms in manufacturing, retail, and other services. 38 (or 12.30 %) of these firms reported electricity to be the greatest single obstacle to their business.

Figure I.14: *Female worker share and firm perceptions (2013-2014)*



The BEEPS interviewed 345 firms between February 2013 and April 2014 and asked: "To what degree is Electricity an obstacle to the current operations of this establishment?" Firm responses range between 0 (no obstacle) and 4 (very severe obstacle). Blue line represents the linear regression line (β: 0.0065, p: 0.489).

surveys do not. Therefore, this analysis is confined to the panel dataset. Table I.10 presents the results of estimating the panel data model outlined in equation I.2 on a number of binary outcome variables capturing different aspects of the job-search behavior of non-employed respondents. Column A1 presents the effect of treatment on whether the respondent is currently both without employment and looking for a job (i.e. unemployed). The negative and statistically insignificant effect suggests that the effect is not driven by an increase in involuntary unemployment. Instead, this evidence suggests that the results are explained by women making the active decision to exit the labor force.

However, it remains to be determined why women are leaving the labor force. For instance, unemployed women might be dissuaded from job-search by a perceived lack of labor market opportunities. The LSMS 2007 and THPS 2011 asked working-age respondents not currently in the labor force to motivate why they are not seeking employment. Columns A2 to A6 report the estimated effect of treatment on a series of indicator variables representing these self-reported motivations. For example, the outcome variable in column A2 is a dummy variable indicating respondents who are unemployed and report that they are not seeking employment because they are housewives. Together, the outcome variables used in columns A1 to A6 of table I.10 completely describe all non-working individuals in the sample. Therefore, these estimates sum up to the combined effect size of 0.16 presented in column 1 of table I.8. Simi-

larly, the coefficients presented in columns B1 to B6 decompose the estimate presented in column 4 of table I.8 (indicating an effect size of 0.15). The estimates produced by this exercise are all statistically insignificant. However, it reveals that the effect on employment is almost entirely driven by women exiting the labor force to become housewives. In particular, the small coefficients reported in column 5 suggests that the reduction in labor force participation does not appear to be driven by a perceived lack of labor market opportunities. These findings suggest that the effects reflect conscious labor allocation decisions by households.

Table I.10: *Job search activities and motivations*

Dataset:	Panel of women 15-49					
Panel:	A					
Resolution:	District					
Outcome:	Searching	Reason for not searching				
		Housewife	Studies	Retired	No jobs	Other
Column:	(1)	(2)	(3)	(4)	(5)	(6)
timing×Z	-0.0094	0.15	0.0099	-0.00090	-0.018	0.030
	(0.0095)	(0.097)	(0.024)	(0.0072)	(0.015)	(0.049)
R-squared	0.0014	0.016	0.056	0.0015	0.0016	0.010
Clusters	43	43	43	43	43	43
Observations	2582	2582	2582	2582	2582	2582
Panel:	B					
Resolution:	Municipality					
Outcome:	Searching	Reason for not searching				
		Housewife	Studies	Retired	No jobs	Other
Column:	(1)	(2)	(3)	(4)	(5)	(6)
timing×Z	-0.012	0.17*	0.015	-0.0016	-0.018	0.0024
	(0.015)	(0.086)	(0.024)	(0.010)	(0.022)	(0.027)
R-squared	0.0017	0.013	0.060	0.0014	0.0012	0.017
Clusters	84	84	84	84	84	84
Observations	2340	2340	2340	2340	2340	2340

All models include district and year fixed effects. Standard errors in parentheses are adjusted for clustering at the district level: *** p < 0.01, ** p < 0.05, * p < 0.1.

While limitations in the firm-level data make it difficult to study the role of labor demand directly, the issue can be addressed indirectly using one particular feature of the Tajik economy. Tajikistan's agricultural sector uses electricity mainly for irrigation between May and September, and was therefore not affected by the restricted winter-time electricity supply (see figure I.5). If

the main results are driven by labor demand shocks from the firm side, then the effects would be weaker in places where agriculture is the dominant employer. Similarly, the effects would be stronger in places where firms depend on electricity throughout the year, for instance in districts with a significant manufacturing sector. Therefore, I can use differences in firm-side vulnerability at the district level to indirectly test the importance of the demand-side channel. First, I split the main sample by the median of agricultural land per capita, as well as manufacturing output per capita, to create two groups of approximately equal size for each case.[23] Second, I estimate equation I.1 separately for each sub-sample. The results are presented in table I.11, and show that the main results are driven particularly by women living in districts that have comparatively large agricultural sectors and comparatively small manufacturing sectors. This contradicts the notion that the results are mainly driven by firm-side changes in labor demand.

Table I.11: *Agricultural and manufacturing districts*

Outcome:	Employment (=1 if working)			
Dataset:	Repeated cross-section (women aged 15-49)			
Resolution:	District			
Split by:	Agricultural land/capita		Manufacturing output/capita	
Median:	Above	Below	Above	Below
Column:	(1)	(2)	(3)	(4)
timing × Z	-0.21**	-0.050*	-0.057	-0.17*
	(0.096)	(0.026)	(0.037)	(0.083)
R-squared	0.089	0.035	0.039	0.10
Clusters	37	14	19	32
Observations	14729	16155	15338	15546

All models include district and year fixed effects. These estimates correspond to the main result reported in column 1 of table I.6. Standard errors in parentheses are adjusted for clustering at the district level: *** p < 0.01, ** p < 0.05, * p < 0.1.

I.6.3 Forms of Employment and Intensive Margin Effects

Another concern is that changes in the extensive margin of employment might not capture all the relevant changes in female labor market activities. First, the correct interpretation of the extensive margin effect might depend on whether women who exit the labor force were working full-time or part-time. This information is only available in the panel data, as the DHS only collected information on extensive margin of employment. Table I.12 decomposes the results

[23] For this purpose I use TAJSTAT district-level statistics. See appendix I.B for maps

presented in columns 1 and 4 of table I.8 by part-time employment (less than 40 hours worked per week in the last 14 days) and full-time employment (40 or more hours worked per week in the last 14 days). Using this definition, the share of full-time workers in the 2007 LSMS survey was 63.96% for employed women and 73.35% for employed men. The results suggest that the effects are driven to a similar extent by exits from full-time and part-time employment.

Table I.12: *Full-time and part-time employment*

Data:	Panel (women 15-49)			
Sample:	District		Municipality	
Outcome:	Full-time	Part-time	Full-time	Part-time
Column:	(1)	(2)	(3)	(4)
timing × Z	-0.087	-0.077	-0.070	-0.081
	(0.098)	(0.058)	(0.076)	(0.053)
R-squared	0.023	0.039	0.022	0.037
Clusters	43	43	84	84
Observations	2582	2582	2340	2340

All models include district/municipality and year fixed effects. Standard errors in parentheses are adjusted for clustering at the district/municipality level: *** p < 0.01, ** p < 0.05, * p < 0.1.

Second, in addition to the changes in the extensive margin of employment, there could be intensive margin changes in hours worked. Table I.13 presents the results of estimating equation I.2 on a collection of variables representing the number of hours worked per week in the last 14 days, the number of days worked per week in the last 14 days, and the number of weeks worked in the last 12 months. Columns A1 to A3 use the full sample of women aged 15 to 49, whereas columns A4 to A6 use a sample that has been further restricted to women who are employed in both periods (thus capturing only intensive margin changes). All coefficients are negative, which suggests that exposure to the winter energy crisis is associated with a general reduction in the number of hours, days and weeks worked.

Furthermore, the estimated effects might be interpreted differently depending on what types of employment are driving the results. The household surveys used in this paper provide only very limited details on occupations that are consistent over time. However, all surveys include information on whether the respondent is working for someone outside the family, themselves or a family member. This information offers some indication about whether the results are driven by changes in formal employment (which tends to be for someone outside the family) or by changes in less formal types of employment (such as self-employment or employment in a business or farm owned

Table I.13: *Time spent working (intensive margin)*

Data:	Repeated cross-section (women 15-49)					
Panel:	A					
Resolution:	District					
Sample:	All			Working both periods		
Outcome:	Hours	Days	Weeks	Hours	Days	Weeks
Column:	(1)	(2)	(3)	(4)	(5)	(6)
timing × Z	-7.35***	-1.12**	-7.06***	-4.53	-0.42	-4.67
	(2.34)	(0.42)	(2.35)	(6.20)	(0.42)	(3.99)
R-squared	0.026	0.012	0.011	0.14	0.015	0.0076
Clusters	43	43	43	32	32	32
Observations	2582	2582	2582	394	394	394
Panel:	B					
Resolution:	Municipality					
Sample:	All			Working both periods		
Outcome:	Hours	Days	Weeks	Hours	Days	Weeks
Column:	(1)	(2)	(3)	(4)	(5)	(6)
timing × Z	-7.19**	-1.16**	-7.45**	-2.99	-0.59	-9.25**
	(2.92)	(0.52)	(3.29)	(6.88)	(0.46)	(3.88)
R-squared	0.023	0.011	0.0096	0.14	0.022	0.023
Clusters	84	84	84	57	57	57
Observations	2340	2340	2340	354	354	354

All models include district/municipality and year fixed effects. *Hours* refers to hours worked per week in the last 14 days, *days* refers to days worked per week in the last 14 days, *weeks* refers to weeks worked in the last 12 months. Standard errors in parentheses are adjusted for clustering at the district/municipality level: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

by a family member). I decompose the results presented in tables I.6 and I.8 by whether the respondent is employed by someone outside the family, or by someone inside the family (including self-employment). The findings presented in table I.14 suggest that changes in both types of employment contribute to the main effect, but that effect is stronger for non-family employment. One possible explanation for this result is that family businesses offer more work time flexibility compared to formal employment, and therefore may be compatible with a wider set of distributions between market and household work.

Table I.14: *Employment by type of employer*

Outcome:	Employment (=1 if working) by type of employer			
Panel:	A			
Resolution:	District			
Dataset:	Repeated cross-section (women 15-49)		Panel (women 15-49)	
Employer:	Other	Self/family	Other	Self/family
Model no:	(1)	(2)	(3)	(4)
timing × Z	-0.058***	-0.039	-0.11**	-0.058
	(0.018)	(0.036)	(0.051)	(0.091)
R-squared	0.070	0.042	0.021	0.0057
Clusters	51	51	43	43
Observations	30884	30886	2582	2582
Panel:	B			
Resolution:	Municipality			
Dataset:	Repeated cross-section (women 15-49)		Panel (women 15-49)	
Employer:	Other	Self/family	Other	Self/family
Model no:	(1)	(2)	(3)	(4)
timing × Z	-0.061***	-0.026	-0.11**	-0.038
	(0.019)	(0.034)	(0.055)	(0.077)
R-squared	0.090	0.060	0.018	0.0045
Clusters	212	212	84	84
Observations	29860	29862	2340	2340

All models include district/municipality and year fixed effects. Standard errors in parentheses are adjusted for clustering at the district/municipality level: *** p < 0.01, ** p < 0.05, * p < 0.1.

I.6.4 Fertility and Family Size

Another concern is that the results might reflect changes in fertility and family size. The hypothesis that electrical blackouts sometimes lead to unplanned fertility shocks has been the subject of lively debate. Perhaps the most famous example is the popular notion of "blackout-babies" following the great New York blackout of 1965, which was later dispelled as a modern myth by J. R. Udry (1970). However, some later studies from developing countries have found that blackout events can have positive effects on fertility (see e.g. Burlando, 2014; Fetzer et al., 2018). Since childbirth is likely to be negatively related to employment both in the short and long run, it could be the case that the winter energy crisis affected female employment through a fertility shock.

In order to test the potential influence of fertility, I begin by estimating the effect of exposure to the winter crisis on the total number of living children born by the respondent. Column 1 of table I.15 indicates a small, negative, and statistically insignificant effect on the number of children. This finding suggests that changes in family size are not likely to explain the results. The results presented in columns 2 and 3 confirm that the main findings are robust to controlling for the number of children.[24] Column 3 also estimates an interaction term between treatment and the total number of children ($timing \times Z \times children$), which reveals that the treatment effect increases significantly with family size. Columns 4-6 find similar evidence using the municipality-level treatment variable. These findings suggest that, while the main results of this paper are not explained by changes in family size, the effects are increasing with the number of children.

Besides changes in family size (which might be a slow-moving variable), one might worry that exposure to the winter energy has short-run timing effects on fertility decisions. If winter-time electricity restrictions increases the fertility rates temporarily, it might not have a large effect on the total number of children, but still cause women to leave their employment due to a recent birth. In order to test this hypothesis, I define a variable *birth* indicating whether the respondent has given birth at some point in the 12 months preceding the date of the interview. This variable is intended to capture short-term changes in fertility through recent birth. Similarly to the results pertaining to family size, column 1 of table I.16 indicates a small, negative, and statistically insignificant effect on recent births (alternative measures using one-month and six-month periods are presented in tables I.28 and I.29 in the appendix). This finding reinforces the notion that, while women who gave birth within the last 12 months are significantly less likely to be working, the reduction in electricity access did not have important effects on fertility. The estimates presented in columns 2 and 3 confirm that the main results are robust to controlling for

[24] In these specifications, I also control for the age of the respondent, which is highly correlated with the number of children. The reported coefficients for *age* and *children* reveal that the probability of employment increases with age and decreases with the number of children.

Table I.15: *Number of children*

Dataset:	Repeated cross-section (married women 15-49)					
Resolution:	District			Municipality		
Outcome:	Children	Employment		Children	Employment	
Column:	(1)	(2)	(3)	(4)	(5)	(6)
timing × Z	-0.0095	-0.092**	-0.070*	-0.037	-0.078**	-0.055
	(0.060)	(0.040)	(0.039)	(0.084)	(0.039)	(0.040)
timing × Z			-0.012**			-0.013**
× children			(0.0059)			(0.0057)
children		-0.028***	-0.026***		-0.027***	-0.026***
		(0.0073)	(0.0077)		(0.0052)	(0.0055)
age	0.15***	0.014***	0.014***	0.15***	0.014***	0.014***
	(0.0056)	(0.0017)	(0.0017)	(0.0039)	(0.0012)	(0.0012)
R-squared	0.54	0.12	0.12	0.54	0.14	0.14
Clusters	51	51	51	212	212	212
Observations	30886	30884	30884	29862	29860	29860

All models include district/municipality and year fixed effects. Standard errors in parentheses are adjusted for clustering at the district/municipality level: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

recent births, and that the interaction between the treatment effect and recent births does not seem to exert an important influence. Columns 4-6 present similar results for the municipality-level treatment variable.

Table I.16: *Birth within last 12 months*

Dataset:	Repeated cross-section (married women 15-49)					
Resolution:	District			Municipality		
Outcome:	Birth	Employment		Birth	Employment	
Column:	(1)	(2)	(3)	(4)	(5)	(6)
timing × Z	0.0029	-0.091**	-0.091**	0.012	-0.086**	-0.084**
	(0.0071)	(0.040)	(0.040)	(0.0080)	(0.039)	(0.040)
timing × Z			-0.017			-0.056
× birth			(0.044)			(0.038)
birth		-0.098***	-0.097***		-0.13***	-0.13***
		(0.013)	(0.014)		(0.012)	(0.013)
R-squared	0.027	0.12	0.12	0.024	0.091	0.091
Clusters	51	51	51	212	212	212
Observations	30886	30884	30884	29862	29860	29860

All models include district/municipality and year fixed effects. Standard errors in parentheses are adjusted for clustering at the district/municipality level: *** p < 0.01, ** p < 0.05, * p < 0.1.

I.6.5 Male Migration

Another concern is that the results could be driven by changing patterns of male labor migration, which is very frequent in the Tajik labor market. For instance, if the loss of electricity access increases male labor migration, then the male absence might increase the burden of domestic work among remaining women and make other forms of employment difficult. On the other hand, male migration could have a positive effect on female employment if, for example, it compels remaining women to take on more responsibilities in the family business or family farm. In either case, it is conceivable that electricity restrictions might affect the labor market outcomes of women through the migration patterns of their partners. Since the 2012 and 2017 DHS surveys only targeted female respondents (and include only very limited information on husbands/partners), it is not possible to directly observe in this data how the electricity restrictions affected male labor migration. Instead, I construct a proxy variable based on whether the husband or partner of a female respondent is recorded as living with the household at the time of the interview.

Column 1 of table I.17 presents the results of estimating equation I.1 on a variable indicating whether the husband is presently living in the household at the time of the interview. The estimated effect is positive and statistically significant, which indicates that exposure to electricity restrictions led to increased husband presence (suggesting a decrease in the migration rate of married men). However, column 2 shows that controlling for husband presence in the main specification does not erase the results. Column 3 also includes an interaction term between husband presence and the treatment variable, which again does not remove the main effect (but increases its estimated variance). This exercise indicates that exposure to the winter energy crisis increases the likelihood of husband presence, and that the presence of husbands is negatively correlated with female employment.[25] However, it also indicates that husband presence it is not driving the results, which suggests that male labor migration is not likely to explain the overall findings of this paper.

Table I.17: *Husband presence*

Data:	Repeated cross-section (married women 15-49)					
Resolution:	District			Municipality		
Outcome:	Husband Present	Employment		Husband Present	Employment	
Column:	(1)	(2)	(3)	(4)	(5)	(6)
timing × Z	0.071**	-0.10**	-0.13*	0.073**	-0.12***	-0.10
	(0.029)	(0.040)	(0.072)	(0.031)	(0.036)	(0.066)
timing × Z × Husb. present			0.024			0.0013
			(0.070)			(0.060)
Husband present		-0.075***	-0.077***		-0.074***	-0.069***
		(0.015)	(0.016)		(0.014)	(0.016)
R-squared	0.033	0.085	0.085	0.033	0.084	0.11
Clusters	51	51	51	212	212	212
Observations	19984	19983	19983	19366	19365	19365

All models include district/municipality and year fixed effects depending on the resolution of the treatment variable. Standard errors in parentheses are adjusted for clustering at the district/municipality level: *** p < 0.01, ** p < 0.05, * p < 0.1.

[25] It should be noted that this finding contradicts Kan and Aytimur (2019) who find no effect of male migration on female labor force participation in Tajikistan. However, the causality of that relationship is not addressed here.

I.7 Conclusion

I study the effect of electricity provision on the allocation of female labor in Tajikistan during a period of severe electricity shortages. I find that decreased access to electricity reduces female employment. This paper thus provides new evidence supporting a positive relationship between electricity provision and female employment.

I explore a number of possible explanations for these results, and conclude that the most likely explanation is related to home production. The employment effect is specific to women and increases with the number of children, and appears to be slightly larger for married women. The effect does not seem to be driven by changes in the labor demand of firms, large changes in fertility, or changing patterns of male labor migration. Instead, the self-reported motivations of women in the sample suggest that the effect is driven by a deliberate transition into domestic work. Furthermore, the reduction in female employment is accompanied by decreased ownership of electrical household appliances that are used in home production. These results are thus consistent with the hypothesis that electricity provision promotes female employment by facilitating the adoption of labor-saving electrical appliances that release women from unpaid domestic labor.

This interpretation intersects conceptually with two longstanding strands of thought in development economics. First, it builds on the idea that broad public commitments to infrastructure provision can initiate technological transitions, as famously formulated in the so called "big-push" model by Murphy et al. (1989). Households might invest in electricity-dependent technologies only if they expect future electricity supply to be sufficient, which means that credible public commitments to electricity provision may be a necessary condition for households to adopt labor-saving technologies in the home. Second, the notion that domestic productivity growth releases female labor from the home mirrors a mainstream argument in development macroeconomics about the causes of structural change in the early stages of economic development, which emphasizes the role of agricultural productivity growth in releasing workers from the agricultural sector.[26]

The new empirical approach of this paper extends the literature on the labor supply effects of electricity provision beyond the context of rural electrification programs. Early papers that find large positive effects of electrification on female labor supply have relied on geography-based instrumental variables approaches to account for the endogeneity of infrastructure constructions. These studies have been criticized for possible violations of the exclusion restrictions. I use a different approach based on a large-scale natural experiment in Tajikistan, and find similar evidence that electricity provision has significant effects on female labor supply. The estimates produced by this paper are not

[26] See e.g. Johnston and Mellor (1961), and later papers by Timmer (1988), Gollin et al. (2002), Restuccia et al. (2008), Bustos et al. (2016)

directly comparable to earlier findings that focus on the extensive margin of electricity access. However, it could be argued that the median effect size I find when interpreting the reduced form estimates though an IV approach (a 12 percentage points reduction on a mean of 25 percent baseline employment when exposed to 16 hours of blackout per day) would be somewhat smaller in magnitude compared to the effect size estimated by Dinkelman (2011) (a 9.5 percentage points increase on a mean of 7 percent female employment when getting a grid-connection), but larger than the minimal effects found in later papers by Burlig and Preonas (2021), Salmon and Tanguy (2016) and Lee et al. (2020b). However, since the variation in electricity access studied in this paper is different from that used in the earlier literature, the main point of comparison should be qualitative rather than quantities. In this regard, this paper contributes new evidence that the provision of household electricity has positive and economically meaningful effects on female employment.

This paper is the first to study the effects of a long-term *reduction* in electricity access, which may lead to different results compared to papers that study improvements in access. For instance, the labor supply effects of electricity likely depends on the social and economic dynamics of technology adoption. While access to home electricity is a necessary condition for the use of electrical household appliances, it is not sufficient to ensure that the new technologies are adopted. For instance, the initial costs may be prohibitive for poor and credit constrained households. Furthermore, the diffusion of new technologies often involves a process of social learning where information frictions can delay adoption even in the absence of physical barriers (see e.g. Foster and Rosenzweig, 1995; Conley and C. R. Udry, 2010). For this reason, the full impact of electrification may materialize only gradually over time, perhaps over generations, and may be difficult to detect in empirical designs that study the effects of new connections. By contrast, in the Tajik setting, the electricity-based technologies are initially fairly well known and relatively widely adopted, but become less feasible due to the severe electricity deficits. This could generate larger effects compared to studies based on rural electrification projects. On the other hand, investments in electrical appliances are likely irreversible to some extent, which may limit the technological adjustment in response to a reduction in electricity access relative to an improvement in access. It is also possible that the contrast between the findings of this study and recent papers by Burlig and Preonas (2021), Salmon and Tanguy (2016), Van de Walle et al. (2017), and Lee et al. (2020b) partly reflects differences in setting. Tajikistan's arid climate with cold winters mean that households allocate a large share of household resources to energy, which includes time spent collecting and preparing fuels for the heating season. This means that the labor-saving potential of electricity could be greater in Tajikistan compared to countries with milder climates, such as India, Nigeria or Kenya.

Finally, the results of this paper add to the ongoing debate about the role of electricity infrastructure in economic development by highlighting the im-

portance of the quality of supply. It therefore relates to the small but diverse literature that studies the costs of poor electricity supply reliability in developing countries, which so far has focused on firm-level outcomes (see e.g. Reinikka and Svensson, 2002; Alby et al., 2012; Chakravorty et al., 2014; Allcott et al., 2016; Fried and Lagakos, 2020). If the electricity supply is of low quality, it may be rational for households to continue to rely on traditional methods of cooking, washing, cleaning and heating, rather than invest in machines and devices that require electricity to operate. The Tajik experience demonstrates that, in an environment characterized by universal connection to the grid, regular supply interruptions may still significantly attenuate the benefits of electrification. Therefore, one lesson that emerges from these results is that studies seeking to evaluate the economic and social impact of electrification in developing countries should strive to take the intensive margin of electricity access into account whenever possible. As yet, this aspect of electricity provision calls for future research.

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Appendices

Appendix I.A Gorno-Badakhshan Autonomous Oblast

As discussed in the main text of this paper, the institutional context provides strong reasons to exclude GBAO from the analysis. Figure I.15 plots the daily electricity availability at the district level for Tajik districts located in the GBAO region between 2012 and 2018. The red line represents the average across all districts. Unlike the other regions of Tajikistan, the GBAO was not subjected to the seasonal electricity shortages associated with the winter energy crisis, as GBAO operates a separate power system that is not connected to the main Tajik grid (or the CAPS).

However, while GBAO was spared from the winter energy crisis, its electricity supply environment since independence has generally been worse than other parts of Tajikistan. In response to the poor state of the electricity infrastructure in this region, a large-scale infrastructure development program was initiated in 2002 with financial assistance from the Aga Khan Fund for Economic Development, and since 2012 the GBAO grid also supplies parts of the Shighnan district in Afghanistan. The different trajectory with respect to electricity provision and infrastructure development also means that GBAO provides a poor counterfactual for other Tajik districts.

In this section, I show that the exclusion of GBAO from the analysis does not materially affect the results. Table I.18 replicates the regression results presented in table I.6 in the main text (cross-sectional regressions), while including respondents from GBAO. Table I.19 replicates the panel data regressions presented in table I.8 in the main text (panel data regressions), while including respondents from GBAO. Table I.20 replicates the regression results presented in table I.9 in the main text (appliances), while including respondents from GBAO. The results presented in these tables show that, while strongly motivated by the institutional context, the exclusion of GBAO does not materially change the main results of this paper.

Figure I.15: *Daily winter time electricity availability by season 2012 - 2018 (GBAO)*

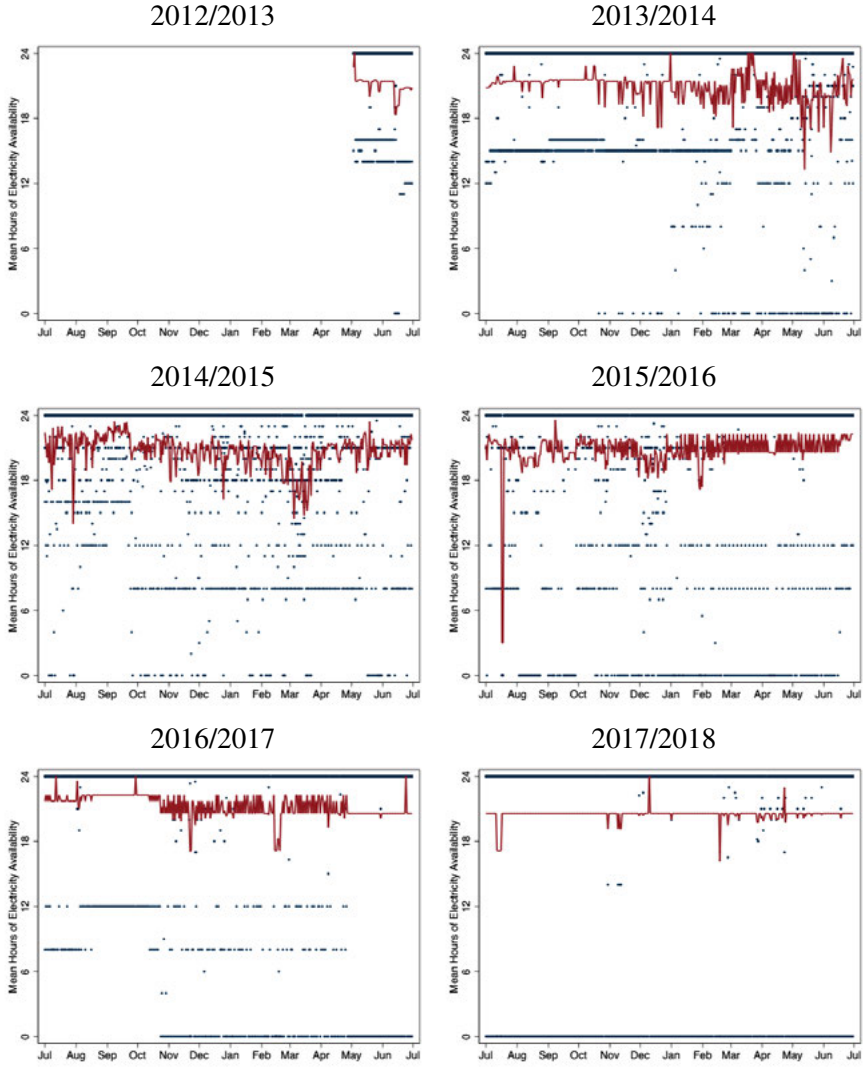


Table I.18: *The effect of the winter energy crisis on employment (inc. GBAO)*

Outcome:	Employment (=1 if working)				
Dataset:	Repeated cross section (women aged 15-49)				
Resolution:	District				
Years:	All years (2003-2017)			2003-2012	2012-2017
Sample:	Women	Married	Unarried	Women	Women
Column:	(1)	(2)	(3)	(4)	(5)
timing × Z	-0.090**	-0.11**	-0.062	-0.095	-0.091
	(0.040)	(0.041)	(0.047)	(0.068)	(0.063)
R-squared	0.071	0.092	0.059	0.086	0.054
Clusters	54	54	54	54	53
Observations	33182	21218	11964	22962	18937
Resolution:	Municipality				
Years:	All years (2003-2017)			2003-2012	2012-2017
Sample:	Women	Married	Unarried	Women	Women
Column:	(6)	(7)	(8)	(9)	(10)
timing × Z	-0.087**	-0.11**	-0.060	-0.100	-0.078
	(0.039)	(0.042)	(0.049)	(0.062)	(0.052)
R-squared	0.088	0.11	0.087	0.11	0.074
Clusters	212	212	212	190	181
Observations	29886	19383	10503	20379	17527

All models include location and year fixed effects. Standard errors in parentheses clustered at the district/municipality level: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table I.19: *The effect of the winter energy crisis on employment (panel, inc. GBAO)*

Outcome:	Employment (=1 if working outside home)					
Dataset:	panel (men & women aged 15-49)					
Resolution:	District			Municipality		
Sample:	Women	Men	Both	Women	Men	Both
Column:	(1)	(2)	(3)	(4)	(5)	(6)
timing × Z	-0.17**	0.056	-0.064	-0.15**	0.0041	-0.080
	(0.076)	(0.048)	(0.043)	(0.076)	(0.060)	(0.055)
R-squared	0.011	0.032	0.0056	0.0067	0.036	0.0081
Clusters	46	46	46	84	84	84
Observations	2718	2597	5315	2360	2258	4618

All models include location and year fixed effects. Standard errors in parentheses are adjusted for clustering at the district/municipality level: *** p < 0.01, ** p < 0.05, * p < 0.1.

Table I.20: *The effect of the winter energy crisis on appliances (inc. GBAO)*

Resolution:	District			
Dataset:	Repeated cross-section (households)			
Outcome:	Generator	Washing machine	Computer	Refrigerator
Column:	(1)	(2)	(3)	(4)
timing × Z	0.15***	-0.088***	-0.085**	0.035
	(0.026)	(0.032)	(0.035)	(0.064)
R-squared	0.079	0.21	0.15	0.28
Observations	19426	19427	19426	19370
Dep. var. mean	0.070	0.27	0.13	0.53
Outcome:	Air conditioner	Television	DVD-player	Satellite dish
Column:	(5)	(6)	(7)	(8)
timing × Z	-0.0026	0.0047	0.00087	0.018
	(0.019)	(0.020)	(0.067)	(0.072)
R-squared	0.15	0.14	0.43	0.32
Observations	19416	19268	19429	19425
Dep. var. mean	0.15	0.93	0.53	0.35

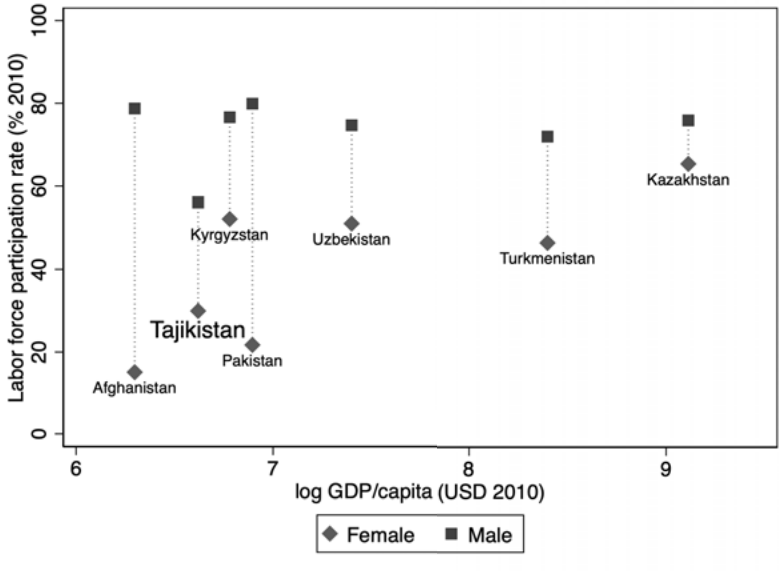
All models include district and year fixed effects. Standard errors in parentheses are adjusted for clustering at the district level: *** p < 0.01, ** p < 0.05, * p < 0.1.

Appendix I.B Additional Figures and Maps

I.B.1 The Tajik Labor Market in Regional a Context

According to ILO estimates, the labor force participation rate of women in Tajikistan has declined slightly since independence but has remained roughly around 30%, while the labor force participation rate of men has declined from about 60% in 1999 to about 50% in 2019 (World Bank, 2021a). As shown in figure I.16, the female labor force participation rate in Tajikistan is only slightly higher than that of Afghanistan and Pakistan. However, the gap between male and female employment is similar to that of other post-Soviet Central Asian countries like Kyrgyzstan, Uzbekistan and Turkmenistan.

Figure I.16: *Labor force participation and log GDP per capita*

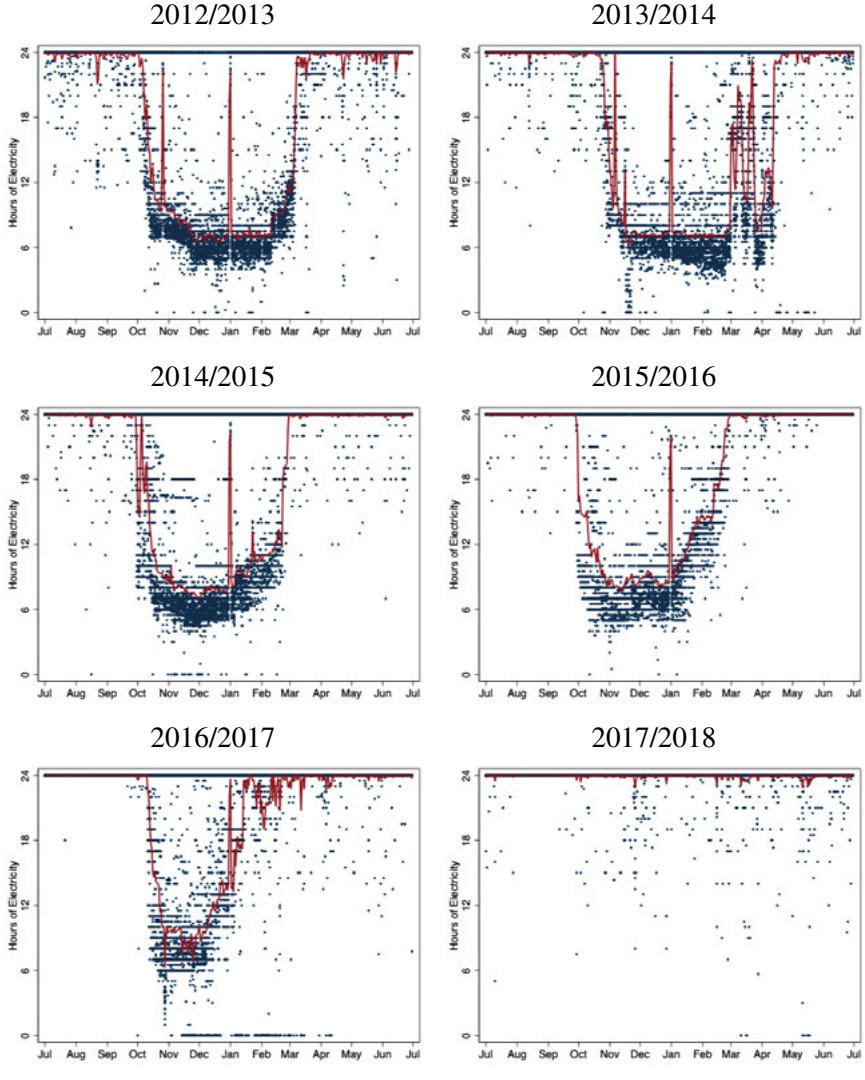


Source: World Bank Development Indicators: labor force participation rate (proportion of the population ages 15 and older that is economically active).

I.B.2 Daily Electricity Availability 2012 to 2018

Figure I.17 plots the daily electricity availability at the district level for Tajik districts between 2012 and 2018 (excluding GBAO). The red line represents the average across all districts. The figures illustrate a strong seasonal variability in electricity access that diminishes over time, as Tajikistan eventually overcame its winter-time electricity deficits.

Figure I.17: *Daily winter time electricity availability by season 2012 - 2018*



I.B.3 Agricultural and Manufacturing Districts

Figure I.18: *Districts with high (red) and low (white) agricultural land/cap.*

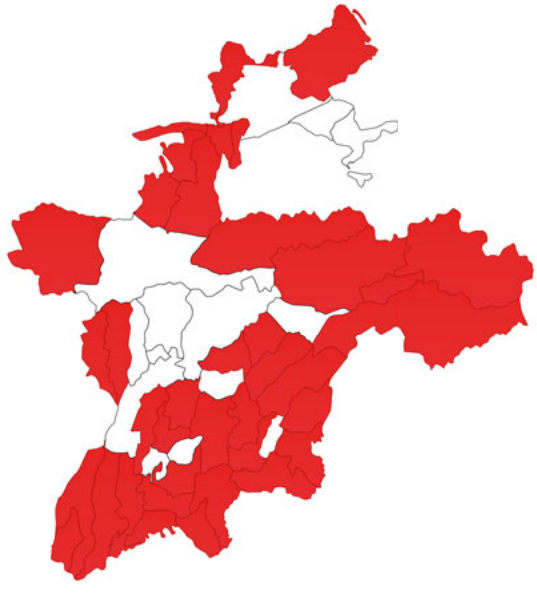
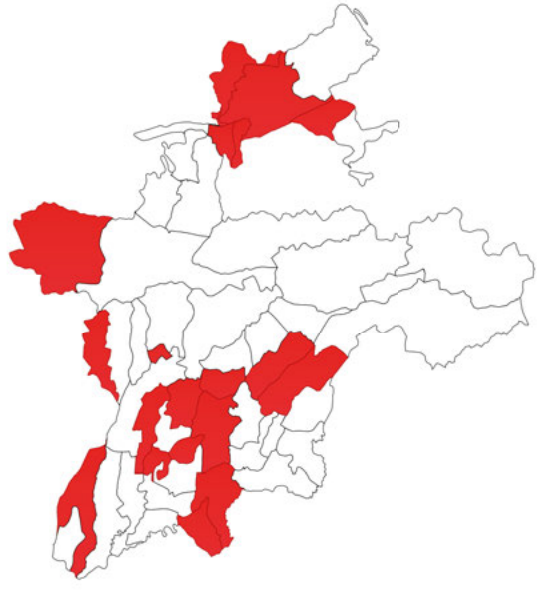


Figure I.19: *Districts with high (red) and low (white) manufacturing output/cap.*



I.B.4 Additional Maps

Figure I.20: *District-level map with transmission and generation*

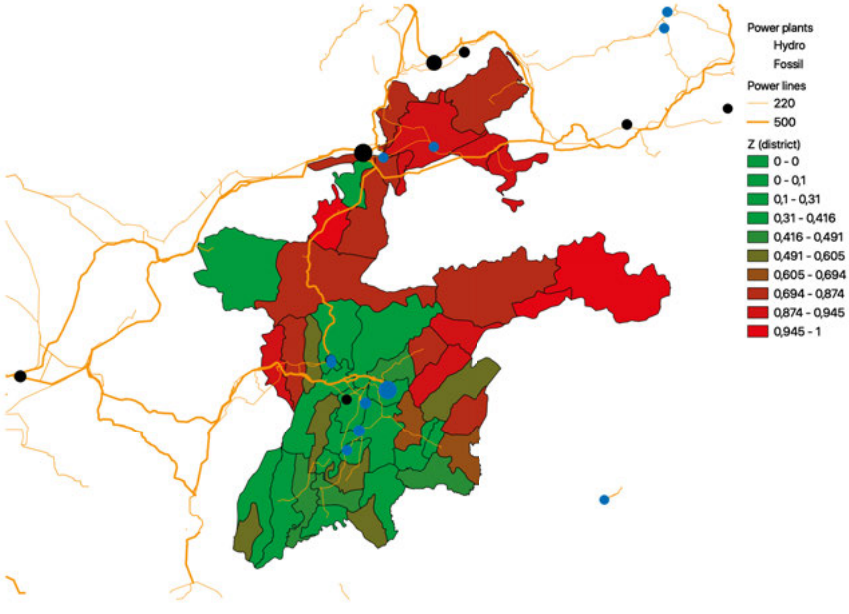
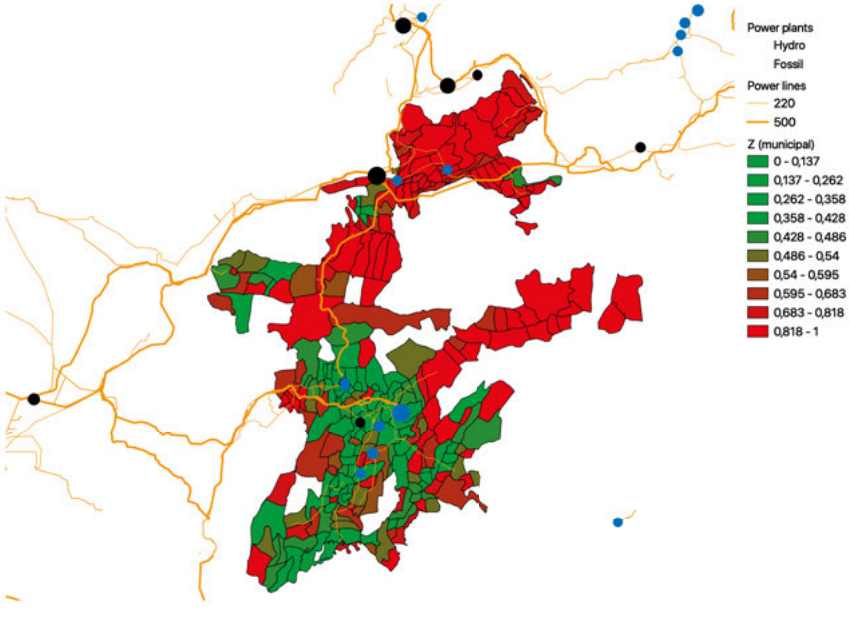


Figure I.21: *Municipality-level map with transmission and generation*



Appendix I.C Summary Statistics

The descriptive statistics presented in table I.21 show that the labor market participation rate of women declined over the study period, as indicated by a falling fraction of female respondents reported to be currently working. In the 2003 LSMS survey, roughly 44% of the female respondents aged 15-49 were reported as working, and in the 2017 DHS the corresponding number is only about 24%. The apparent decline could be partly due to changes in definitions: the questions regarding current work status in 2003 and 2007 refers to the last 14 days, whereas the corresponding question in 2012 and 2017 refers only to the last 7 days. However, such changes in measurement cannot fully account for the negative trend in female labor market participation, which can be observed also between surveys using the same definition. The ownership of household appliances (washing machines and refrigerators) and other electrical devices (television sets) show a constant increase over the study period. The ownership of small generators for the production of electricity within the household follow a less regular pattern. Very few households owned generators in the period before the winter energy crisis (2003-2007), but by 2012 the share of households owning generators had increased to about 14%, followed by a slight decline to about 9% in 2017. These changes are similar to those reported for manufacturing firms in table I.1, which show an increase in generator ownership at the onset of the crisis, which persists to some extent after its conclusion.

Table I.21: *Descriptive statistics*

Survey year	**2003**		**2007**		**2012**		**2017**	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Women (aged 15-49)								
Age	28.291	9.781	28.284	9.978	28.983	9.872	29.465	9.663
Married	0.595	0.491	0.583	0.493	0.670	0.470	0.706	0.455
Husband present	0.566	0.496	0.530	0.499	0.621	0.485	0.632	0.482
Working	0.441	0.497	0.320	0.467	0.256	0.436	0.236	0.425
Observations	5709		7341		8172		9709	
Households								
Household size	6.656	3.045	6.666	2.732	6.443	2.945	6.287	2.823
Rural location	0.642	0.479	0.633	0.482	0.565	0.496	0.563	0.496
Owns generator	0.005	0.070	0.016	0.124	0.136	0.342	0.094	0.291
Owns washing machine	0.123	0.328	0.115	0.319	0.261	0.439	0.447	0.497
Owns refrigerator	0.316	0.465	0.358	0.479	0.549	0.498	0.727	0.446
Owns television	0.764	0.425	0.927	0.261	0.963	0.189	0.983	0.131
Observations	3294		3903		4834		6084	

Appendix I.D Additional Tables

I.D.1 Placebo Tests

In this section, I run a series of placebo tests that use alternative definitions of the timing of treatment. I estimate the model specified in equation I.1 on the full sample of women and on the sub-sample of married women, and use placebo treatment periods occurring in 2003, 2007 or 2017 instead of the actual treatment period in 2012. Table I.22 reports the results when using observed blackout durations to represent the intensity of treatment. The tests show that significant estimates are produced even when the timing of the treatment is incorrectly defined. This suggests that the parallel trends assumption is invalid and should be rejected. This confirms the potential issues associated with using observed blackouts to indicate the intensity of treatment, as discussed in section I.4.2.

Table I.22: *Placebo (blackouts at district level)*

Outcome:	Labor force participation (=1 if working outside home)							
Resolution:	District							
Test:	Placebo						Treatment	
Timing:	2003		2007		2017		2012	
	All	Married	All	Married	All	Married	All	Married
Model no:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
timing ×	0.0087***	0.010***	0.0029*	0.0028	-0.0085***	-0.0090***	-0.0035***	-0.0038**
blackouts	(0.0023)	(0.0029)	(0.0015)	(0.0018)	(0.0017)	(0.0021)	(0.0013)	(0.0015)
R-squared	0.072	0.089	0.070	0.086	0.072	0.089	0.071	0.084
Clusters	52	52	52	52	52	52	52	52
Observations	22783	14550	22783	14550	22783	14550	30955	20026

Standard errors in parentheses cluster adjusted at the district level: *** p < 0.01, ** p < 0.05, * p < 0.1.

Table I.23 reports the results of placebo tests performed with the nighttime lights instrument at both the district and municipality level. The results reported in columns 7 and 8 (15 and 16) are included for reference purposes and are identical to those reported in columns 1 and 2 (6 and 7) of table I.6. When using the nighttime lights instrument, significant effects appear only in the cases where the timing is correctly defined. This means that the parallel trends assumption cannot be rejected, which supports the validity of the empirical strategy.

Table I.23: *Placebo (nighttime lights instrument)*

Outcome:	Labor force participation (=1 if working)							
Dataset:	Repeated cross section (women aged 15-49)							
Resolution:	District							
Test:	Placebo						Treatment	
Timing:	2003		2007		2017		2012	
Sample:	All	Married	All	Married	All	Married	All	Married
Model no:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
timing × Z	0.029	0.0053	0.0017	0.010	-0.023	-0.012	-0.097**	-0.11**
	(0.11)	(0.15)	(0.052)	(0.052)	(0.11)	(0.12)	(0.039)	(0.040)
R-squared	0.069	0.086	0.069	0.086	0.069	0.086	0.069	0.083
Clusters	51	51	51	51	51	51	51	51
Observations	22751	14530	22751	14530	22751	14530	30884	19983
Resolution:	Municipality							
Test:	Placebo						Treatment	
Timing:	2003		2007		2017		2012	
Sample:	All	Married	All	Married	All	Married	All	Married
Model no:	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
timing × Z	0.014	-0.018	-0.068	-0.078*	0.045	0.076	-0.087**	-0.11**
	(0.092)	(0.11)	(0.046)	(0.046)	(0.085)	(0.089)	(0.039)	(0.042)
R-squared	0.092	0.12	0.092	0.12	0.092	0.12	0.088	0.11
Clusters	190	190	190	190	190	190	212	212
Observations	21840	13980	21840	13980	21840	13980	29860	19365

Standard errors in parentheses cluster adjusted at the district level: *** p < 0.01, ** p < 0.05, * p < 0.1.

I.D.2 Instrumental Variables Approach

The main estimates presented in tables I.6 and I.8 are reduced form estimates that cannot be directly interpreted in terms of real economic concepts. They can be interpreted only in terms of the direction and statistical significance of the effects. In this section, I use a two-stage least squares (2SLS) approach to re-scale the reduced form estimates into economically meaningful units. This approach relies on additional assumptions (that are not necessary for making the central arguments of this paper), but provides a useful and more direct economic interpretation to the point estimates produced in this paper. The 2SLS approach is summarized by the following first and second stage equations:

$$\begin{aligned} \text{first stage:} \quad & \text{blackouts}_{i,l,t} = \beta_0 + \beta(\text{treatment}_t \times \text{Z}_l) + \gamma_l + \gamma_t + \varepsilon_{l,t} \\ \text{second stage:} \quad & y_{i,l,t} = \tilde{\beta}_0 + \tilde{\beta}(\widehat{\text{blackouts}}_{l,t}) + \gamma_l + \gamma_t + \tilde{\varepsilon}_{i,l,t} \end{aligned} \tag{I.4}$$

Where $\widehat{\text{blackouts}}_{l,t}$ represents the predicted values obtained from the first stage regression. Table I.24 presents the estimated treatment effects identified by $\hat{\beta}$. The 2SLS estimates presented in columns 1 and 2 of table I.24 are re-weighted versions of the reduced form estimates presented in columns 1 and 2 of table I.6; columns 3 and 4 of table I.24 correspond to the reduced form estimates presented in columns 5 and 6 of table I.6; and columns 5 and 6 of table I.24 correspond to the reduced form estimates presented in columns 1 and 4 of table I.8. The estimates range between -0.0064 and -0.012. Overall, the evidence presented in table I.24 are in line with the main results, which suggest that exposure to household electricity restrictions is having a negative effect on female employment, but also provides an indication of magnitudes. For example, the result reported in column 1 suggests that a woman who experienced the median daily blackout period (16 hours and 20 minutes) would be roughly 12 percentage points less likely to participate in the labor force compared to a woman with full access to electricity.

Table I.24: *Second stage*

Outcome:	Labor force participation (=1 if working outside home)					
Dataset:	Repeated cross-section				Panel	
Resolution:	District		Municipality		District	Municipality
Sample:	All	Married	All	Married	All	All
Column:	(1)	(2)	(3)	(4)	(5)	(6)
timing × blackouts	-0.0075*** (0.0015)	-0.0088*** (0.0015)	-0.0064*** (0.0013)	-0.0082*** (0.0018)	-0.012** (0.0058)	-0.014** (0.0066)
First stage F	8.17	7.32	14.1	12.7	5.87	6.55
Clusters	51	51	212	212	43	84
Observations	30884	19983	29860	19365	2574	2340

All models include district/municipality and year fixed effects. Standard errors in parentheses are adjusted for clustering at the district/municipality level: *** p < 0.01, ** p < 0.05, * p < 0.1.

Table I.25 reports the first stage regression results corresponding to each estimate presented in table I.24 (using the corresponding column numbers). The first stage regressions indicate the correlation between Z_d and Z_m and the average daily wintertime blackout period is sufficiently strong to constitute relevant instruments.

Table I.25: *First stage*

Outcome:	Mean daily winter-time blackout duration (2012-2015)					
Dataset:	Repeated cross-section				Panel	
Resolution:	District		Municipality		District	Municipality
Sample:	All	Married	All	Married	All	All
Column:	(1)	(2)	(3)	(4)	(5)	(6)
timing × Z	12.9***	12.2***	13.7***	13.1***	12.9**	10.6**
	(4.50)	(4.53)	(3.65)	(3.67)	(5.82)	(4.12)
Clusters	51	51	212	212	43	84
Observations	30884	19983	29860	19365	2438	2340

All models include district/municipality and year fixed effects. Standard errors in parentheses are adjusted for clustering at the district/municipality level: *** p < 0.01, ** p < 0.05, * p < 0.1.

I.D.3 Appliances: Using Blackouts and Municipality-Level Treatment

The evidence presented in table I.5 shows that longer blackout periods are associated with lower employment rates during the winter energy crisis for women aged 15 to 49. These results provide some support for the existence of a positive relationship between access to home electricity and female labor force participation. Focusing instead on household-level outcomes, table I.26 reports that exposure to blackouts is associated with changes in the ownership patterns of appliances and other household assets. Households belonging to districts that sustained longer blackouts during the winter energy crisis exhibit a lower tendency to own washing machines when compared to households that experienced shorter blackout durations (but more likely to own electrical generators). Columns 2, 4 and 6 of table I.26 also include household-level controls for the location of the household (rural or non-rural) and the altitude of the sample cluster in kilometers. However, as discussed in the paper, these results should not be given a causal interpretation due to the potential endogeneity of observed blackouts (which is why the pre-crisis nighttime light instrument is preferred over observed blackouts for the main specifications).

Table I.26: *The effect of blackouts on appliances and household asset ownership*

Dataset:	Repeated cross-section (households)					
Resolution:	District					
Outcome:	Generator		Washing machine		Refrigerator	
Model no:	(1)	(2)	(3)	(4)	(5)	(6)
timing ×	0.0065***	0.0066***	-0.0030*	-0.0039***	-0.00058	-0.0020
blackouts	(0.0011)	(0.0010)	(0.0015)	(0.0013)	(0.0018)	(0.0017)
rural		0.025		-0.18***		-0.26***
		(0.015)		(0.017)		(0.023)
altitude		-0.0030		-0.020		-0.089
		(0.016)		(0.033)		(0.058)
R-squared	0.079	0.080	0.21	0.24	0.29	0.33
Observations	18090	18090	18091	18091	18042	18042
Dep. var. mean	0.072	0.072	0.27	0.27	0.53	0.53

All models include municipality and year fixed effects. Standard errors in parentheses are adjusted for clustering at the district level: *** p < 0.01, ** p < 0.05, * p < 0.1.

Table I.27 reproduces table I.9 in the main text using the nighttime lights index defined at the municipality level. The results are qualitatively identical.

Table I.27: *Appliances (municipality-level treatment)*

Resolution:	Municipality			
Dataset:	Repeated cross-section (households)			
Outcome:	Generator	Washing mach.	Computer	Refrigerator
Column:	(1)	(2)	(3)	(4)
timing × Z	0.17***	-0.10**	-0.10***	0.022
	(0.032)	(0.040)	(0.033)	(0.039)
R-squared	0.11	0.26	0.17	0.33
Observations	17518	17519	17518	17472
Dep. var. mean	0.072	0.27	0.13	0.54
Outcome:	Air cond.	Television	DVD-player	Satellite dish
Column:	(5)	(6)	(7)	(8)
timing × Z	-0.033	0.011	-0.053	-0.021
	(0.023)	(0.015)	(0.046)	(0.058)
R-squared	0.19	0.16	0.44	0.33
Observations	17508	17376	17521	17519
Dep. var. mean	0.16	0.94	0.54	0.35

All models include municipality and year fixed effects. Standard errors in parentheses are adjusted for clustering at the municipality level: *** p < 0.01, ** p < 0.05, * p < 0.1.

I.D.4 Recent Births

Table I.28: *Birth within last 6 months*

Data:	Repeated cross-section (married women 15-49)					
Resolution:	District			Municipality		
Outcome:	Birth	Employment		Birth	Employment	
Model no:	(1)	(2)	(3)	(4)	(5)	(6)
timing × Z	-0.0027	-0.097**	-0.097**	-0.0060	-0.088**	-0.088**
	(0.0040)	(0.039)	(0.040)	(0.0052)	(0.039)	(0.039)
timing × Z ×			-0.080			-0.058
birth			(0.063)			(0.059)
birth		-0.16***	-0.15***		-0.15***	-0.14***
		(0.019)	(0.020)		(0.016)	(0.017)
R-squared	0.012	0.072	0.072	0.018	0.090	0.090
Clusters	51	51	51	212	212	212
Observations	30886	30884	30884	29862	29860	29860

All models include district/municipality and year fixed effects. Standard errors in parentheses are adjusted for clustering at the district/municipality level: *** p < 0.01, ** p < 0.05, * p < 0.1.

Table I.29: *Birth within last month*

Data:	Repeated cross-section (married women 15-49)					
Resolution:	District			Municipality		
Outcome:	Birth	Employment		Birth	Employment	
Model no:	(1)	(2)	(3)	(4)	(5)	(6)
timing × Z	-0.0013	-0.097**	-0.097**	-0.0016	-0.088**	-0.088**
	(0.0013)	(0.039)	(0.039)	(0.0014)	(0.039)	(0.039)
timing × Z ×			-0.18**			-0.19***
birth			(0.074)			(0.072)
birth		-0.12**	-0.12**		-0.12**	-0.11**
		(0.055)	(0.057)		(0.054)	(0.055)
R-squared	0.0048	0.070	0.070	0.011	0.088	0.088
Clusters	51	51	51	212	212	212
Observations	30886	30884	30884	29862	29860	29860

All models include district/municipality and year fixed effects. Standard errors in parentheses are adjusted for clustering at the district/municipality level: *** p < 0.01, ** p < 0.05, * p < 0.1.

I.D.5 Twelve-Month Employment

The main specifications presented in this paper use a definition of labor force participation that refers to activities undertaken within one or two weeks before the interview (see table I.4 in the main text). Here I use an alternative measure based on whether respondents worked at least one day in the last twelve months. The two definitions are highly correlated (a coefficient of 0.9504), but may capture slightly different aspects of female labor force participation. Table I.30 replicates the main results presented in table I.6 using the alternative twelve-month definition of employment. The results are similar to the main results, which indicates that the conclusions of this paper are not sensitive to the choice between the two definitions.

Table I.30: *The effect of the winter energy crisis on employment (12 month)*

Outcome:	Employment (=1 if working some time last 12 months)				
Dataset:	Repeated cross-section (women aged 15-49)				
Resolution:	District				
Years:	All years (2003-2017)			2003-2012	2012-2017
Sample:	All	Married	Unarried	All	All
Model no:	(1)	(2)	(3)	(4)	(5)
timing × Z	-0.091**	-0.11**	-0.063	-0.11*	-0.078
	(0.043)	(0.047)	(0.048)	(0.063)	(0.076)
R-squared	0.070	0.084	0.060	0.085	0.062
Clusters	51	51	51	51	50
Observations	30878	19977	10901	21169	17836
Resolution:	Municipality				
Years:	All years (2003-2017)			2003-2012	2012-2017
Sample:	All	Married	Unarried	All	All
Model no:	(1)	(2)	(3)	(4)	(5)
timing × Z	-0.084**	-0.10**	-0.058	-0.094	-0.084
	(0.042)	(0.046)	(0.052)	(0.064)	(0.055)
R-squared	0.092	0.11	0.091	0.12	0.088
Clusters	212	212	212	190	181
Observations	29855	19360	10495	20348	17522

All models include district/municipality and year fixed effects. Standard errors in parentheses are adjusted for clustering at the district/municipality level: *** p < 0.01, ** p < 0.05, * p < 0.1.

Appendix I.E Adjusting for Spatial Correlation

Since the assignment of treatment is spatial, one might worry that the error term is correlated not only within geographical units (which can be addressed by adjusting standard errors for clustering), but also between nearby geographical units. If the outcome variable (employment) is highly spatially correlated, then a failure to account for this correlation could cause the standard errors to be under-estimated, leading to an over-estimation of the accuracy of the estimated effects. In order to address this potential issue, I use the spatial correction proposed by Conley (1999) implemented through the *acreg* STATA package provided by Colella et al. (2019). Tables I.31 and I.32 reproduce the main estimates presented in columns A1 and B1 of tables I.6, and columns 1 and 4 of table I.8, using threshold distances of 50, 100, 150 and 200 kilometers (based on the coordinates of district and municipality centroids). This means that I allow the error terms of individuals in each district or municipality to be correlated with those located within a distance of 50, 100, 150 and 200 kilometers. These results show that the estimates are robust to spatial correlation in the error term.

Table I.31: *Repeated cross-section estimates (correcting for spatial correlation)*

Outcome:	Employment (=1 if working outside home)							
Dataset:	Repeated cross-section (women aged 15-49)							
Resolution:	District				Municipality			
Threshold:	50 km	100 km	150 km	200 km	50 km	100 km	150 km	200 km
Column:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
TZ	-0.097***	-0.097**	-0.097***	-0.097***	-0.087***	-0.087***	-0.087***	-0.087***
	(0.037)	(0.048)	(0.030)	(0.027)	(0.024)	(0.028)	(0.031)	(0.030)
R-squared	0.069	0.069	0.069	0.069	0.088	0.088	0.088	0.088
Clusters								
Observations	30884	30884	30884	30884	29860	29860	29860	29860

All models include district/municipality and year fixed effects. Standard errors in parentheses clustered at the district/municipality level (fixed effects and clusters are defined at the level of treatment): *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table I.32: *Panel estimates (correcting for spatial correlation)*

Outcome:	Employment (=1 if working outside home)							
Dataset:	Panel (women aged 15-49)							
Resolution:	District				Municipality			
Threshold:	50 km	100 km	150 km	200 km	50 km	100 km	150 km	200 km
Column:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
TZ	-0.16***	-0.16***	-0.16***	-0.16***	-0.15**	-0.15***	-0.15**	-0.15***
	(0.042)	(0.021)	(0.039)	(0.0093)	(0.073)	(0.038)	(0.061)	(0.029)
R-squared	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63
Clusters								
Observations	2582	2582	2582	2582	2340	2340	2340	2340

All models include district/municipality and year fixed effects. Standard errors in parentheses clustered at the district/municipality level (fixed effects and clusters are defined at the level of treatment): *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Appendix I.F Proximity to Physical Infrastructure

In this section, I outline an alternative measure of treatment intensity based on the physical proximity to Tajik electricity infrastructure that existed before the onset of the energy crisis. First, I identify and locate all Tajik power plants that were in operation before November 2009 using information provided by Tajikistan's national integrated power company Barqi Tojik. The power plants are listed in table I.33. Second, I calculate the Euclidean distance between each of these plants and the centroids of each Tajik district in the sample.

Table I.33: *Power plants*

Name	Year	Latitude	Longitude	Type	Capacity (MW)
Nurek	1972	38.3717	69.3481	Hydro	2700
Baipaza	1985	38.2674	69.1237	Hydro	600
Kairakkum	1956	40.2759	69.815	Hydro	126
Sarband	1962	37.8839	68.937	Hydro	240
Varzob 1	1936	38.586	68.7785	Hydro	0.75
Varzob 2	1949	38.6122	68.7767	Hydro	14.4
Sangtuda 1	2008	38.0435	69.0583	Hydro	670
Dushanbe	1961	38.6106	68.7726	Thermal	230
Yavan	1968	38.296	68.932	Thermal	120

Next, I define three district-level measures of proximity to Tajik power plants:

$$\Delta_{1,d} = \min(\delta_{d,j}) \tag{I.5}$$

$$\Delta_{2,d} = \sum_{j=1} (\delta_{d,j}) \tag{I.6}$$

$$\Delta_{3,d} = \sum_{j=1} (\delta_{d,j} m_j) \tag{I.7}$$

where $\delta_{d,j}$ is the distance between district d and power plant j, and m_j is the installed capacity of power plant j. $\Delta_{1,d}$ thus captures the distance of district d to its closest plant, $\Delta_{2,d}$ the distance to all plants, and $\Delta_{3,d}$ the distance to all plants where each plant is weighted by its installed capacity. All three measures offer a crude way of determining the physical position of each district with respect to the central Tajik power systems. I also normalize each measure to the range between 0 and 1 using the formula $x_{normalized} = (x - \min(x))/(\max(x) - \min(x))$. This linear transformation preserves the relationships among the original data values while making the different measures comparable across specifications. Similarly to the nighttime light instrument used in the main specification, a Δ_d close to one implies that the district is far removed from central Tajik power systems, and thus can be considered

to have been more severely exposed to electricity restrictions during the winter energy crisis. On the other hand, a Δ_d close to zero implies that the district is located in close proximity to central Tajik power systems, and thus can be considered to have been less exposed. Table I.34 is a correlation matrix showing how the different measures of power plant proximity are related to each-other, to the nighttime lights instrument, and to observed blackouts.

Table I.34: *Correlation matrix*

	Z_d	$\Delta_{1,d}$	$\Delta_{2,d}$	$\Delta_{3,d}$
$\Delta_{1,d}$	0.4899	1		
$\Delta_{2,d}$	0.7985	0.5336	1	
$\Delta_{3,d}$	0.7696	0.4460	0.9787	1
$blackouts_d$	0.6578	0.4977	0.5014	0.4304

Figures I.22, I.23 and I.24 show the spatial distribution of $\Delta_{1,d}$, $\Delta_{2,d}$ and $\Delta_{3,d}$ respectively across Tajik districts.

Figure I.22: $\Delta_{1,d} = \min(\delta_{d,j})$

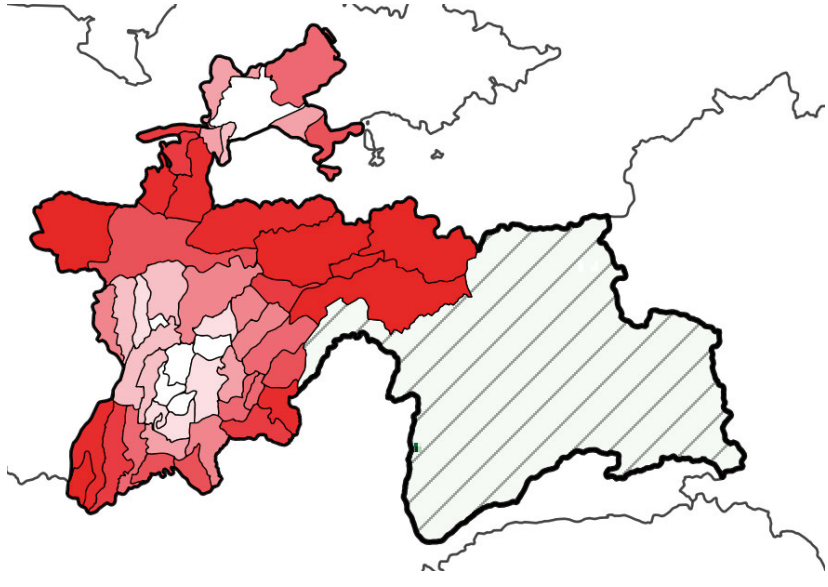


Figure I.23: $\Delta_{2,d} = \sum_{j=1}(\delta_{d,j})$

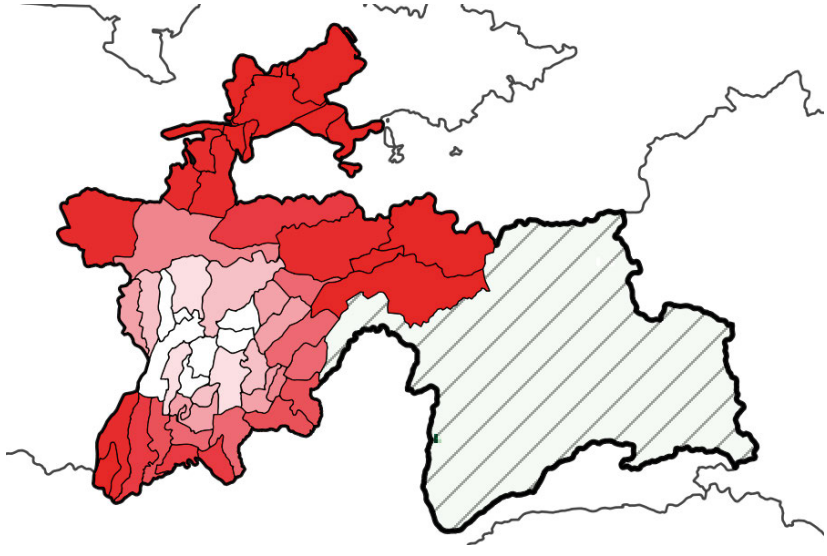


Figure I.24: $\Delta_{3,d} = \sum_{j=1}(\delta_{d,j} m_j)$

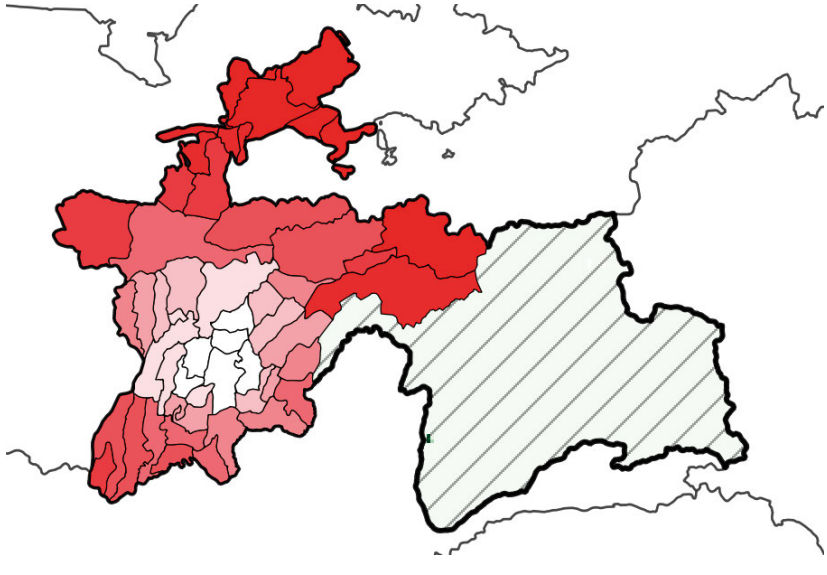


Table I.35 presents the results of estimating equations I.1 and I.2 with the definition of treatment intensity given by equations I.5-I.7. The results are generally consistent with those produced by the main specification, but the estimates are less accurate. I find negative effects on female employment, with larger coefficient estimates for married women. The effect is visible in both the

repeated-cross sectional data and the panel data, and there is no corresponding effect for men.

Table I.35: *The effect of distance to power plants on employment*

Outcome:	Employment (=1 if working)					
Treatment var.:	Distance to closest powerplant: $\Delta_1 = \min(\delta)$					
Dataset:	Repeated-cross section (women 15-49)			Panel (men & women 15-49)		
Sample:	All	Married	Unarried	All	Women	Men
Model no:	(1)	(2)	(3)	(4)	(5)	(6)
timing $\times \Delta_1$	-0.074	-0.080	-0.074	-0.22**	-0.34**	-0.068
	(0.092)	(0.093)	(0.11)	(0.11)	(0.14)	(0.14)
R-squared	0.070	0.084	0.061	0.0087	0.013	0.032
Clusters	52	52	52	43	43	43
Observations	30955	20026	10929	5054	2590	2464
Treatment var.:	Sum of distance to power plants: $\Delta_2 = \sum(\delta)$					
Dataset:	Repeated-cross section (women 15-49)			Panel (men & women 15-49)		
Sample:	All	Married	Unarried	All	Women	Men
Model no:	(7)	(8)	(9)	(10)	(11)	(12)
timing $\times \Delta_2$	-0.060	-0.076*	-0.025	-0.066	-0.15	0.046
	(0.047)	(0.045)	(0.063)	(0.082)	(0.13)	(0.066)
R-squared	0.071	0.084	0.061	0.0052	0.0072	0.032
Clusters	52	52	52	43	43	43
Observations	30955	20026	10929	5054	2590	2464
Treatment var.:	Sum of distance to power plants (weighted by capacity): $\Delta_3 = \sum(\delta m)$					
Dataset:	Repeated-cross section (women 15-49)			Panel (men & women 15-49)		
Sample:	All	Married	Unarried	All	Women	Men
Model no:	(13)	(14)	(15)	(16)	(17)	(18)
timing $\times \Delta_3$	-0.068	-0.087*	-0.024	-0.057	-0.13	0.048
	(0.054)	(0.051)	(0.069)	(0.087)	(0.14)	(0.075)
R-squared	0.071	0.084	0.061	0.0049	0.0055	0.032
Clusters	52	52	52	43	43	43
Observations	30955	20026	10929	5054	2590	2464

All models include district and year fixed effects. Standard errors in parentheses clustered at the district level: *** p < 0.01, ** p < 0.05, * p < 0.1.

Appendix I.G Nighttime Light Index

I.G.1 Spatial Resolution

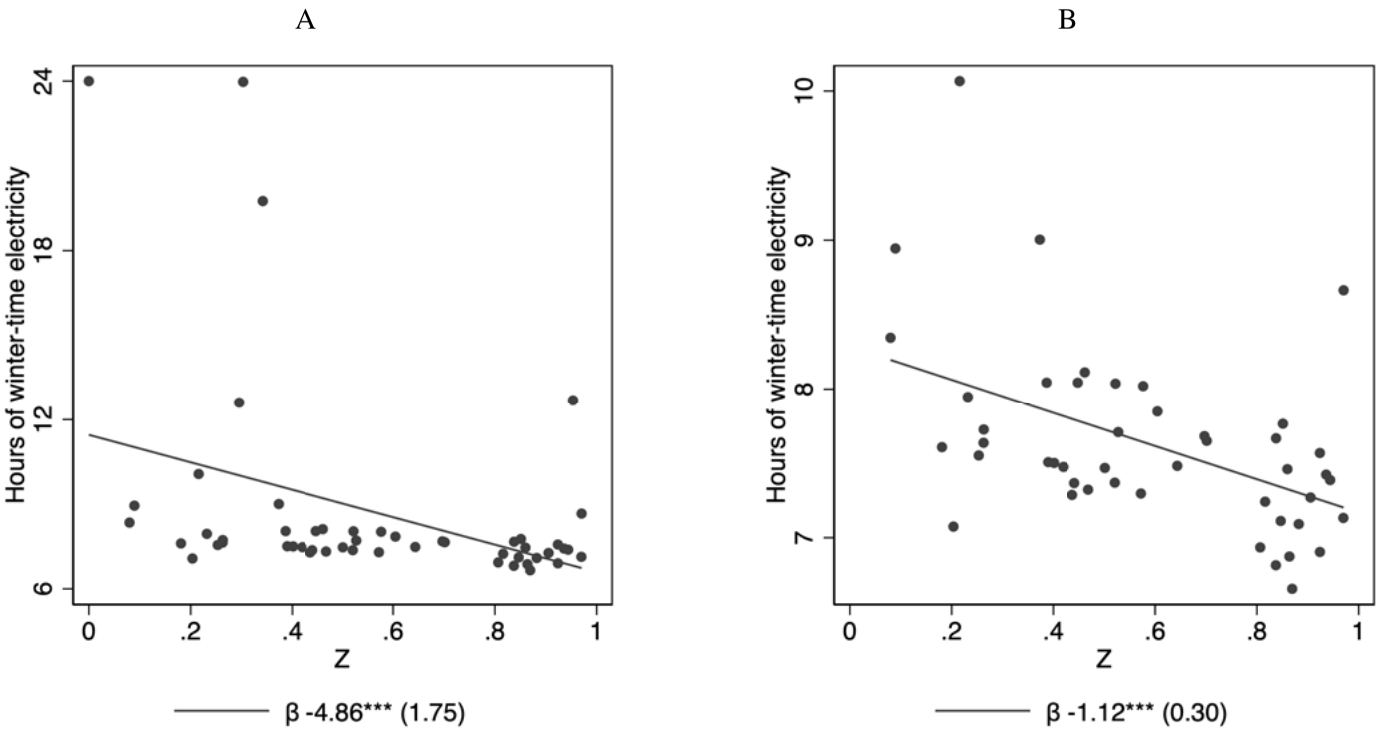
The empirical strategy of this paper uses a nighttime lights index Z defined in two ways: one that varies at the district (rayon) level, and one that varies at the municipality (Jamoat) level. The latter achieves a higher spatial resolution in the treatment variable by offering more than five times the number of geographical units. The advantage of a higher spatial resolution is that local variation in exposure could be exploited for increased statistical power. Conceptually, if the true exposure to treatment varies at the municipality level, then the use of a district level proxy would inevitably introduce some measurement error that could attenuate the estimated effects. But there are also some drawbacks to using the higher resolution variable. First, due to random coordinate displacement in the DHS geospatial data, some households would almost certainly be assigned to the wrong municipalities, which gives rise to measurement error in the treatment variable. By contrast, the district-level approach will always assign observations to the correct geographical unit. Therefore, it is not evident whether the use of a higher resolution would decrease or increase the risk of measurement error in practice. Furthermore, since scheduled blackouts were generally decided and imposed at the district level (at least according to official accounts), the district-level treatment should theoretically be sufficient to capture the relevant variation in electricity provision during the crisis. Therefore, the district-level measure is weakly preferred. However, since the trade-off is not obvious, I have opted to present both measures in parallel for most results in the paper.

I.G.2 Correlates of the Nighttime Light Index

Figure I.25 illustrates the correlation between the nighttime lights index (on the X-axis) and the hours of daily average winter-time electricity availability during the crisis (on the Y-axis) at the district level. This measure of electricity availability is equal to $24 - blackouts_j$, as defined in section I.4.2. The figure illustrates that the nighttime lights index is negatively correlated with daily winter-time electricity availability during the crisis (and thus positively correlated with the average daily blackout period). The negative relationship is accentuated by a few districts that enjoyed high levels of winter-time electricity availability throughout the crisis and tend to be (correctly) classified as having experienced a low intensity of treatment. Panel B therefore restricts the sample to districts that experienced 12 or more hours of blackouts on average and shows a similar relationship (although with a smaller slope).

Figure I.26 decomposes the measure of electricity availability presented in figure I.25 by season. Panel A illustrates that the nighttime lights index is negatively correlated with average daily winter-time electricity availability (and thus positively correlated with the average daily blackout period) during the

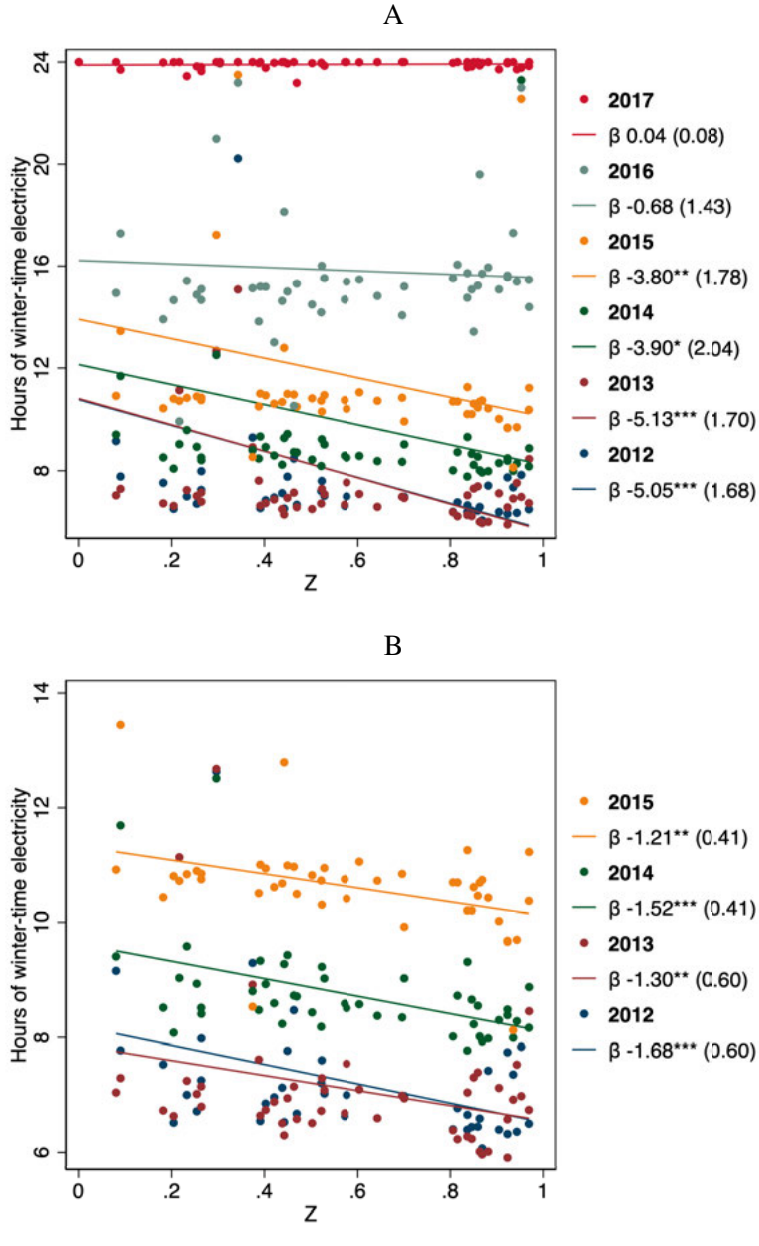
Figure I.25: *Z_d and hours of winter-time electricity availability (= 24 − blackouts)*



The figures represent district-level average winter-time electricity availability calculated using CU data from the winter months (November, December, January and February) during the winter crisis (2012 to 2015). Slope coefficients are displayed with corresponding standard errors in parentheses. Panel B includes only districts with less than 12 hours of daily winter-time electricity availability

period of the winter-energy crisis (2012 to 2015). However, this relationship disappears as the energy situation improves, which suggests that these spatial differences in exposure were associated with the initial shock and then gradually dissipated as Tajik infrastructure were adjusted to the new conditions. Again, the negative relationship is accentuated by a few districts that enjoyed close to 24 hours of winter-time electricity availability throughout the crisis and are classified as having experienced a low intensity of treatment. However, as indicated by panel B, the negative relationship is robust to the exclusion of such observations.

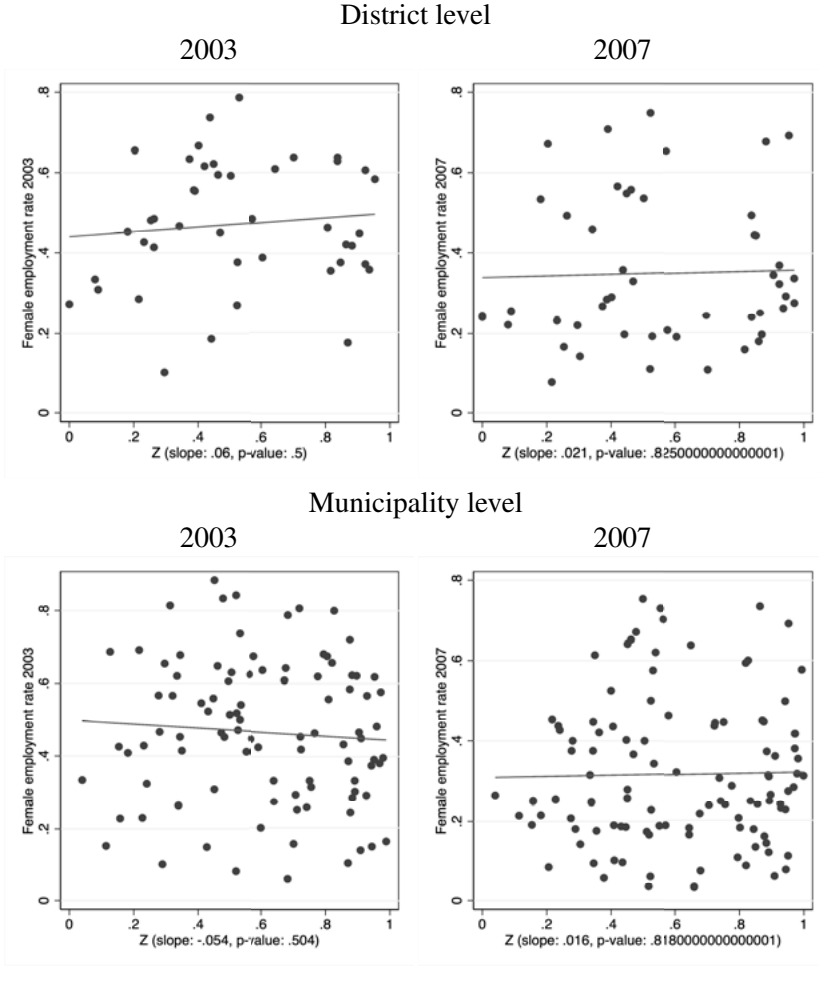
Figure I.26: *Z_d and winter-time electricity availability by season*



The figures represent district-level average winter-time electricity availability calculated using CU data from the winter months (November, December, January and February) corresponding to winter-seasons between 2012 and 2017. Slope coefficients are displayed with corresponding standard errors in parentheses. Panel B restricts the sample to the years of the energy crisis (2012-2015), and excludes districts with more than 15 hours of daily winter-time electricity availability

Figure I.27 and I.28 illustrate the correlation between the nighttime light index Z_d and district level female labor force participation (of women aged 15-49), as well as and a number of other economic outcomes measured prior to the energy crisis. Figure I.27 uses district aggregates derived from the pre-treatment surveys in 2003 and 2007. While there are large differences in average female labor force participation between districts (ranging between approximately 10 and 80 percent), it does not appear to be strongly correlated with Z_d.

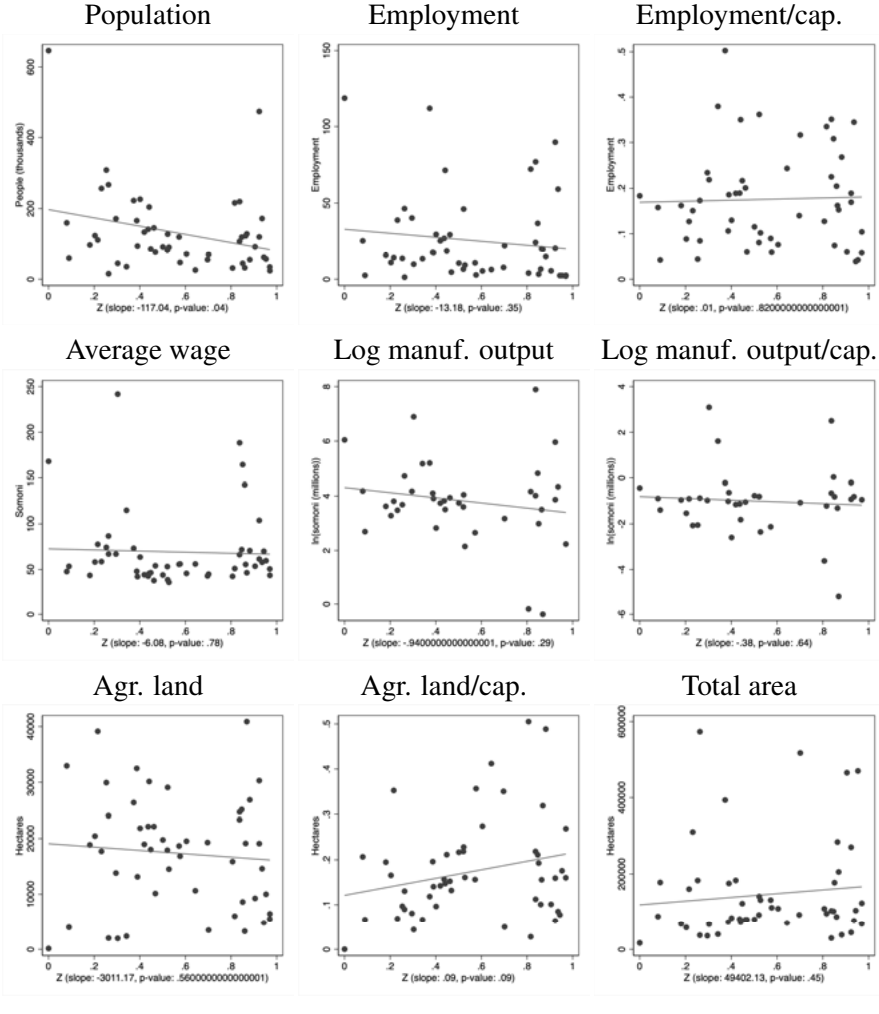
Figure I.27: *Correlation with pre-treatment female employment rates*



The aggregate statistics used in figure I.28 are published at the district level by TAJSTAT and include population, manufacturing output, wages and employment. The data is from 2005 (the earliest year for which district-level statistics are available). The figures show that Z_d is relatively evenly

distributed with regard to most of the pre-treatment characteristics. Z_d is somewhat negatively correlated with initial population size of the districts, partly due to the influence of the capital city of Dushanbe itself. However, Tajikistan's two largest population centers can be identified at different sides of the scale: the capital city Dushanbe with a population size of 646 0000 ($Z_{dushanbe} = 0$) and the northern Ghafurov district (including the regional capital Khujand) with a population size of 473 0000 ($Z_{ghafurov} = 0.94$).

Figure I.28: *Correlation with various district-level outcomes*



Appendix I.H A Theoretical Example

In this section, I draw up a simple example of how access to electricity could increase female labor supply though improvements in home productivity. The reasoning is analogous to theories of structural change that emphasize the role of agricultural productivity improvements in releasing labor for the industrial sector (See e.g. Johnston and Mellor (1961), Timmer (1988) and Gollin et al. (2002)), and draws on elements from Matsuyama (1992). The economic decision maker is a household with two members: one male and one female. The household is endowed with one unit of labor for each household member, which is divided between the labor market and home production. Male labor exported to the market l_m is exchanged for market consumption goods c at the rate w, whereas the corresponding rate for female labor l_f is δw. The parameter $\delta \in (0,1)$ represents the ratio between the female and male wage rate.[27] Male and female labor is also used interchangeably to produce domestic goods with the home production function $d = a \times f(l)$, where $l = 2 - l_f - l_m$ expresses total labor devoted to home production and a represents a linear productivity term in home production. The home production function is continuously differentiable and satisfies the standard conditions of positive but decreasing marginal productivity, $f'(l) > 0$ and $f''(l) < 0$, as well as $\lim_{l \to 0} f'(l) = \infty$. The household derives utility from the consumption of market goods c and domestic goods d, and chooses a feasible consumption bundle $\{c,d\}$ by allocating labor between the labor market and home production. Preferences are given by a non-homothetic Stone-Geary class utility function, which for simplicity is assumed to take the logarithmic shape (but any function of this class can be used). The household decision thus consists in choosing l_f and l_m to solve the following maximization problem:

$$\begin{aligned} \max_{l_f, l_m} \quad & ln(c) + ln(d - \gamma) \\ \text{where} \quad & d = af(2 - l_m - l_f) \geq \gamma \\ \text{and} \quad & c = l_m w + l_f \delta w \end{aligned} \tag{I.8}$$

subject to the resource constraint requiring that l_f and l_m are both confined to the closed unit interval. The parameter γ imposes a minimum subsistence requirement on the consumption of domestic goods. To ensure that the subsistence requirement can be met, it is further assumed that $0 < \gamma \leq af(2)$. It is clear from I.8 that for any $\delta \in (0,1)$ there exist no internal solution where both household members are simultaneously dividing their time between market and home production. In other words, at least one of the two household members will be fully specialized in one activity. This result captures the general pattern, although somewhat exaggerated, of the division of labor within Tajik households. When $\delta < af'(1)/(af(1) - \gamma) < 1$, the problem has a corner

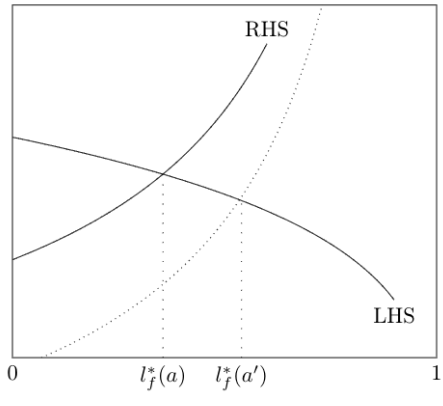
[27] For example, $\delta = 0.6$ implies that the female wage rate is 60% of the male wage rate, which would be consistent with the observed (unadjusted) gender wage gap in the Tajik labor market.

solution where both household members are fully specialized in one activity each. For the purpose of this exercise, however, I will consider only the case where $\delta \geq af'(1)/(af(1)-\gamma)$. Under this condition, the problem has a unique interior solution with regard to female labor, such that $l_m^* \in (0,1)$ and $l_m^* = 1$ by inference. The optimal allocation of female labor can then be expressed by taking the first order conditions of I.8 and rearranging:

$$f(1-l_f^*) = f'(1-l_f^*)\left(\frac{1}{\delta}+l_f^*\right)+\frac{\gamma}{a} \tag{I.9}$$

Note that the left-hand side of equation I.9 is strictly decreasing, while the right-hand side is strictly increasing with respect to l_f. Therefore, in order to balance the equation the optimal female market labor supply must increase with a (home productivity), and decrease with γ (the subsistence requirement for domestic goods). The female to male wage ratio, as manifested in δ, is positively related to female labor supply. Therefore, improvements in home productivity and improvements in the relative wages of female to male workers can have similar effects on female employment. [28] Figure I.29 simulates two possible solutions to equation I.9 using two different levels of home productivity. As illustrated, all else being equal, $a' > a$ implies that $l_f^*(a') > l_f^*(a)$.

Figure I.29: *Illustration of the equilibrium*



The result described by equation I.9 can be summarized in three intuitive mechanisms that determine female labor supply: wage disadvantages facing women in the labor market (δ), which affect the opportunity cost of domestic work; the subsistence requirement (γ), which affects the basic demand for domestic goods; and home productivity (a), which affects the labor required to produce a given quantity of domestic goods. This stylized example illustrates

[28] It can be noted that the overall wage rate does not affect the optimal female labor supply in this example. However, this follows from the logarithmic utility function and is not a general result.

that, if domestic goods are necessity goods, and if the public provision of electricity increases the productivity of labor in home production, then electricity provision can release female labor from unpaid domestic work and increase female labor market participation.

II. Small-Scale Mining and Agricultural Development: Evidence from Northwestern Tanzania

I would like to express my gratitude to Niklas Bengtsson, Mikael Elinder, Mounir Karadja, Annika Lindskog, Raoul van Maarseven, Eva Mörk, Anna Tompsett, as well as to the members of the ASWEDE network and UCFS group in Uppsala for helpful comments and suggestions.

II.1 Introduction

Small-scale mining is rapidly changing the economic landscape across rural Sub-Saharan Africa. In many areas it has become the largest source of employment outside agriculture, and millions of people currently depend on it for their livelihoods. But what role do non-farm activities like small-scale mining play in the poor and predominantly agricultural economies where they emerge? While Bazillier and Girard (2020) find that small-scale mining has positive spillover effects on consumption in nearby rural communities, little is still known about its wider economic consequences. For instance, small-scale mining and its associated activities can bring new employment opportunities and higher returns to labor, but is also frequently associated with negative environmental consequences, hazardous work conditions, and child labor. Therefore, small-scale mining could have theoretically ambiguous and offsetting effects on key development indicators such as educational investments and health. Furthermore, small-scale mining could have ambiguous effects on local agriculture. Small-scale mining could harm agriculture through land degradation and water pollution, and could also cause a general retreat from agricultural production as farmers reallocate their household resources to more productive purposes. However, several papers have also proposed small-scale mining is complementary with agriculture (see e.g. Hilson, 2016). Mining incomes can alleviate credit constraints and provide smallholder farmers with an informal insurance. Therefore, it is possible that small-scale mining could increase agricultural investments and lead to more input intensive farming practices. This question relates to a broader discussion about the existence of positive within-household spillovers from the rural non-farm sector to smallholder farming in Sub-Saharan Africa, and, more generally, to the relationship between agriculture and rural industries in the early stages of economic development.

In this paper, I produce new evidence from the recent gold mining boom in northwestern Tanzania to study how the emergence of rural industries, in the form of small-scale mining sites, affected the economic activities of local populations. The expansion of the small-scale gold mining sector in Tanzania over the last two decades has much in common with similar developments taking place in other mineral-rich Sub-Saharan African countries. It was fueled by rising gold prices and largely driven by migrant miners and prospectors seeking to discover and develop new gold deposits across the countryside. The pursuit of new mineral deposits to exploit generated sudden surges of small-scale gold mining activity in some rural locations, whereas similar locations nearby could remain largely unaffected. I take advantage of the resulting spatial and temporal variation in mining activity to estimate how the emergence of small-scale mining influenced the consumption, investment, and agricultural production decisions of nearby households. I use geocoded data on small-scale mining licenses issued by the Tanzanian Ministry of Energy and Min-

erals (MEM) to track the emergence of new mining sites, and combine this data with household data from three waves of the Tanzanian National Panel Survey collected in 2008, 2010 and 2012. Together, the household survey data and mining register data allows me to observe the outcomes of approximately one thousand households in northwestern Tanzania over time, and measure their responses as new small-scale gold mining sites appear across the rural landscape. The estimation framework relies on a generalized difference-in-differences methodology, which compares changes in the outcomes of households located close to where new mining sites emerge to changes in the outcomes of households located further away.

The results indicate that the emergence of small-scale gold mining causes nearby households to reduce their agricultural output by allocating fewer resources to agricultural production. When new mining sites emerge, the total value of agricultural output produced by households within a 10 km radius decreased by roughly TSh 140 000 (about USD 100) compared to other households, which corresponds to about one third of the average value of output. The negative effect on output appears to be driven by households allocating less resources to agricultural production across all input categories; including land, labor, and other farm inputs. Furthermore, this reallocation does not appear to be accompanied by any improvements in agricultural productivity or technology adoption. Simultaneously, households that are exposed to small-scale mining experience significantly increased levels of consumption. When new mining sites emerge, the average monthly per-capita food consumption of nearby households increases by roughly TSh 14 000 (about USD 10) compared to other households. Furthermore, the emergence of small-scale mining does not appear to have any observable negative effects on the school attendance or health outcomes of children in nearby households, which may suggest that the often-discussed potential harms of mining are offset by the positive income effect. These results support the hypothesis that small-scale mining can improve the welfare of local populations, but speak against the existence of significant positive spillovers from the non-farm sector to smallholder agriculture. Despite anecdotal evidence that many households across rural Sub-Saharan Africa use income from small-scale mining and other off-farm activities to finance agricultural investments, it thus appears that Tanzanian households in general substitute away from traditional agricultural activities when alternative sources of employment become available.

II.2 Background

The term *small-scale mining*, or *artisanal and small-scale mining* (ASM), is often used to describe a subset of mining activities that is distinguishable in methods and scope from so-called *industrial mining*, or *large-scale mining* (LSM). Industrial mining is characterized by capital-intensive techniques in-

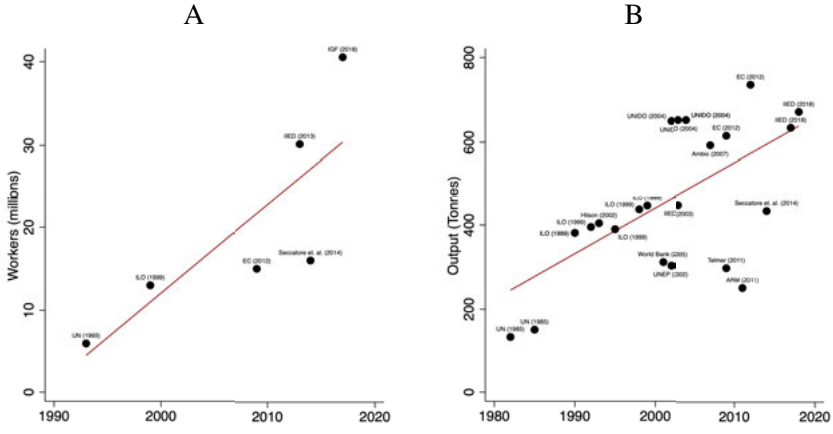
volving heavy machinery and skilled labor, and in mineral-rich developing countries the industrial mining sector tends to be a highly productive sector compared to the surrounding economy. However, the scope for employment in this sector tends to be limited, and industrial mining operations therefore often have a minor impact on local labor markets. Small-scale mining, by contrast, is characterized by comparatively limited capital investments, labor-intensive techniques, and the exploitation of smaller mineral deposits that are less suitable for mechanized extraction. The small-scale mining sector produces only a small fraction of total mining output in most countries, but it tends to employ large numbers of workers of various skill levels. As a consequence, despite making a comparatively modest contribution to national accounts, the impact of small-scale mining on local labor markets may significantly exceed that of the industrial mining sector. In some sub-Saharan African countries, Seccatore et al. (2014) estimate that small-scale mining directly employs between 2 and 6 percent of the population[1], and recent estimates by the IGF (2017) suggest that small-scale mining now may directly employ as many as 40 million workers globally (see figure II.1). While exact figures are hard to come by, it is clear that the small-scale mining sector dwarfs industrial mining in terms of total global employment. Simultaneously, mall-scale mining represents only a small fraction of global mining output.

The recent rise of small-scale mining has attracted the attention of researchers of various disciplines, and generated a wealth of qualitative evidence describing its economic and social impact on local communities. This literature highlights the importance of small-scale mining as a source of livelihood for many, but also discusses a number of challenges posed by this industry. For instance, small-scale mining is associated with environmental degradation and deforestation (e.g. Tarras-Wahlberg et al., 2000; Hilson, 2002b; Ghose, 2003; Hilson and Pardie, 2006; Telmer and Veiga, 2009; Hirons, 2011; Bansah et al., 2018; Hook, 2019), hazardous working conditions and adverse health impacts (e.g. IIED, 2013; WHO, 2016; Ajith and Ghosh, 2019; Afrifa et al., 2019; Cossa et al., 2021), child labor and negative effects on schooling (e.g. Hilson, 2008; Hilson, 2012; Potter and Lupilya, 2016; O'Driscoll, 2017; Bansah et al., 2018), and it has been connected with crime and violence (e.g. Bansah et al., 2018; Zvarivadza and Nhleko, 2018; Schwartz et al., 2021).[2] Furthermore, it

[1] According to Seccatore et al. (2014) ASM employed roughly 16 million people worldwide in 2013 and produced approximately 400 metric tonnes of gold, which is approximately 15% of total world production reported by US Geological Survey (2013). His estimates suggest that ASM then employed a significant share of the population in Sierra Leone (6.4%), Central African Republic (6.5%), DRC (4.1%), Zimbabwe (3.8%), Liberia (3.4%), Mali (2.2%), and Tanzania (2.1%).

[2] Small-scale mining has also been linked with organized violence, especially in settings with weak government institutions. This notion is captured by the notion of 'conflict minerals', which implies a causal relationship between the existence of (small-scale) mining rents and increased risks of political instability and armed conflict (see e.g. IIED, 2013; Berman et al., 2017).

Figure II.1: *Estimates of global small-scale gold mining employment and output*



Note: Markers represent estimates from the previous literature on (A) the global number of workers in small-scale gold mining, and (B) the global output of small-scale gold mining. The red line represents a linear trend. Sources: UN (1985), UN (1993), ILO (1999), Hilson (2002a), Bank (2005), UNEP (2002), UNIDO (2004), IIED (2003), Swain et al. (2007), Telmer (2011), ARM (2011), EC (2012), IIED (2013), Seccatore et al. (2014), IIED (2018a) and Delve (2022)

has also been speculated that small-scale gold mining could adversely affect the agricultural sector, which often is the primary source of livelihood for rural populations near small-scale mining areas. Case studies from Tanzania (Kitula, 2006), Zimbabwe (Ncube-Phiri et al., 2015), Ghana (Obiri et al., 2016), and Mozambique (Mujere and Isidro, 2016) propose that small-scale mining could harm agriculture through water pollution and land degradation, and Hilson and Laing (2017) discuss how the rise of gold mining in Guyana caused labor movements that led to the virtual collapse of Guyana's sugar industry.

Despite the rich literature on this topic, there has been little effort so far to use quantitative research designs for causal inference, which means that the overall local economic impact of small-scale mining remains elusive. A recent paper by Bazillier and Girard (2020) is the sole exception, finding that, in Burkina Faso between 1998 and 2014, a one percent increase in the gold price raised the consumption level of households in small-scale mining areas by roughly 0.12%, which suggests that small-scale mining has significant positive economic spillovers on local populations. However, several questions remain open. Small-scale gold mining could provide employment for some, while harming the livelihoods of others, and the evident risks to human capital development posed by child labor and health hazards could be offset by less conspicuous income effects that are likely to go in the opposite direction (Santos, 2018; Ahlerup et al., 2020). Similarly, Ofosu et al. (2020) notes

that, while small-scale mining could harm local agriculture by causing environmental damage or competing for scarce resources, it could also have positive spillover effects. J. B. Jønsson and Fold (2011) argues that surplus from mining may be used to improve agricultural productivity. In fact, case study evidence from sub-Saharan Africa suggest that farmers in small-scale mining areas often use supplementary mining incomes to purchase agricultural inputs[3] Several authors, including Rosenzweig and Wolpin (1993), Banerjee and Duflo (2005), and Karlan et al. (2014), have emphasized poor credit and insurance markets as an important obstacle to agricultural development in developing countries. In this context, as suggested by Ellis (1998), Barrett et al. (2001) and Haggblade, P. Hazell, and Reardon (2010), the rural non-farm sector can offer opportunities for income diversification and liquidity that promote a more intensive use of agricultural inputs. The *income effect* associated with improved employment opportunities (such as small-scale mining) may thus allow liquidity constrained households to expand agricultural production. However, emerging alternative sources of employment may also cause households to substitute away from agriculture as they seek the higher returns for their labor. Therefore, if agricultural labor cannot be freely replaced with machinery (or some other non-labor substitute), the *substitution effect* associated with higher labor costs will drain the local agricultural sector of workers and reduce agricultural output.[4]

The effects of small-scale mining on local agriculture is thus related to a broader discussion about the relationship between the non-farm sector and agriculture during the early stages of economic development, and the potential for growth spillovers (or positive "farm-nonfarm linkages") between the two sectors.[5] There is little direct empirical evidence on how the growth of rural non-farm industries affects agriculture in developing countries. However, several papers have studied how participation in rural non-farm activities is correlated with agricultural input expenditure at the household level. Savadogo et al. (1994) find that non-farm income is positively correlated with the formation of farm capital among smallholder farmers in Burkina Faso (specifically equipment for animal traction), and that it contributes positively to land and labor productivity. Similarly, Oseni and Winters (2009) find that households in rural Nigeria with access to non-farm earnings spend significantly more on agricultural inputs compared to other households. Diiro (2013) find similar

[3]See e.g. Maconachie and Binns (2007) in Sierra Leone; Kamlongera (2011) in Malawi; Hilson and Garforth (2012) in Mali and Ghana; Mkodzongi and Spiegel (2019) in Zimbabwe

[4]It should be mentioned that in a closed economy, where food (being a necessary good) cannot be imported from surrounding areas, this effect would be counteracted by rising food prices, which is why development macroeconomists since Lewis (1954) have generally considered agricultural productivity growth to be a prerequisite for large-scale industrialization.

[5]This discussion goes back at least to the 1980's (see e.g. Haggblade, P. Hazell, and Brown, 1989; P. B. Hazell and Haggblade, 1990; Reardon, 1997; Delgado et al., 1998; Barrett et al., 2001; Haggblade, P. B. Hazell, et al., 2007; Haggblade, P. Hazell, and Reardon, 2010)

results for Uganda. Maertens (2009) finds that Senegalese households that engage in off-farm wage labor spend more on agricultural inputs and achieve higher agricultural output compared with other households. More recently, a paper by Dedehouanou et al. (2018) finds that off-farm self-employment is positively correlated with expenditure on agricultural inputs among farmers in rural Nigeria. The evidence that emerges from these studies is consistent with a dominant income effect, which means that households with access to non-farm sources of employment use the additional income to invest in agriculture and expand production. However, this literature has struggled to motivate a causal interpretation of the results due to the difficulty of finding exogenous variation in non-farm sector employment opportunities and the endogeneity of households decisions to participate in such activities. An ideal experiment to study the local effects of rural non-farm industries on agricultural production decisions would instead randomly distribute non-farm industries across space, and then compare outcomes between households that get access to non-farm employment (treatment) and those that do not (control). In this paper, I argue that the unpredictable spread of gold discoveries across north-western Tanzania between 2008 and 2012 provides a natural experiment that approximates this ideal in the case of small-scale gold mining.

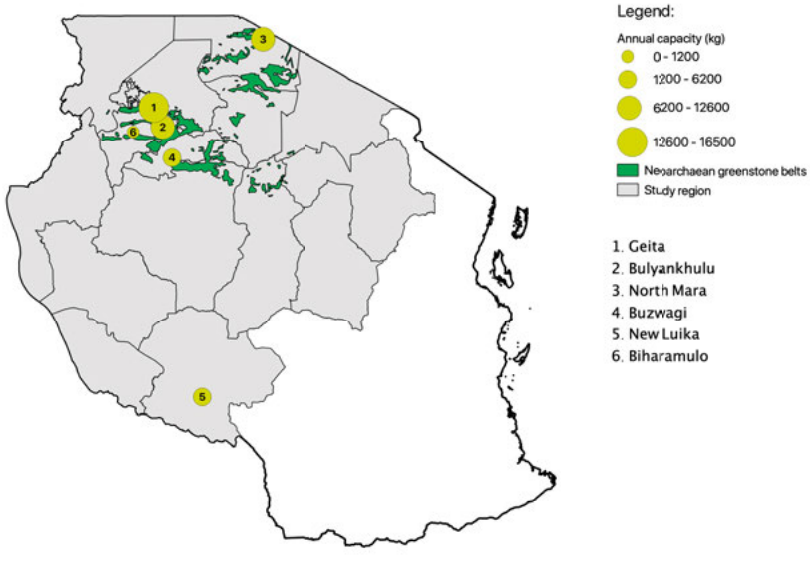
II.3 Setting

The gold mining sector in Tanzania can be traced back to the German colonial period when the first gold discoveries were made around Lake Victoria, yet it is only recently that gold has become an important component of the Tanzanian economy. Tanzania's total annual output of processed gold has increased rapidly from about 0.4 tonnes in 1998 to about 46 tonnes in 2015, and Tanzania is now among the more prominent gold producers in Africa.[6] In a pattern typical of mineral-rich developing countries, the rise of the gold mining sector in Tanzania has been characterized by a distinct dualism. While the majority of extraction is performed by mining companies operating large-scale industrial mines (see figure II.2), there also exist a vast number of small-scale gold mines scattered across the countryside. The exact extent of the small-scale mining sector in Tanzania is uncertain, but its economic impact has been growing. The Tanzania Ministry of Energy and Minerals (MEM, 2012) estimates that the total number of small-scale miners roughly quadrupled between the late 1980s and 2010, and recent estimates range between 700 000 and 1 500 000

[6]In 2015, Tanzania produced roughly 1.5% of the world's total output of processed gold. In the same year, the value of Tanzania's gold exports was roughly $1.3 billion. This means that gold accounted for roughly one fifth of Tanzania's total export value, and more than 95% of its mineral exports.

(see e.g. World Bank, 2015; Hilson, 2016; Mutagwaba et al., 2018).[7] By contrast, in 2015 the entire large-scale mining and quarrying industry of Tanzania directly employed only around 30 000 workers, which means that small-scale mining, even by conservative estimates, accounts for more than 95 percent of mining employment in Tanzania (see appendix II.A.1 for descriptive statistics). However, in terms of output, the relationship between small-scale and large-scale mining is reversed. Small-scale mining produces only about 10 percent of Tanzania's total gold output (World Bank, 2015), which reveals the stark productivity difference between the two sectors.

Figure II.2: *Major gold mines in Tanzania*



Source: US Geological Survey (2015). Note: Most gold mining in Tanzania takes place on the greenstone belts located in the north-west around Lake Victoria. The major mining companies in Tanzania include: Barrick Gold, which operates the Bulyanhulu, Buzwagi and North-Mara mines; AngloGold Ashanti, which operates the Geita mine; and Shanta gold, which operates the New Luika Mine.

[7] These estimates roughly match official statements by Tanzania's Minister of Energy and Minerals, who estimated that small-scale mining employed more than one million workers in 2014, which would imply that small-scale mining engages approximately 2% of Tanzania's population to some extent (Muhongo, 2015). However, it should be noted that the conventional estimates of the total number of gold miners in Tanzania have criticized in a recent survey by IPIS (2018). The authors of this paper performed manual counts of the number of workers at a number of small-scale mining locations in the districts of Geita, Mara, Shinyanga and Kigoma, and suggest that the commonly accepted estimates of the mining population may be inflated by as much as 40-60%. However, even these lower estimates suggest that gold mining is a very significant sector in terms of employment.

As previously discussed, small-scale mining has often been criticized for its association with hazardous working conditions, frequent use of child labor, and negative environmental impacts. Several case studies have studied these issues in the Tanzanian context. For example, Straaten (2000), Appleton et al. (2004) and Bose-O'Reilly et al. (2008) discuss human exposure to mercury used in small-scale gold mining in the north-western districts of Tanzania; Bråtveit et al. (2003) study the risk of chronic pulmonary diseases due to dust exposure in small-scale mining in the Simanjiro district; and Potter and Lupilya (2016) study child labor in small-scale gold mining in the Geita district. Issues such as these, in combination with the difficulty of effectively taxing small-scale mining operations, have historically led policymakers in sub-Saharan Africa to treat the sector with suspicion or hostility (Fisher, 2007; Banchirigah and Hilson, 2010). In recent decades, however, many governments in the region have come to increasingly recognize the potential role of small-scale mining for poverty alleviation and gradually moved toward a policy of legalization and formalization. In Tanzania, this formalization process can be said to have started with the 1998 Mining Act, which first introduced formal mineral rights for small-scale mining operators.[8] Furthermore, the Tanzanian national strategy for growth and poverty reduction (MoF, 2005; MoF, 2010) now includes explicit support to the small-scale miners, and a number of reforms and government programs have been directed toward strengthening the institutions and legal frameworks surrounding the small-scale mining sector. However, despite considerable efforts, the formalization process has progressed slowly, and the small-scale mining sector is still largely belongs to the informal economy (see e.g. Mwaipopo et al., 2004; Fisher et al., 2009; Aizawa, 2016).

The legal structure of small-scale mining in Tanzania is centered around so-called Primary Mining Licenses (PMLs). These licenses are required by law for all mine operations with capital investments below USD 100 000. They grant the holder the exclusive right to prospect and mine for minerals within an area of up to 10 hectares for a period of 7 years. PML's are issued on a "first come, first served" basis by the Ministry of Energy and Minerals (MEM) and are reserved exclusively for Tanzanian citizens. During the time period covered in this paper (2008-2012), the cost of applying for a PML was TZS 50 000 (about USD 30), to which is added an annual fee of TZS 80 000 (about USD 50) per hectare (MEM, 2015). However, despite the existing legal framework, the small-scale mining sector in Tanzania remains highly informal in practice. In addition to the fees, which can be prohibitively high for some small-scale miners, the application procedure itself presents an obstacle. For example, the 2010 Mining Act requires all PML applicants to draw up environmental

[8]The subsequent 2010 Mining Act is currently the main legislation governing small-scale mining in Tanzania. It is similar to the 1998 Act, but reduced the fees and eased the application procedures for small-scale miners seeking to secure formal mineral rights.

protection plans and to submit annual reports to the MEM. There are few control mechanisms in place to ensure that the operations on the ground match the submitted documents, but the formal requirements can pose a barrier to entry for people without bureaucratic experience. The licensing system has therefore tended to favor economic and political elites, who are able to secure the formal mineral rights when new discoveries are made (IPIS, 2018; IIED, 2018b). Often, these individuals lack the knowledge and willingness to carry out small-scale mining operations themselves. Therefore, it is common practice for PML holders to informally sub-lease the actual extraction to professional miners, so-called "pit owners" or "mine owners", that have experience in small-scale mining. The pit owners organize the mining activities on the ground, and are responsible for practically all aspects of operating the business, including the initial investments at the mining site, acquisition of equipment and hiring of workers. This also means that pit-owners take on most of the operational risks. In some cases, the pit owner and the MPL holder are the same person. In general, however, the formal side of the business represented by the PML holder (who is legally responsible for compliance with government mandated environmental and safety standards) is disconnected from the actual mining operation on the ground.

The informal character of small-scale mining in Tanzania means that the obligations between PML holders, pit owners and mine workers are rarely outlined in written contracts. In practice, however, the details of these relationships are strictly regulated by informal agreements and social norms that are remarkably consistent across time and space. For example, mining proceeds are generally distributed through elaborate output-sharing agreements that allocate to each participant a pre-defined share of the total output produced in a given period. A number of independent case-studies from mining sites in Tanzania suggest that the standard division gives about 30% of output to the PML holder, 40% to the pit owner, and 30% to be divided as wages among the mine workers (Mwaipopo et al., 2004; J. B. Jønsson and Fold, 2009; IPIS, 2018). Many small-scale mining enterprises are complex organizations that contain various types of workers, ranging from unskilled laborers, such as hoistsers and ore crushers, to skilled specialists, such as explosives experts, mine technicians and engineers. Unskilled labor is sometimes recruited from the local countryside, whereas the specialized labor tends to be supplied be full-time migrating workers. Workers are hired to dig the gold ore out of the mining pits, to crush the rocks into a fine dust and to separate the gold particles by sluicing, panning or through chemical processing. Mine workers are typically supplied with food during their period of employment, and wages are paid in the form of bags of gold ore, which workers can process themselves or sell to

merchants.[9] The share of output allocated to an individual mine worker varies based on the level of specialization, as well as the risks and discomfort associated with the particular task. For instance, skilled workers such as drillers receive a larger share than hoistsers, and workers employed underground in the mining pits receive a larger share than similarly skilled workers employed on the surface.

Despite the "small-scale" epithet, small-scale mining operations vary significantly in size, and may contain anything between a handful of workers to several thousand. A survey by IPIS (2018) found that among 337 small-scale gold mines and processing sites in north-western Tanzania, the largest site in the sample hosted around six thousand workers, while the median site employed 30 workers. The average labor returns to small-scale gold mining in Tanzania is uncertain, but independent qualitative field studies by Bryceson and J. Jønsson (2013) and IPIS (2018) both suggest typical monthly incomes of roughly 100 USD. This implies that the labor income of small-scale gold miners is approximately double the average wage rate in agriculture.[10] The higher earnings offered by mining are also likely to raise the local equilibrium wage rate of other occupations. Phillips et al. (2001) noted in an early paper on Tanzanian small-scale mining that the reservation wage of what they refer to as "menial labor" appeared to be between 4 to 6 times higher in mining areas compared to non-mining areas. However, differences in average wages do not necessarily reflect a wage-premium in mining, as workers may sort themselves into or out of the mining sector based on individual characteristics, such as ability or luck, which makes direct comparisons inappropriate. Yet, for those workers who can access the opportunities offered by small-scale gold mining, either directly or indirectly, the qualitative evidence suggests considerable income advantages over the traditional agricultural activities that dominate economic life in rural Tanzania.

II.4 Data and Empirical Strategy

The empirical strategy of this paper combines data on mining activities with household survey data to identify the effect of mining on nearby populations. I use register data on Primary Mining Licenses (PMLs) from the Tanzanian Ministry of Energy and Minerals (MEM) to track the expansion of small-scale mining across north-western Tanzania between 2008 and 2012. This data is

[9] The true gold content of individual bags can vary substantially, and is generally unobservable. Therefore, the selection of bags tends to be a crucial event for miners. J. B. Jønsson and Fold (2009) notes that religious rituals and sacrifices sometimes are carried out to increase the chances of selecting the most valuable bags.

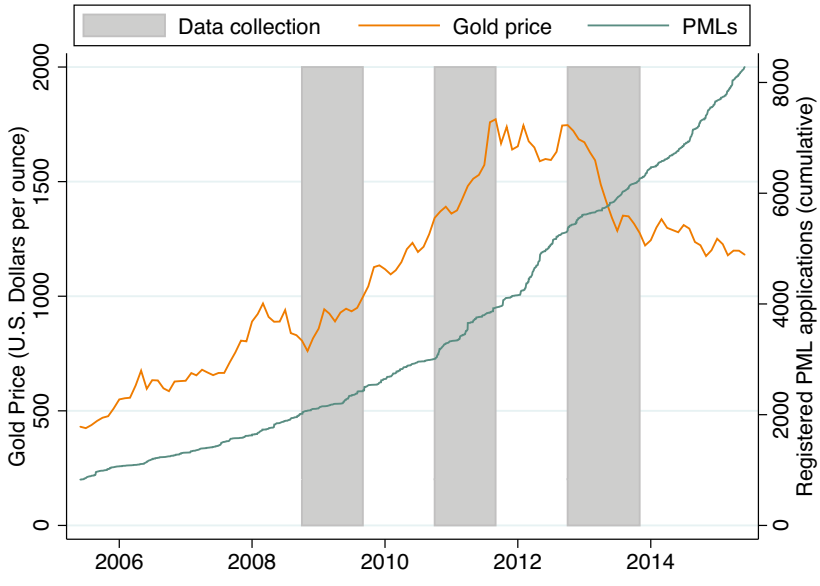
[10] See Nerman (2015) for details on rural wages in Tanzanian agriculture. However, since the market wage generally exceeds the shadow wage of household labor in agriculture, the average income difference between farmers and small-scale gold miners is likely higher.

combined with household survey data from three consecutive waves of the Tanzania National Panel Survey (NPS). The NPS is a series of household surveys conducted by the Tanzania National Bureau of Statistics, which makes it possible to follow the outcomes of individual households and household members over time. The survey uses a stratified multi-stage cluster sampling design to produce a sample that is representative at the national level. Interviews for the first survey round were conducted between October 2008 and September 2009 and included 3 265 households in total. These households were revisited in two subsequent survey rounds conducted in 2010/2011 and 2012/2013. In cases where households moved or split up, the individual household members were tracked down and added to the sample along with members of the new household. Among households visited in the first round, about 87% are observed in all three periods . The small-scale mining sector expanded rapidly across north-western Tanzania during the time period covered by the panel (2008 to 2012). Figure II.3 shows the cumulative frequency of PML applications submitted to the MEM. The gray bars indicate the data collection period for the three NPS survey waves. The figure also illustrates the world market price for gold. The rising gold price is often cited as one important contributing factor to the growth of the small-scale mining sector across Sub-Saharan Africa in this period.

The NPS covers a range of social and economic topics, and in particular it provides detailed information on household agricultural activities. The agricultural outcomes studied in this paper refer to the "Masika" season, which is the main agricultural season in Tanzania that coincides with the long rains that usually span between March and May.[11] This survey data makes it possible to track the agricultural decisions and outcomes of individual households over time as the small-scale mining sector expanded across the countryside. Therefore, this paper focuses on the gold producing regions in North-Western Tanzania. Specifically, I restrict the sample to households belonging to the administrative regions of Dodoma, Arusha, Mbeya, Simiyu, Geita, Katavi Singida, Tabora, Rukwa, Kigoma, Shinyanga, Kagera, Mwanza, Mara and Manyara (the study region is illustrated in figure II.4). These regions contain all significant gold ore deposits in Tanzania, according to MEM maps, and contain more than 95% of all known gold occurrences. The sample is also restricted to households that are observed in all three survey waves, resulting in a balanced

[11] The NPS also asks respondents to report agricultural outcomes from the last "Vuli" season, which is the secondary agricultural season associated with the short rains around November and December. However, due to the timing of data collection the Vuli-season outcomes reported in the surveys can refer to different years depending on the date of the interview. Furthermore, Vuli season outcomes are only relevant for part of the sample (specifically households located along the Northern and Eastern border) that are affected by the bi-modal agricultural cycle. Therefore, limiting the analysis to the main Masika season provides more consistent agricultural outcomes for comparison across time and space. However, it should also be noted that the results are robust to pooling Vuli and Masika season outcomes.

Figure II.3: *Data collection, gold price and PML applications*

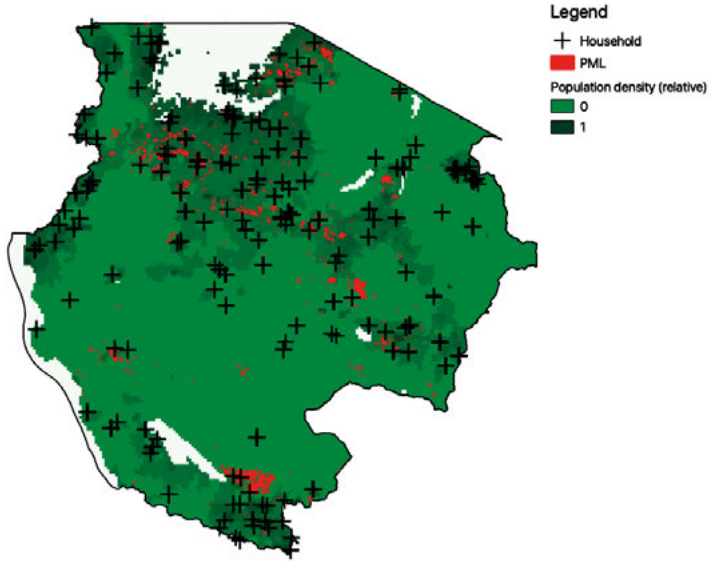


Note: the gray bars represent the period of data collection for the three waves of the Tanzania National Panel Survey: 2008/09, 2010/11 and 2012/13. The Green line represents the cumulative number of registered PML applications. The yellow line represents the world market price of gold in USD/ounce (Source: COMEX).

panel consisting of roughly one thousand (965) households observed in three time periods.

The PML data contains information on 11 888 licenses issued by the MEM between August 1999 and October 2018. The licensing system for small-scale mining was introduced by the 1998 Mining Act requires all small-scale miners to obtain PMLs specifying their areas of operation. The PML register includes detailed information about the geographical boundaries of each small-scale mining concession, as well as the names of applicants, the date of application was received, the date when the PML was granted, and the number of times the license has been renewed. Figure II.4 shows the geographical distribution of PMLs across the study region, as well as the location of NPS survey clusters. Over the study period, the number of PMLs increased significantly. Between the start of data collection in the first NPS wave (October 2008) and the end of data collection in the third wave (November 2013), roughly 5000 new PMLs were issued for small-scale gold mining, covering a total area of about 40 000 hectares.

Figure II.4: *Geographic distribution of PMLs and households*

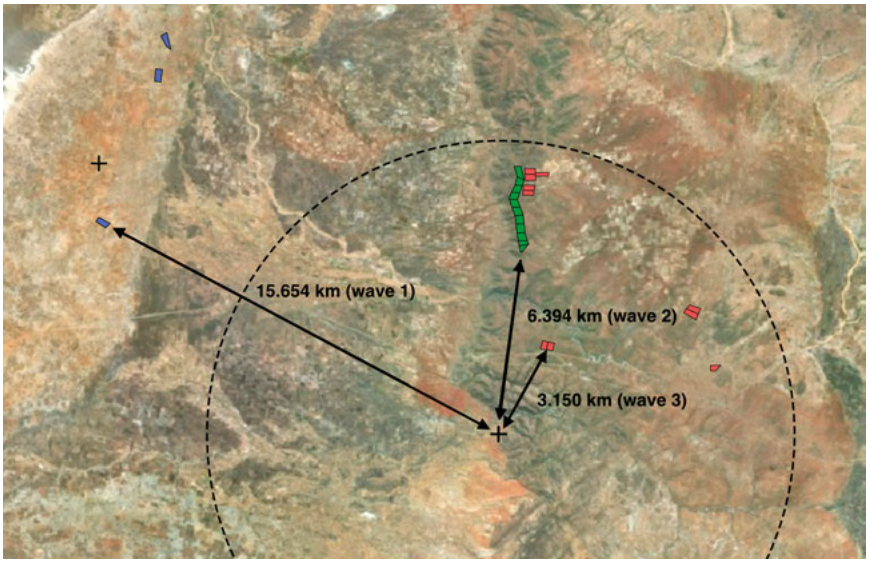


Note: The map illustrates the geographical distribution of Primary Mining Licenses and NPS sampling clusters across the study area

The identification strategy of this paper exploits changes in the geographical distribution of small-scale gold mining sites over time resulting from new gold deposits being discovered. The expansion of mining sites meant that the small-scale mining sector reached into new locations over the course of the three survey waves, which makes it possible to compare changes in the outcomes of households that become exposed to small-scale mining to those that

remain unexposed. In order to define exposure, I calculate the geographical distance between each household and the closest PML application in each survey wave. Since the number of PMLs is monotonically increasing over the study period, this distance is monotonically decreasing. Figure II.5 illustrates an example of how the distance between a household and its closest PML decreases between each survey wave. At some point, the distance to the closest PML may be small enough that the household can be considered to become exposed to small-scale mining and get access to the employment opportunities it offers. I define this threshold to be 10 kilometers. This means that households that have a PML within a 10 kilometers radius of their location are considered to be exposed to small-scale mining (i.e. to the "treatment"), whereas households that do not have a PML within a 10 kilometers radius of their location are considered to be not exposed.[12]

Figure II.5: *Distance to the closest mining location*



Note: Blue, Green and red areas represent PML applications existing at the beginning of data collection for wave one (2008), two (2010) and three (2012) of the NPS. The + symbol indicates household locations. The dotted circle illustrates a 10 kilometer threshold from one such location.

Of the total sample of 965 households, 95 were within 10 kilometers of a PML in the first wave, 102 in the second wave, and 150 in the third wave. This means that the identifying variation is derived from 55 instances of households changing treatment status due to the emergence of new mining locations in their near vicinity. The estimation framework uses a difference-in-differences

[12] As the 10 kilometer threshold is arbitrary (like any threshold), a range of thresholds is used to test the robustness of the results to alternative treatment definitions.

approach that includes household and time fixed effects to control for unobservable time-invariant household heterogeneity and time-specific common shocks. I use a "stacked-by-event" approach following Cengiz et al. (2019) to avoid potential issues associated with staggered treatment designs in the presence of heterogeneous treatment effects, which can be a source of bias in traditional two-way fixed effects models.[13] I create two event-specific data sets, each containing all observations from the households that entered treatment at a specific time (i.e. between the first and the second wave, or between the second and the third wave), as well as all observations from households that remained untreated throughout the three waves (the clean controls). I then pool (or "stack") these event-specific data sets to create the final data set. This procedure essentially transforms the original three-period setting with staggered treatment into a two-group, two-period design that is robust to heterogeneous treatment effects.

The main empirical specification is then given by:

$$y_{i,t,e} = \beta M_{i,t,e} + \gamma_{i,e} + \delta_{t,e} + \varepsilon_{i,t,e} \quad , \tag{II.1}$$

where $y_{i,t,e}$ represents the outcome of household i at the time t belonging to the event-specific dataset e. $M_{i,t,e}$ is a binary treatment variable representing exposure to small-scale mining. It is equal to one (or zero) for observations where the closest PML application is located at a distance less (or more) than 10 km from the household's location. To account for potentially endogenous migration decisions, I use the household's location in the first wave when calculating distances. $\gamma_{i,e}$ and $\delta_{t,e}$ represent household-event and time-event fixed effects. The effect of small-scale mining on the outcome y is captured by the coefficient β, which estimates the change in y for households that come within proximity of a PML compared to other households. This coefficient captures the average treatment effect on the treated (ATT), under the assumption that the treatment status is as good as randomly allocated conditional on the household and time fixed effects, i.e. that $\mathrm{E}(\varepsilon_{i,t,e}|M_{i,t,e}, \gamma_{i,e}, \delta_{t,e}) = \mathrm{E}(\varepsilon_{i,t,e}|\gamma_{i,e}, \delta_{t,e})$. Without true randomization, the credibility of this assumption is essential to the internal validity of the estimates. One way to indirectly test this assumption is to consider pre-treatment trends. In order to study pre-trends, as well as dynamic treatment effects, I therefore estimate an event-study specification

[13] I prefer the stacked-by-event approach since it is robust to treatment effects that change over time within treated units, which can invalidate the standard difference-in-differences assumptions for causal inference in settings where there are $T > 2$ periods and treatment is staggered (Athey and Imbens, 2018; Sun and Abraham, 2020; De Chaisemartin and d'Haultfoeuille, 2020; Imai and Kim, 2021; Goodman-Bacon, 2021) That said, I also estimate simpler two-way fixed effects specification which generates very similar results. I also use the diagnostics tests proposed by Jakiela (2021) and conclude that the bias caused by heterogeneous treatment effects is not likely to be severe in this case.

given by:

$$y_{i,t,e} = \sum_{k=-1}^{k=1} \beta^k \hat{M}^k_{i,t,e} + \gamma_{i,e} + \delta_{t,e} + \varepsilon_{i,t,e} \quad , \tag{II.2}$$

where $\hat{M}^k_{i,t,e}$ is a dummy variable indicating observations occurring k periods after the first time period when the household is observed after becoming treated (such that $\hat{M}^{-1}_{i,t,e}$ indicates units observed who entered treatment between time t and $t+1$, $\hat{M}^0_{i,t,e}$ indicates units who entered treatment between time $t-1$ and t, and $\hat{M}^1_{i,t,e}$ indicates units who entered treatment between time $t-2$ and $t-1$). In all the main specifications adjust the standard errors for clustering at the village level, but in appendix II.B I also allow for arbitrary forms of spatial correlation using household coordinates. Finally, to measure the sensitivity of the results to different thresholds of "proximity", I estimate a modified version of equation II.1 that includes additional 10 km intervals between 10 and 40 km:

$$y_{i,t,e} = \sum_{j=1}^{j=4} \beta^j \tilde{M}^j_{i,t,e} + \gamma_{i,e} + \delta_{t,e} + \varepsilon_{i,t,e} \quad , \tag{II.3}$$

where $\tilde{M}^j_{i,t,e}$ is a dummy variable indicating whether a household i in time t is located within $j \times 10$ kilometers of a small-scale gold mining site.

II.5 Results

II.5.1 The Effect of Small-Scale Mining on Agricultural Output

Table II.1 presents the effect of exposure to small-scale mining on agricultural output. The estimates correspond to β in equation II.1, and thus capture how the agricultural output of a household changes, on average and relative to other households, after a small-scale gold mining site emerges within a 10-kilometer radius. The main specification presented in column 1 indicates that, as new mining sites emerge, the total value of output of nearby households decreased by about TSh 140 000 (roughly USD 100) relative to other households. This corresponds to about one quarter of households' total annual value of output. Columns 2 and 3 decompose this result into an intensive and extensive margin effect. The intensive margin effect is captured by column 2, which restricts the sample to households that cultivate some land in each of the three survey waves. This estimate is slightly smaller but not significantly different from that presented in column 1. Column 3 uses a linear probability model, where the dependent variable indicates whether the household produced any agricultural output at all. The estimate is imprecisely estimated but negative, indicating

Table II.1: *Effect of Mining on Output*

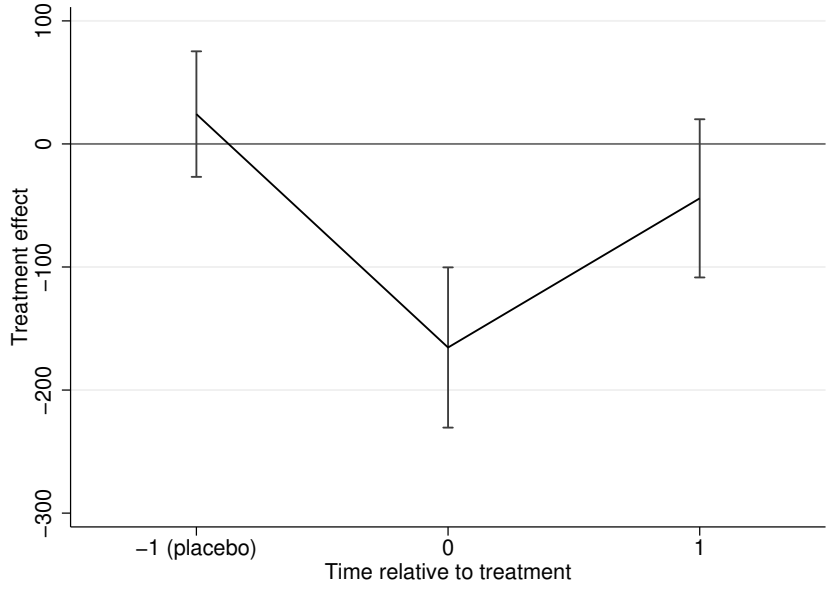
Measure:	Imputed			Self-reported			
Outcome:	Value of output		Any outp.	Value of output		Value of sales	
Sample:	Farms any	Farms All	Farms any	Farms any	Farms All	Farms any	Farms All
Model:	(1)	(2)	(3)	(4)	(5)	(6)	(7)
M (10km)	-155.2***	-146.1**	-0.052	-106.6**	-72.6	-90.8***	-91.9**
	(47.1)	(68.9)	(0.077)	(52.1)	(77.4)	(27.1)	(38.0)
R-squared	0.42	0.43	0.49	0.37	0.36	0.47	0.47
Observations	4977	3492	4977	4977	3492	4977	3492

Note: All models include year-event and household-event fixed effects. The independent variable is defined M = 1 for households within 10 km of registered PML applications. The labels "farms any/all" refer to households that cultivate some land in any/all of the three time periods. Agricultural outcomes refer to Masika season. Amounts in TSh (thousands) $\approx$ 0.7 $USD. R^2 accounts for the fixed effects. Standard errors in parentheses are adjusted for clustering at the village level: *** p < 0.01, ** p < 0.05, * p < 0.1.

that households become about 5 percentage points less likely to produce any output when new mining sites emerge in the vicinity.

In order to measure the value of output, the main specification relies on a method used by Gollin and Udry (2021), whereby the value of households' agricultural output is imputed using revealed prices from agricultural sales. A distribution of prices is calculated for each crop using the quantities and revenue reported by households corresponding to the sale of each crop. The median crop price (by location) is then multiplied with the reported quantity of harvested crops for households to obtain the total value of crops produced. This imputation method produces a measure of output that reflects the total value of harvested crops, while being less sensitive to subjective differences in the individual assessment of crop values. An alternative method would be to use the households' self-reported valuations of the total value of the harvest or value of crop sales. This approach is used in columns 4-7. Columns 4-5 use the self-reported value of harvest. This measure may suffer from different biases in subjective valuations and the difficulty of valuing output that is consumed within the household itself. Columns 6-7 instead use self-reported value of sold crops. This outcome is likely to suffer less from subjective differences in valuation (as farmers may report the observed sales price), but has the disadvantage of only capturing the part of output which reaches the market. It can also include output that is carried over from previous agricultural seasons. For these reasons, the imputed value of output is used in the main specifications presented in columns 1-2. The results are reproduced using a standard two-way fixed effects approach and a method proposed by De Chaisemartin and d'Haultfoeuille (2020) in appendix II.B.

Figure II.6: *Effect of Mining on Output: pre-trends and dynamics.*

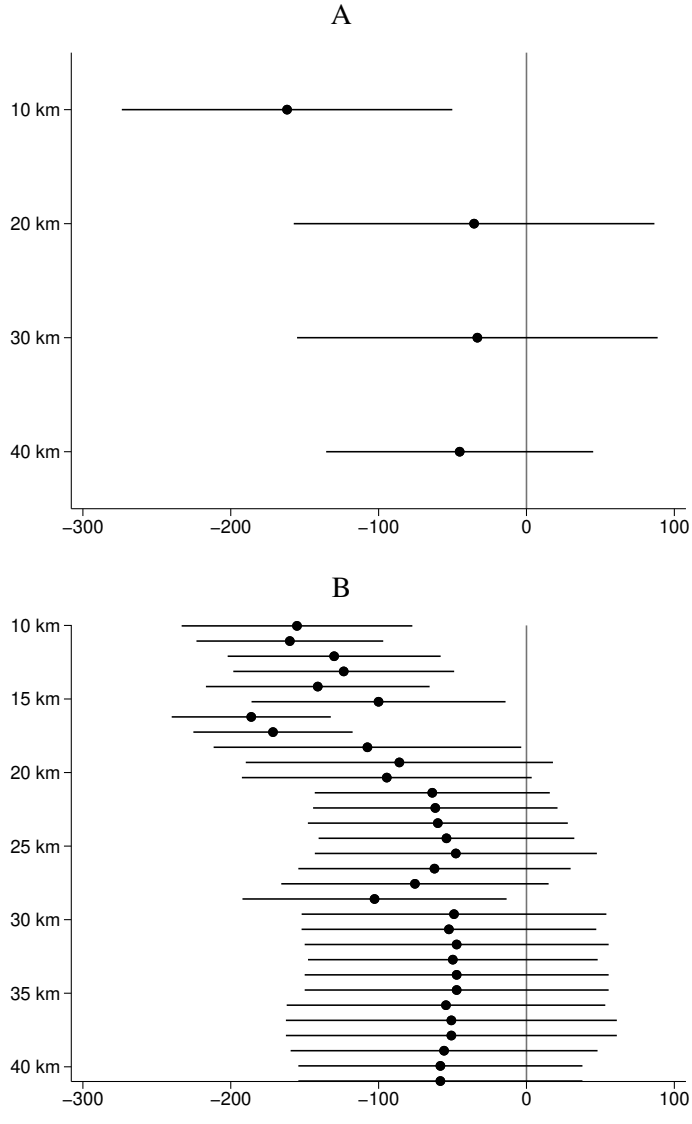


Note: Estimates measured on the y-axis represent the β^k coefficients obtained from estimating equation II.2 on the value of agricultural output. Vertical bars represent 95% confidence intervals. Amounts in TSh (thousands) $\approx$ 0.7 $USD. Standard errors in parentheses are adjusted for clustering at the village level: *** p < 0.01, ** p < 0.05, * p < 0.1.

The main result presented in column 1 of table II.1 suggest that households that become exposed to small-scale gold mines (the treatment group) reduce their agricultural output relative to households that did not (the control group) after becoming exposed. This relative change can be interpreted as a causal effect of small-scale mining on output, if one assumes that the treatment and control groups would have experienced similar developments if small-scale mining had not expanded. This assumption cannot be evaluated directly, as the counter-factual outcomes of the treatment group are unobservable. However, since all households are observed three times, and many are observed twice before entering into treatment, it is possible to introduce a placebo treatment one period before the true timing of treatment to test this assumption indirectly: diverging trends prior to the treatment would suggest that the parallel trends assumption is violated and cast doubt on the validity of the empirical approach. The three-period structure also makes it possible to estimate a dynamic treatment effect using lags of the treatment variable. Figure II.6 presents a graphical illustration of the results obtained from estimating equation II.2 on the total value of output. These coefficient estimates are comparable to those presented in column 1 of table II.1. The placebo estimate is close to zero and not statistically significant. This means that the treatment and the control groups evolved similarly before treatment, and indicates that the parallel trends assumption cannot be rejected. Furthermore, figure II.6 indicates that the negative effect on output is concentrated in the period directly following treatment (i.e. 0-2 years after the emergence of a small-scale gold mine nearby). Two periods after treatment (i.e. 2-4 years after the emergence of a small-scale gold mine nearby), the effect remains negative, but the estimate is smaller.

The 10 km threshold distance used to define proximity and exposure to mining sites is somewhat arbitrary. Therefore, panels A and B of figure II.7 illustrates the effect of small-scale mining on agricultural output when using different distances. Panel A presents the results obtained from estimating equation II.3, which includes four 10 km distance intervals spanning 10 and 40 km of proximity to small-scale mining sites, i.e. $d \in (0,10)$, $d \in (10,20)$, $d \in (20,30)$, and $d \in (30,40)$. Panel B instead illustrates the treatment effects obtained from repeatedly estimating equation II.1 using different thresholds (between 10 and 40 km) to define proximity to small-scale mining sites. In both cases, the sample includes households that farmed in any of the three waves and the outcome variable is the imputed value of agricultural output, which means that the estimates are comparable to those presented in column 1 of table II.1. In both cases, the results show that the treatment effect is generally confined to the lower range of distances. This provides some support for the identification strategy of this paper and suggests that the 10-kilometer threshold used in the main specifications is reasonable. In figure II.8 in appendix II.A I show how the share of treated households changes with different thresholds.

Figure II.7: *Effect of Mining on Output: different thresholds*



Note: In panel A, markers represent the β^k estimates obtained by estimating equation II.3 (and are thus obtained from a single regression model). In panel B, markers represent the β estimates obtained by estimating equation II.1 repeatedly using different treatment thresholds (and are thus obtained from separate regression models). Horizontal lines represent 95% confidence intervals.

II.5.2 Mechanisms Related to Production Decisions

The evidence presented in table II.1 (and figures II.6 and II.7) suggest that the emergence of small-scale mining causes the local agricultural sector to contract. In this section, I argue that this relationship is proximately explained by changes in households' resource allocation. In particular, households that become exposed to small-scale gold mining appear to devote less basic inputs to agricultural production.

Table II.2: *Basic inputs: land and labor*

Dep.var:	Land (acres)		Labor (days)		Labor by activity (days)		
					Planting	Weeding	Harvest
Sample:	Farms any	Farms All	Farms any	Farms All	Farms any	Farms any	Farms any
Model:	(1)	(2)	(3)	(4)	(5)	(6)	(7)
M (10km)	-1.10***	-1.28***	-16.8**	-16.3*	-8.40**	-5.04	-8.17
	(0.20)	(0.20)	(6.72)	(9.30)	(3.90)	(4.25)	(8.06)
R-squared	0.58	0.60	0.44	0.40	0.35	0.42	0.24
Observations	4977	3492	4977	3492	4977	4977	4977

Note: All regressions include year-event and household-event fixed effects. The labels "farms any/all" refer to households that cultivate some land in any/all of the three time periods. Agricultural outcomes refer to Masika season. R^2 accounts for the fixed effects. Standard errors in parentheses are adjusted for clustering at the village level: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table II.2 reports the effect of small-scale mining on land and labor used in agriculture. The estimates presented in columns 1 and 3 indicate that households cultivate approximately one acre less, and use approximately 17 fewer labor days in agriculture (including own and hired labor) after becoming exposed to small-scale mining. For reference, these effects correspond to roughly one third of the mean number of acres cultivated, and about one fifth of the mean number of labor days (as per the Masika season of 2012). The estimates presented in columns 2 and 4 report that the effect remains when the sample is restricted to households that cultivate some land in each of the three time periods, which suggests that the intensive margin effect is driving this relationship. The estimates presented in columns 5-7 decompose the effect on labor inputs by the type of activity (planting, weeding, harvesting), and shows that the negative effect is relatively evenly distributed across activities. In particular, the negative effect on days spent in planting and on cultivated land suggests that the reduction in agricultural output is due to substitution away from agriculture, rather than, for example, reductions in productivity or increased crop losses. In the heterogeneity analysis presented in appendix II.C.1, I show that the reduction in agricultural labor can be observed for both men and women, and is primarily driven by individuals below 30 years of age.

The reduction in basic agricultural input use is accompanied by a parallel decrease in input expenditure, but also a significant increase in household consumption. Column A1 of table II.3 indicates that households reduce their total expenditure on agricultural inputs by roughly 36 000 TSh when new small-scale mining sites emerge nearby, which corresponds to around a quarter of the mean expenditure in this time period. Columns A2-A6 decomposes this effect by categories of expenditure. The negative effect is visible across all categories, but is statistically different from zero only in the case of seeds and land rents. The negative effect on input expenditure contrasts with the positive effect on consumption, as presented in columns B1-B6. Column B1 indicates that households increase their average monthly consumption by roughly 78 000 TSh when new small-scale mining sites emerge nearby. This positive effect is mainly driven by increasing food consumption, as shown in column B2. It is similar in magnitude to the effects found by Bazillier and Girard (2020) in Burkina Faso.[14]

The positive effect on food consumption suggests that the observed local reduction in agricultural output is compensated by food produced elsewhere, which means that other areas in Tanzania and abroad could experience increased demand for agricultural output. The descriptive statistics presented in appendix II.7 show that, in the sample covered by the Tanzania NPS, agricultural production in general increased between 2008 and 2012 (the average area cultivated increased by roughly 17 %). Therefore, it is possible that the estimates presented in this paper are influenced by general equilibrium effects going in the opposite direction, which might cause farmers in non-mining areas to expand their agricultural output to a greater extent than they would have done without the rise of small-scale mining. Such general equilibrium effects are certain to exist to some extent and may contribute to the results of this paper. However, they are unlikely to explain the full local effects of small-scale mining. The estimate presented in column B5 also suggests a negative effect on household expenditure related to transportation. This is consistent with the notion that proximity to small-scale mining creates more local opportunities for trade and reduces the need to travel far distances for employment.

As discussed in section II.2, it has been observed that farmers often use mining incomes to finance the purchase of various agricultural inputs, such as fertilizers or seeds. While the evidence presented so far suggest that total input expenditure actually declines, it is still possible that small-scale gold mining facilitates the adoption of productivity-enhancing agricultural technologies. In particular, if households use income from non-farm activities to finance a technological transition, then the observed reduction in agricultural output and

[14]The consumption figures used to produce these estimates are adjusted for local differences in consumer prices using an index provided by the Tanzanian National Bureau of Statistics to better reflect changes in real consumption. However, the effects do not appear to be driven by relative price changes. Alternative specifications using different consumption measures are explored in appendix II.D.

Table II.3: *Household consumption and agricultural input expenditure*

Panel:	A					
Dep.var:	Agricultural input expenditure					
	Total	Seeds	Fertilizers	Pesticides	Wages	Rents
Model:	(1)	(2)	(3)	(4)	(5)	(6)
M (10km)	-35.7***	-7.52***	-9.28	-3.12	-11.5	-4.32**
	(11.6)	(2.55)	(5.61)	(1.94)	(7.57)	(2.04)
R-squared	0.46	0.20	0.51	0.16	0.29	0.24
Observations	4977	4977	4977	4977	4977	4977
Panel:	B					
Dep.var:	Consumption (per adult equivalent)					
	Total	Food	Education	Health	Transp.	Other
Model:	(1)	(2)	(3)	(4)	(5)	(6)
M (10km)	77.8**	66.3***	0.042	3.81	-7.69	15.3**
	(33.4)	(24.1)	(3.17)	(6.00)	(8.11)	(6.45)
R-squared	0.54	0.42	0.56	0.12	0.36	0.52
Observations	4975	4975	4975	4975	4977	4977

Note: All regressions include year-event and household-event fixed effects. Consumption includes the value of food produced by the household itself and is corrected for local consumer price differences using an index provided by the Tanzanian Bureau of Statistics. Amounts in TSh (thousands) $\approx$ 0.7 \$USD. Agricultural expenditure refer to Masika season. R^2 accounts for the fixed effects. Standard errors in parentheses are adjusted for clustering at the village level: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

basic inputs could distract from deeper technological changes that can improve agricultural productivity in the long run. Table II.4 evaluates this possibility by studying the use of various agricultural technologies. Columns A1-A7 include the full sample of households, whereas columns B1-B7 use households that cultivate some crops in each of the three survey waves. The outcome variables indicate whether the household made any use of the technology in the Masika season of the relevant year. The results show that, with the tentative exception of fertilizer use presented in column B2, there is little evidence that the emergence of small-scale mining sites led to increased technology adoption.

Table II.4: *Technology: advanced inputs and techniques*

Panel:	A					
Sample:	Farms any					
Dep.var:	Improved seeds	Fertilizers	Pesticides	Draft animals	Machinery	Any (1-5)
Model:	(1)	(2)	(3)	(4)	(5)	(6)
M (10km)	-0.12**	0.017	-0.039**	-0.050	-0.026	-0.10*
	(0.051)	(0.048)	(0.018)	(0.047)	(0.064)	(0.059)
R-squared	0.29	0.47	0.31	0.58	0.36	0.52
Observations	4977	4977	4977	4977	4977	4977
Panel:	B					
Sample:	Farms all					
Dep.var:	Improved seeds	Fertilizers	Pesticides	Draft animals	Machinery	Any (1-5)
Model:	(1)	(2)	(3)	(4)	(5)	(6)
M (10km)	-0.098	0.087*	-0.040	0.053	0.0054	-0.068***
	(0.074)	(0.049)	(0.026)	(0.11)	(0.13)	(0.026)
R-squared	0.32	0.48	0.32	0.58	0.38	0.51
Observations	3492	3492	3492	3492	3492	3492

Note: The dependent variables in columns 1-5 indicate whether a technology was used in the Masika season. The dependent variable in column 6 indicates whether any of these technologies was used (and since technologies are not mutually exclusive estimates in columns 1-5 do not sum up to the estimate in column 6). All regressions include year-event and household-event fixed effects. The labels "farms any/all" refer to households that cultivate some land in any/all of the three time periods. R^2 accounts for the fixed effects. Standard errors in parentheses are adjusted for clustering at the village level: *** p < 0.01, ** p < 0.05, * p < 0.1.

II.5.3 Other Potential Mechanisms

The negative relationship between local small-scale mining activity and agricultural investments and output could simply be the result of households sub-

stituting away from agricultural production as better non-farm employment opportunities become available. However, before settling with this interpretation, there are some alternative explanations to consider.

First, it is possible that a new gold discovery may increase in-migration and affect farmers through the local land markets. In general, the geological properties of small-scale gold mining locations tend not to intersect directly with agricultural land, which means that small-scale mining operators might not compete directly with farmers for the same land resources. However, migration flows could still increase the general demand for land resources, as migrants need space for housing and other auxiliary activities surrounding the gold mines, which could spill over to the demand for arable land and generate a positive shock in land prices. From this perspective, the results of this paper could be explained entirely by changes in the land market, as local farmers sell some of their agricultural plots and consume the additional income (although the strong consumption response would be difficult to reconcile with standard economic theory as it appears to contradict the permanent income hypothesis). On the other hand, large flows of migrant miners could harm agricultural property values through increased encroachment, theft and damage to crops. While this mechanism cannot explain the observed positive effects of small-scale mining on consumption, it could provide a possible explanation for the general scale-down of agricultural production.

However, evidence from village-level migration data presented in table II.16 in appendix II.E suggest that the emergence of new mining sites had small and statistically insignificant effects on migration to survey villages. These results should not be interpreted as evidence of absence of migration in general (since new mining towns and temporary settlements next to the deposits may attract most migrant miners), but only suggests that there was no increase in migration to the original villages covered by the survey. Therefore, the people who already lived in areas where new small-scale mines open up might be somewhat less directly affected by migration than one could suspect. Instead, the results suggest a small decrease in out-migration, which may reflect a reduced need for workers to leave the village for employment elsewhere. This evidence is consistent with a longstanding notion that small-scale mining can reduce rural-urban migration by providing local employment to rural populations (See e.g. ILO, 1999; J. B. Jønsson and Fold, 2011; Barreto et al., 2018). Regarding the effect of small-scale mining on agricultural land markets, a lack of data makes it difficult to account directly for this mechanism. However, the NPS asks farmers to report both the approximate value and size of each plot, which can be used as a rough approximation of market value per acre. Using this measure, the findings presented in table II.18 in appendix II.E show that land values did not appear to increase as a result of the treatment, which means that the consumption response is unlikely to be the result of a positive wealth shock through rising property values. Furthermore, if the positive consumption effect was the result of rising land values (as opposed to improved

labor market opportunities), then one would expect the effects to be particularly concentrated among larger landowners. However, this does not appear to be the case. Instead, the heterogeneity analysis presented in table II.12 in appendix II.C suggests that the effect is particularly strong among households with small farms and poor access to communications (as measured by distance to major roads). The emergence of small-scale mining also does not appear to have large adverse effects on perceptions and experiences related to crime and safety. Table II.19 in appendix II.E reports a small negative estimated effect on satisfaction with crime and safety, but also a small negative effect on households' exposure to crop theft, both of which are statistically insignificant.

Another potential mechanism relates to the environmental impact of small-scale gold mining, which could harm the agricultural sector directly. Again, this explanation could potentially account for the declining agricultural output, but is difficult to reconcile with the fact that the same farmers who scale back production experience increased consumption. Therefore, while it cannot be ruled out that small-scale mining might harm agriculture through water pollution and land degradation, the environmental damage itself appears to be an unlikely explanation for the overall results of this paper. In addition to the environmental effects of mining on crops, one might worry that proximity to small-scale mining sites could have adverse effects on the health of local populations, especially children, whether they are directly engaged in mining activities or not. However, while the full health impact of small-scale mining are difficult to ascertain from existing data, the indicators provided in the NPS do not reveal any significant negative effects. First, as shown in table II.3, the emergence of small-scale mining sites did not appear to increase health-related expenditure despite increasing overall consumption levels. Second, a number of health indicators appear to improve as a result of the emergence of new small-scale mining sites. This is reflected in tables II.20 and II.21 in appendix II.F, which show some indications of positive effects on anthropometric health indicators among children.

However, it is important to note that the absence of evidence of negative health effects does not constitute evidence that such effects do not exist, especially since the range of observable indicators is limited. In particular, while the effects related to child, height, weight and BMI presented in appendix II.F may form the basis of a cautious optimism, they should be interpreted in light of the positive consumption effects whereby improvements in nutritional status could offset harms caused by small-scale mining that go in the opposite direction.[15] A similar combination of opposite effects could apply to schooling. While small-scale mining can attract child laborers who are diverted from school, it may also contribute to the household budget in ways that are conducive to educational investment. The results presented in table

[15]There is a well-documented positive relationship between income and nutrition-related health indicators in developing countries (see Bengtsson (2010) for evidence from Tanzania).

II.22 in appendix II.F suggest that the emergence of gold mines had no effect on the overall school attendance rate of children aged 0 to 20. However, when splitting the sample by children of primary and secondary school age, I find that the emergence of gold mines increased the primary school attendance rate (of children aged 0-13) by roughly 9 percentage points. I also find a negative but statistically insignificant effect on secondary schooling (of children aged 14-20) amounting to a 12 percentage point decrease in the attendance rate.[16] One possible explanation for these heterogeneous results is that the income effects of mining dominate among younger children (allowing households to afford more schooling), while the substitution effects dominates among older children (who are diverted from school by improved employment opportunities). However, the positive effect on primary school attendance suggests that the emergence of gold mining sites in North-Western Tanzania cannot be said to have overall negative effects on education.

II.6 Discussion: threats to internal validity

The key identifying assumption underlying the empirical strategy of this paper requires that any shocks to the outcomes that are not captured by the time fixed effects or household fixed effects must be uncorrelated with the timing of the emergence of small-scale mining operations. In other words, the strategy allows for unobserved cross-sectional heterogeneity that is constant over time and unobserved temporal shocks that are common to all households, but the timing of the emergence of small-scale gold mines should be approximately random from the perspective of nearby individual households. Since future mineral discoveries tend to be sudden and uncertain events that, by definition, are difficult to predict in advance, it is reasonable to assume that local populations would experience them as approximately random events in most cases. However, mineral discoveries are not truly exogenous events. In particular, they depend on the intensity of prospecting, which may be determined by a multitude of economic and social factors that vary at the local level. Therefore, it is impossible to ex-ante rule out the possibility of confounding variables that influence the likelihood of gold discoveries.

For example, extreme weather events like flooding could temporarily decrease the likelihood of new mineral discoveries, while simultaneously causing soil erosion and destroying crops. If that is the case, then failing to account for weather would cause the estimates to be biased. It is also possible that hu-

[16] This result is comparable in magnitude to the findings of Ahlerup et al. (2020), who find that, in a sample of 30 African countries, individuals who spent their adolescence in districts with gold mines tended to have lower educational attainment as adults, presumably due to higher instances of child labor. They find that the existence of a (large-scale) gold mine in the same district at age 12 reduces average educational attainment by 0.14 to 0.18 points on a scale between 0 (no education) and 9 (post-graduate education).

man interventions, such as road constructions, could make some areas more open to prospecting while also affecting local conditions for agricultural production. In appendix II.G I address some of these issues, and show that the results are robust to controlling for rainfall and changes in the distance to major roads. Another concern is that local agricultural outcomes could directly influence the probability of new gold deposits being discovered, which would lead to reverse causality. For instance, areas that suffer from a poor harvest due to inadequate rainfall or crop disease may experience increased prospecting activity as local farmers attempt to use gold discoveries to mitigate transitory income shocks. While this appears unlikely in practice, since high-risk and high-return activities like mineral prospecting tend to be a poor insurance strategy against short-run consumption risk, it does pose a theoretical challenge to the internal validity of the findings.[17] In appendix II.G, I address the issue of reverse causality by studying anticipatory effects of small-scale mining, and find no evidence that past agricultural outcomes or changes in consumption predict the emergence of new mining sites.

Another concern is that the results may be affected by endogenous attrition. For instance, the emergence of small-scale mines may cause some households to relocate or split up, and thereby decrease the probability that some households and individuals are successfully relocated in later survey rounds. Since households must be observed in all three rounds of the NPS to be retained in the sample, it is possible that households are endogenously selecting into and out of the sample based on whether they are exposed to small-scale mining. To address this issue, table II.26 in appendix II.G shows that, for the 1100 households observed in the study area in the original 2008 survey (among which 135 drop out due to attrition), future exposure to small-scale mining does not affect the probability of dropping out of the sample, which suggests that endogenous attrition is not a significant concern. However, the analysis also suggests that households already living in small-scale mining areas when first observed in 2008 tended to experience higher attrition rates compared to households in other areas. This finding is consistent with the notion that people living in mining areas tend to be more mobile and harder to track over time compared to other rural populations, but does not pose a threat to the empirical strategy of this paper.

Another potential threat to internal validity follows from issues related to measurement and the definition of the treatment variable. The treatment variable $M_{i,t,e}$ in equation II.1 indicates whether there exist at least one application for Primary Mining License within a 10 km radius of the household. This variable is designed to capture a household's exposure to the small-scale mining sector, but in order to fulfill this purpose, two crucial assumptions must hold.

[17] Apart from prospecting, many studies observe households seeking out existing mining operations to cope with adverse agricultural outcomes and poverty spells. This has given rise to a somewhat pejorative notion of small-scale mining as a "distress-driven" activity, but views diverge on the accuracy of this description (See Hilson, 2009)

First, the location and timing of PML applications must correspond reasonably well with the onset of actual mining activities at the given location, meaning that M is a good enough proxy for the presence of small-scale mining at the local level. For instance, some active mining operations may lack licenses, and some licenses may have no active mining operations. This could cause measurement error in M, which could lead to biased estimates. In general, it is not uncommon for small-scale mining to take place without a formal license. In some cases, the mining operation may be too small to motivate the effort required to obtain a license and the cost of around USD 30.[18] However, due to the low cost of obtaining a license and the large potential returns from PML ownership, it is unlikely that any significant mineral deposit that becomes public knowledge would long escape also becoming subject to a PML application. Therefore, it is reasonable to assume that the date when PML applications are submitted is closely linked to the timing of mineral discoveries. However, it is also possible that some PMLs applications observed in the data have been made in expectation of future gold discoveries that never materialize. Therefore, the data on PML applications does not provide a perfect measure of actual mining activity. To address this issue, I compare PML locations in the license data with the location of 337 verified gold mining and processing sites visited by IPIS (2018) in a recent survey. The results of this exercise are presented in appendix II.H, and indicate a close correspondence between confirmed sites and registered PML applications. This suggests that the registered PML applications provide a reasonable proxy for local small-scale mining activity.

A second issue relates to how households are assigned into the treatment group based on distance from mining locations. The 10 km buffer is intended to reflect the maximum distance most workers would be willing to travel for employment, and is a common threshold used in the literature. It is also broadly consistent with studies on daily mobility in Sub-Saharan Africa (e.g. Bryceson, Mbara, et al., 2003; Tanser et al., 2006). However, the threshold is somewhat arbitrary and ignores local characteristics of the terrain and transportation infrastructure. However, these factors would be difficult to account for without making additional arbitrary assumptions. Therefore, the 10 km buffer is preferred, even if it is not expected to exactly correspond with the true radius of treatment. To address test the sensitivity of the results to different thresholds, I also use different buffer distances ranging 10-40 km. This exercise is useful in two respects. First, it can detect whether the estimated effects are robust to small adjustments in the buffer threshold. If the empirical strategy is valid, then small changes to the threshold should not qualitatively affect the results. Second, the same exercise can be used to show that the

[18] In other cases, delays in licensing procedures cause miners to operate informally for extended periods until the PLM application is approved. To address this issue, I use the date of application rather than the date of issue when determining the time a PML appears.

estimated treatment effects are confined to definitions of treatment that are reasonable as to the distance to mining sites, and become less significant as the threshold distance is increased. This provides a sort of placebo test that can be used to indirectly evaluate the soundness of the identification strategy.

A third issue related to measurement follows from GPS offsetting. All coordinates for rural clusters provided in the NPS data have been subjected to a scrambling procedure that off-sets each coordinate by 0 to 5 km in a random direction. In addition, a randomly drawn sub-set consisting of 1% of rural observations are off-set by 0 to 10 km in a random direction. The noise introduced by these procedures mean that the observed treatment variable ($M_{observed}$), which is defined using the provided household coordinates, contains a random error component that can make it differ from the true variable (M_{true}). Since this is an example of classical measurement error, it will tend to bias the estimated effects toward zero. However, as the off-set distances are drawn from a known uniform distribution, it is possible to calculate the probability of miss-classification $\Pr(M_{observed} \neq M_{true})$ for each observation in the sample. In appendix II.I, I use a simple formula to calculate the probability of miss-classification associated with each observation in the sample, and use this information to investigate the potential bias introduced by measurement error. As expected, restricting the sample to observations with lower risk (or no risk) of miss-classification leads to somewhat larger estimated effects. Overall, this analysis shows that the measurement error introduced by GPS-offsetting does not appear to alter the results significantly.

II.7 Conclusions

The findings of this paper suggest that the expansion of small-scale gold mining in north-western Tanzania had a negative effect on the agricultural output of nearby households. Households that become exposed to small-scale mining reduce the amount of land, labor and variable inputs used in agricultural production, and thus allocate fewer resources to agriculture overall. However, the reduction in agricultural production is accompanied by significant improvements in consumption. The source of this additional consumption is not observable in the data, but a reasonable interpretation is that these households benefit from the direct and indirect income opportunities offered by the emergence of small-scale mining as they substitute away from agricultural production. The small-scale mining sector thus appears to significantly improve the economic welfare of nearby populations. Furthermore, I find no evidence of negative effects on the health outcomes of children, and no overall negative effects on schooling, which may be due to offsetting income effects. The main empirical results are summarized in table II.5.

While the evidence presented in this paper suggests a rivalry relationship between small-scale mining and agriculture at the local level, it does not rule

Table II.5: *Summary of main findings*

Outcome	Estimated effect				Mean	Unit
	Sign	Size	SE	95% CI		
Output	-	155.2	(47.1)	62.1 - 247.5	394.5	TSh (thousand)
Labor	-	16.8	(6.72)	3.6 - 30	83.6	Days
Cultivated land	-	1.1	(0.2)	0.7 - 1.5	3.98	Acres
Input expenditure	-	35.7	(11.6)	13 - 58.4	90	TSh (thousand)
Consumption	+	77.8	(33.4)	12.3 - 143.3	292.5	TSh (thousand)

out the possibility of other types of complementarities between the two activities. For instance, farmers may use intermittent mining incomes to smooth consumption between agricultural seasons, or to insure against future risk through increased income diversification. Such welfare effects cannot be captured in the context of this paper, but remains an important topic for future research. Finally, the findings of this paper contradict the hypothesis that non-farm activities have positive spillover effects on smallholder agriculture in sub-Saharan. I find no evidence that small-scale mining increases agricultural input investments or contributes to technology adoption. Instead, it appears that rural households make marginal adjustments away from agriculture when improved outside options become available. Therefore, while small-scale gold mining can improve the livelihoods of local farmers in the short- to medium run, it should not be expected to generate lasting improvements in terms of agricultural development.

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Appendices

Appendix II.A Descriptive Statistics

II.A.1 Aggregate Mining Statistics

Table II.6 presents key statistics on the Tanzanian large-scale mining sector between 1991 and 2007.

Table II.6: *Mining employment, production and exports*

Year	Employment in Mining and Quarrying	Gold output (Kg)	Value of gold exports (Million USD)
1991	.	3851	.
1992	.	3201	.
1993	.	3264	.
1994	.	2549	.
1995	.	320	0.1
1996	.	318	0.2
1997	.	8082	1.5
1998	.	6770	39
1999	.	4890	3
2000	.	15060	114
2001	5630	30088	206
2002	6007	43320	219
2003	.	48018	447
2004	.	48176	530
2005	8783	52236	696
2006	11724	47000	644
2007	11560	40193	627
2008	.	36434	810
2009	.	39112	819
2010	12125	39448	966
2011	11291	42300	1719
2012	15401	40650	1854
2013	17350	42534	1546
2014	24519	40481	2267
2015	30259	46008	2225
2016	35900	.	2241
2017	46226	.	1553

Sources: Tanzania National Bureau of Statistics (NBS), U.S. Geological Survey (USGS), United Nations International Trade Statistics Database (COMTRADE)

II.A.2 Descriptive Statistics from the NPS

Table II.7 presents descriptive statistics of key variables from the NPS survey.

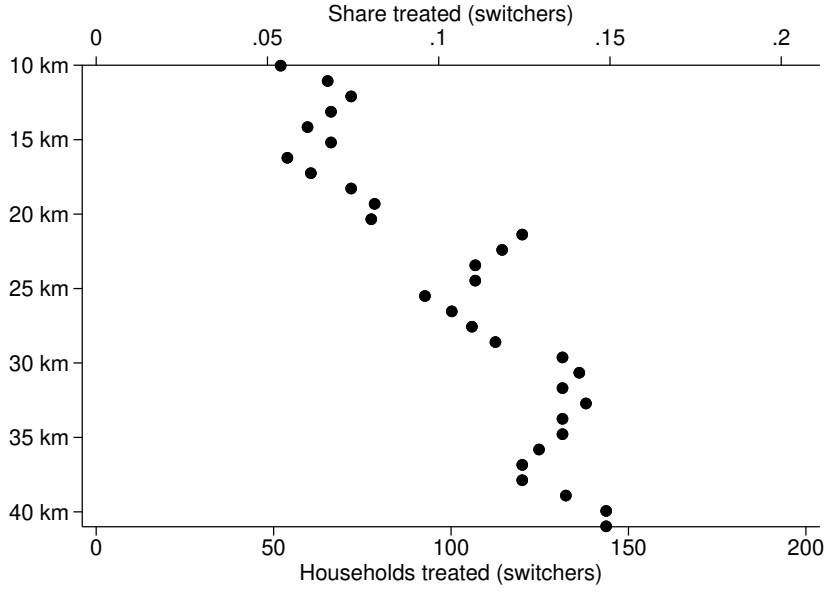
Table II.7: *Descriptive statistics*

	Wave 1 (2008)		Wave 2 (2010)		Wave 3 (2012)		Total (2008-2012)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Household size	5.39	2.66	5.80	2.85	5.90	2.99	5.70	2.84
Farming last Masika	0.83	0.38	0.77	0.42	0.80	0.40	0.80	0.40
Acres owned	3.97	4.00	4.95	6.71	5.70	10.9	4.87	7.75
Soil quality (0-1)	0.31	0.39	0.36	0.42	0.33	0.43	0.33	0.41
Acres cultivted	3.44	3.77	3.50	4.28	3.98	4.48	3.64	4.19
Output:								
Harvest value (imputed)	201.9	280.6	229.3	335.5	394.5	552.7	275.2	415.6
H. value (self-reported)	236.5	511.3	298.9	1113.6	446.6	831.0	327.3	859.0
Sales value	122.1	373.6	161.1	532.9	246.4	702.6	176.5	555.2
Harvest value (Vuli)	47.9	183.8	113.7	411.9	135.4	1020.9	99.0	645.2
Sales value (Vuli)	18.0	118.3	57.2	308.2	127.0	2535.2	67.4	1476.2
Labor:								
All	76.0	85.3	74.1	91.2	83.6	94.1	77.9	90.3
Planting	38.2	49.6	38.3	54.6	42.2	58.7	39.6	54.5
Weeding	35.7	46.0	34.3	47.8	42.1	51.8	37.4	48.7
Harvesting	35.7	46.0	34.6	62.8	41.0	69.7	37.1	60.4
Consumption (TSh):								
All	182.6	140.0	220.9	163.9	292.5	240.7	232.0	191.9
Food and beverages	131.6	92.5	158.1	109.4	213.4	169.8	167.7	132.7
Education	6.73	21.5	10.5	28.4	13.4	35.2	10.2	29.0
Health	9.14	26.3	8.75	17.7	12.7	31.3	10.2	25.8
Transport & comm.	14.4	39.4	18.2	37.4	24.3	52.8	19.0	43.9
Other	20.8	24.1	25.3	30.6	28.6	36.6	24.9	31.0
Input exp. (TSh):								
All	48.5	149.6	49.5	142.4	90.0	265.8	62.7	195.3
Seeds	5.62	13.6	6.24	19.9	13.2	35.4	8.37	24.9
Fertilizers	14.4	90.5	16.1	85.8	27.3	157.2	19.3	116.0
Pesticides	1.80	9.34	1.67	12.0	2.62	17.3	2.03	13.3
Wages	21.9	69.1	21.7	76.0	39.8	145.5	27.8	103.1
Land rents	4.81	32.0	3.83	21.7	7.00	40.6	5.21	32.4
Any tech	0.50	0.50	0.46	0.50	0.56	0.50	0.51	0.50
Technology:								
Improved seeds	0.13	0.34	0.11	0.31	0.31	0.46	0.18	0.39
Fertilizers	0.22	0.41	0.23	0.42	0.28	0.45	0.24	0.43
Pesticides	0.095	0.29	0.079	0.27	0.085	0.28	0.086	0.28
Draft animals	0.31	0.46	0.28	0.45	0.32	0.46	0.30	0.46
Machinery	0.15	0.36	0.15	0.36	0.15	0.36	0.15	0.36
M (10 km)	0.098	0.30	0.11	0.31	0.16	0.36	0.12	0.32
P	0.10	0.29	0.11	0.30	0.15	0.33	0.12	0.31
R	0.99	0.045	0.99	0.055	0.97	0.099	0.98	0.071
Observations	965		965		965		2895	

II.A.3 Share Treated at Different Thresholds

Figure II.8 illustrates the share and number of treated households from which the identifying variation is derived at different threshold distances (i.e. households that switch treatment status during the study period).

Figure II.8: *Number and share of treated households (switchers)*



Appendix II.B Alternative Estimation Methods

In table II.8, I reproduce the main results of this paper while adjusting the standard errors for arbitrary forms of spatial correction, as proposed by Colella et al. (2019), using thresholds at of 100 and 200 kilometers.

Table II.8: *Accounting for spatial correlation*

	Output	Inputs		Expenditure		Technology		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Harvest value	Cultiv-ated area	Days worked	Input exp.	Cons-umption	Impr. seeds	Fert-ilizers	Pest-icides
	A. Threshold: 100 km							
M (10km)	-155.2***	-1.11***	-16.8**	-35.7***	77.8***	-0.12**	0.017	-0.039*
	(29.1)	(0.23)	(6.78)	(9.56)	(29.4)	(0.051)	(0.044)	(0.022)
R-squared	0.61	0.72	0.63	0.64	0.69	0.53	0.65	0.54
Observations	4977	4977	4977	4977	4975	4977	4977	4977
	B. Threshold: 200 km							
M (10km)	-155.2***	-1.11***	-16.8***	-35.7***	77.8**	-0.12**	0.017	-0.039**
	(37.3)	(0.24)	(4.85)	(11.3)	(32.6)	(0.052)	(0.051)	(0.018)
R-squared	0.61	0.72	0.63	0.64	0.69	0.53	0.65	0.54
Observations	4977	4977	4977	4977	4975	4977	4977	4977

Note: All models include year-event and individual-event fixed effects. R^2 accounts for the fixed effects. Standard errors in parentheses are adjusted for clustering at the village level: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

In table II.9, I re-estimate the main results using a standard two-way fixed effects model. Columns 1-7 present the estimated effect of exposure to small-scale mining on agricultural output when using a standard two-way fixed effects strategy, as opposed to the stacked-by-event approach used in the main specification. The results are very similar to the main approach.

Table II.9: *Effect of Mining on Output (two-way FE)*

Measure:	Imputed			Self-reported			
Outcome:	Value of output		Any outp.	Value of output		Value of sales	
Sample:	Farms any	Farms All	Farms any	Farms any	Farms All	Farms any	Farms All
Model:	(1)	(2)	(3)	(4)	(5)	(6)	(7)
M (10km)	-141.1***	-136.5**	-0.049	-102.0**	-74.1	-80.2***	-82.4**
	(45.5)	(67.7)	(0.076)	(51.2)	(77.0)	(25.5)	(36.5)
R-squared	0.42	0.43	0.51	0.37	0.36	0.47	0.47
Observations	2856	1956	2856	2856	1956	2856	1956

Note: All models include year and household fixed effects. The independent variable is defined M = 1 for households within 10 km of registered PML applications. The labels "farms any/all" refer to households that cultivate some land in any/all of the three time periods. Agricultural outcomes refer to Masika season. Amounts in TSh (thousands) ≈ 0.7 $USD. R^2 accounts for the fixed effects. Standard errors in parentheses are adjusted for clustering at the village level: *** p < 0.01, ** p < 0.05, * p < 0.1.

In table II.10 I re-estimate the main results using the Stata-program provided by De Chaisemartin and d'Haultfoeuille (2020). Again, the results are similar to those obtained using the main specification.

Table II.10: *Effect of Mining on Output (C&H)*

Measure:	Imputed			Self-reported			
Outcome:	Value of output		Any outp.	Value of output		Value of sales	
Sample:	Farms any	Farms All	Farms any	Farms any	Farms All	Farms any	Farms All
Model:	(1)	(2)	(3)	(4)	(5)	(6)	(7)
M (10km)	-165.3	-171.0	-0.027	-77.0	-34.4	-60.4	-44.0
SE	76.1	56.7	0.082	68.9	81.3	30.6	49.6
P	0.016	0.0015	0.37	0.13	0.34	0.025	0.19

Note: The labels "farms any/all" refer to households that cultivate some land in any/all of the three time periods. Agricultural outcomes refer to Masika season. Amounts in TSh (thousands) ≈ 0.7 $USD. R^2 accounts for the fixed effects.

Appendix II.C Heterogeneity Analysis

II.C.1 Effect on Labor by Age and Gender

Table II.11 decomposes the effect on agricultural labor by age and gender.

Table II.11: *Labor days*

Outcome:	Age of respondent when first observed in wave 1 (2008)						
Ages:	0-4	5-9	10-14	15-29	30+	0-14	All ages
Model:	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	A. Men and women						
M (10 km)	-0.11	-2.64**	-8.01***	-7.05**	-0.96	-3.53***	-3.56*
	(0.25)	(1.16)	(2.95)	(2.85)	(4.40)	(0.81)	(1.92)
R-squared	-0.0032	0.18	0.27	0.37	0.35	0.29	0.48
Observations	4498	4339	3615	4920	7107	12452	24479
	B. Women						
M (10 km)	-0.100	-3.03***	-8.02***	-6.22	-1.35	-3.31***	-3.49
	(0.29)	(1.14)	(2.50)	(3.82)	(6.44)	(0.75)	(2.63)
R-squared	-0.0077	0.17	0.19	0.40	0.35	0.22	0.49
Observations	2461	2328	1650	2291	3636	6439	12366
	C. Men						
M (10 km)	-0.12	-1.87	-9.02***	-7.39**	-0.66	-4.02***	-3.74**
	(0.35)	(2.67)	(3.36)	(2.96)	(5.08)	(1.15)	(1.77)
R-squared	-0.020	0.20	0.33	0.35	0.36	0.34	0.47
Observations	2037	2011	1965	2629	3471	6013	12113

Note: All regressions include year-event and household-event fixed effects. Agricultural labor outcomes refer to Masika season. R^2 accounts for the fixed effects. Standard errors in parentheses are adjusted for clustering at the village level: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

II.C.2 Soil Quality, Farm Size, Household Size, Communications

Table II.12 presents the results of a heterogeneity analysis where the full sample is split by the median of some variables at baseline, creating two groups of roughly equal size for comparison.

Table II.12: *Heterogeneity*

Outcome:	Output	Land	Labor	Input exp.	Cons.	Output	Land	Labor	Input exp.	Cons.
Model:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	A. Soil quality									
	Poor soil ("good" quality plots = 0)					Better soil ("good" quality plots > 0)				
M (10km)	-124.5	-1.63***	-17.5	-56.5***	97.9**	-190.3***	-1.03***	-25.2**	-13.5	88.9
	(94.6)	(0.56)	(14.6)	(17.2)	(47.8)	(64.8)	(0.28)	(10.7)	(26.5)	(70.8)
R-squared	0.35	0.51	0.39	0.38	0.48	0.40	0.56	0.37	0.49	0.57
Observations	2502	2502	2502	2502	2502	1938	1938	1938	1938	1936
	B. Farm size									
	Small farm (acres ≤ 3)					Larger farm (acres > 3)				
M (10km)	-115.9***	-0.93***	-12.4**	-24.3***	80.8**	-153.0*	-1.46***	-23.1**	-32.6*	65.9
	(32.7)	(0.20)	(5.69)	(8.99)	(34.5)	(86.8)	(0.40)	(11.5)	(17.5)	(55.1)
R-squared	0.40	0.45	0.44	0.49	0.56	0.35	0.44	0.35	0.43	0.51
Observations	2634	2634	2634	2634	2632	2343	2343	2343	2343	2343
	C. Household size									
	Small household (members ≤ 5)					Larger household (members > 5)				
M (10km)	-145.6***	-0.99***	-19.6***	-49.4***	33.0**	-154.8*	-1.28***	-13.1	-17.1	142.9*
	(42.3)	(0.32)	(7.27)	(15.4)	(14.9)	(81.9)	(0.42)	(14.5)	(26.0)	(73.8)
R-squared	0.43	0.50	0.48	0.54	0.53	0.39	0.58	0.37	0.41	0.49
Observations	2706	2706	2706	2706	2704	2271	2271	2271	2271	2271
	D. Communications									
	Dist. to major road > 11.7 km))					Dist. to major road ≤ 11.7 km)				
M (10km)	-305.9***	-1.72***	-27.6***	-38.9***	136.8***	-80.3**	-0.66***	-14.6*	-42.8**	51.5
	(51.4)	(0.25)	(9.04)	(13.8)	(39.2)	(33.4)	(0.24)	(8.19)	(20.2)	(41.1)
R-squared	0.38	0.52	0.42	0.50	0.43	0.45	0.62	0.48	0.44	0.60
Observations	2325	2325	2325	2325	2323	2331	2331	2331	2331	2331

Note: All regressions include year-event and household-event fixed effects. Agricultural outcomes refer to Masika season. R^2 accounts for the fixed effects. Standard errors in parentheses are adjusted for clustering at the village level: *** p < 0.01, ** p < 0.05, * p < 0.1.

Appendix II.D Consumption: Alternative Specifications

Tables II.14 and II.15 presents the effect of small-scale mining on consumption using different consumption measures.

The estimates presented in columns A1-A6 of table II.14 are the same as those presented in the main text, and are included here for reference. Columns B1-B6 use nominal consumption figures that have not been adjusted for local price differences. These estimates reveal that adjusting for local prices slightly increases the size of the estimates, but are similar enough to indicate that price level changes are not driving the effects (also, the difference is not statistically significant).

The consumption measures used in panels C and D also adjust for differences in the demographic composition of households. This measure may take better account of changes in individual welfare that follows from the fact that households have different material and nutritional needs. To produce a measure that considers such differences, the consumption of each household is divided by the weighted sum of household members, using the weights described in table II.13. These "adult equivalent units" are intended to approximately capture the different material needs of household members based on age and gender, and are used by the Tanzania National Bureau of Statistics. Finally, table II.15 reproduces the same estimates using a logarithmic transformation of the dependent variable.

Table II.13: *Adult-equivalent units by gender and age*

Age	Male	Female
0-2	0.40	0.40
3-4	0.48	0.48
5-6	0.56	0.56
7-8	0.64	0.64
9-10	0.76	0.76
11-12	0.80	0.88
13-14	1.00	1.00
15-18	1.20	1.00
19-59	1.00	0.88
60 and more	0.80	0.72

Table II.14: *Consumption: alternative specifications*

	Total	Food	Education	Health	Transp.	Other
	(1)	(2)	(3)	(4)	(5)	(6)
	A: Per household (real prices)					
M (10km)	77.8**	66.3***	0.042	3.81	-7.69	15.3**
	(33.4)	(24.1)	(3.17)	(6.00)	(8.11)	(6.45)
R-squared	0.54	0.42	0.56	0.12	0.36	0.52
Observations	4975	4975	4975	4975	4977	4977
	B: Per household (nominal prices)					
M (10km)	67.4**	59.6***	-0.71	3.50	-9.33	14.4**
	(30.6)	(22.2)	(2.77)	(6.16)	(8.28)	(6.23)
R-squared	0.55	0.42	0.56	0.12	0.36	0.55
Observations	4975	4975	4975	4975	4977	4977
	C: Per adult equivalent (real prices)					
M (10km)	17.4**	14.3**	-0.057	1.04	-3.47*	5.54
	(6.89)	(5.65)	(0.57)	(1.64)	(1.76)	(4.11)
R-squared	0.54	0.43	0.57	0.12	0.30	0.50
Observations	4975	4975	4975	4975	4975	4975
	D: Per adult equivalent (nominal prices)					
M (10 km)	15.1**	12.8**	-0.17	0.92	-3.90*	5.39
	(5.92)	(5.05)	(0.52)	(1.56)	(1.98)	(4.12)
R-squared	0.56	0.46	0.57	0.13	0.30	0.51
Observations	4975	4975	4975	4975	4975	4975

Note: All models include year-event and household-event fixed effects. Amounts in TSh (thousands) ≈ 0.7 \$USD. R^2 accounts for the fixed effects. Standard errors in parentheses are adjusted for clustering at the village level: *** p < 0.01, ** p < 0.05, * p < 0.1.

Table II.15: *Consumption: logarithmic transformations*

	Total	Food	Education	Health	Transp.	Other
	(1)	(2)	(3)	(4)	(5)	(6)
	A: Per household (real prices)					
M (10km)	0.18**	0.27***	-0.084	0.21	-0.013	0.20***
	(0.082)	(0.085)	(0.20)	(0.22)	(0.15)	(0.068)
R-squared	0.62	0.54	0.66	0.20	0.36	0.56
Observations	4975	4975	3504	3858	3013	4971
	B: Per household (nominal prices)					
M (10km)	0.15*	0.24***	-0.13	0.17	-0.054	0.17**
	(0.082)	(0.083)	(0.19)	(0.23)	(0.15)	(0.066)
R-squared	0.63	0.55	0.66	0.21	0.36	0.58
Observations	4975	4975	3504	3858	3013	4971
	C: Per adult equivalent (real prices)					
M (10km)	0.14*	0.23**	-0.12	0.18	-0.057	0.16***
	(0.082)	(0.098)	(0.18)	(0.21)	(0.16)	(0.048)
R-squared	0.53	0.43	0.64	0.20	0.40	0.58
Observations	4975	4975	3504	3858	3013	4971
	D: Per adult equivalent (nominal prices)					
M (10km)	0.10	0.19**	-0.17	0.14	-0.099	0.12***
	(0.079)	(0.093)	(0.17)	(0.22)	(0.16)	(0.040)
R-squared	0.56	0.45	0.65	0.21	0.41	0.60
Observations	4975	4975	3504	3858	3013	4971

Note: All models include year-event and household-event fixed effects. The dependent variables are natural logarithmic transformations of consumption. R^2 accounts for the fixed effects. Standard errors in parentheses are adjusted for clustering at the village level: *** p < 0.01, ** p < 0.05, * p < 0.1.

Appendix II.E Migration, Land use and Crime

Table II.16 presents the effect on in-, out- and net-migration. This data was collected by the NPS from village-level representatives.

Table II.16: *Migration (village level)*

	(1) Out-migration	(2) In-migration	(3) Net-migration
M (10 km)	-8.38	0.49	8.74
	(17.5)	(7.51)	(19.3)
R-squared	0.043	0.034	0.017
Observations	419	418	418

Note: All models include year-event and village-event fixed effects. R^2 accounts for the fixed effects. Standard errors in parentheses are adjusted for clustering at the village level: *** p < 0.01, ** p < 0.05, * p < 0.1.

Table II.17 presents the effect of exposure to small-scale mining on land use and the form of control over agricultural land. The estimates presented in columns A1 and B1 (which are identical) suggest a negative effect on the total amount of land used or controlled by households of roughly one acre. This land disappears from the survey, which makes it impossible to determine whether it was abandoned, sold or put to collective use. The negative effect on cultivated land is larger than the negative effect on total land controlled by the household, which is explained by small (and statistically insignificant) increases in the amount of land rented out or used for other purposes (for instance grazing). Regarding ownership structure, the negative point estimate for the total amount of land used or controlled by households is mainly explained by a reduction in land listed as owned by the household.

Table II.18 presents the effect on total land value and the land value per acre. The land value per acre is computed by dividing the total self-reported land value of agricultural plots provided by farmers by the self-reported total land area. It is therefore subject to two separate sources of potential miss-measurement. However, this measure can serve as a rough approximation for changes in average land values over time under the assumption that the measurement error is consistent within households. The results suggest that the perceived average value of land decreases somewhat, both when considering all land and when restricting to land that is being cultivated, as indicated in columns 3 and 6, but the effects are very noisy and should be interpreted cautiously.

Table II.19 presents the effect of small-scale mining on variables related to crime and safety. Column 1 reports the effect on crop theft, and uses a dependent variable indicating whether the household lost any crops to theft.

Table II.17: *Land use and ownership*

	A: Land use (acres)				
Dep. var.	All	Cultivated	Fallow	Rented out	Other
Model	(1)	(2)	(3)	(4)	(5)
M (10km)	-1.19	-1.10***	-0.084	0.24	0.33
	(0.76)	(0.20)	(0.20)	(0.15)	(0.59)
R-squared	0.41	0.58	0.053	0.046	0.18
Observations	4977	4977	4977	4977	4977
	B: Form of control (acres)				
Dep. var.	All	Owned	Used free of charge	Rented in	Shared
Model	(1)	(2)	(3)	(4)	(5)
M (10km)	-1.19	-0.93	-0.16	-0.11	0.0039
	(0.76)	(0.84)	(0.10)	(0.079)	(0.018)
R-squared	0.41	0.41	0.22	0.49	-0.0026
Observations	4977	4977	4977	4977	4977

Note: All models include year-event and household-event fixed effects. R^2 accounts for the fixed effects. Standard errors in parentheses are adjusted for clustering at the village level: *** p < 0.01, ** p < 0.05, * p < 0.1.

Table II.18: *Self-reported land value*

Land type	All land			Cultivated land		
Dep. var.	Total value		Value/acre	Total value		Value/acre
Sample	Farms any	Farms all periods		Farms any	Farms all periods	
	(1)	(2)	(3)	(4)	(5)	(6)
M (10km)	-1142.4	521.6	-115.3	-1536.6**	-446.5	-89.8
	(975.4)	(1287.7)	(181.3)	(747.6)	(495.4)	(212.5)
R-squared	0.27	0.26	0.36	0.25	0.29	0.33
Observations	4977	3492	3492	4977	3492	3492

Note: All regressions include year-event and household-event fixed effects. The labels "farms any/all" refer to households that cultivate some land in any/all of the three time periods. Amounts in TSh (thousands). R^2 accounts for the fixed effects. Standard errors in parentheses are adjusted for clustering at the village level: *** p < 0.01, ** p < 0.05, * p < 0.1.

Column 2 reports the effect on respondents' stated satisfaction with crime and safety. The survey asked respondents "How satisfied or dissatisfied would you say you are with your protection against crime/your safety?" and records responses on a scale between 1 (very satisfied) and 7 (very dissatisfied). The dependent variable used in column 2 is a dummy variable indicating whether the household responded with a score between 1 and 3, i.e. "very satisfied", "satisfied" or "somewhat satisfied". Since this survey question was introduced with the second wave of the NPS, it omits observations from the NPS 2008 are omitted.

Table II.19: *Crime and safety*

Dep. variable:	Crop theft	Satisfaction with safety
Model:	(1)	(2)
M (10 km)	-0.014	-0.027
	(0.027)	(0.051)
R-squared	0.087	0.13
Observations	4977	7346

Note: All models include year-event and household-event or individual-event fixed effects. R^2 accounts for the fixed effects. Standard errors in parentheses are adjusted for clustering at the village level: *** p < 0.01, ** p < 0.05, * p < 0.1.

Appendix II.F Anthropometrics and Education

Table II.20 presents the effects of small-scale gold mining on the weight, height and BMI of individuals of different ages. Table II.21 instead presents the effects on weight-for-age, height-for-age and weight-for-height z-scores. Panels A-C use the raw z-score, while panels D-F use a dummy variable indicting z-scores below -1.

Table II.20: *Effect on weight, height and BMI*

	Age of respondent in wave one (2008)						
	0-4	5-9	10-14	15-29	30+	0-14	All ages
Model:	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	A. Weight						
M (10km)	2.62*	1.32	0.14	-0.32	0.73	1.33	0.79
	(1.56)	(1.13)	(1.68)	(1.16)	(1.38)	(0.92)	(0.97)
R-squared	0.62	0.76	0.91	0.72	0.89	0.90	0.95
Observations	3627	3141	1989	2679	5439	8757	16875
	B. ln(Weight)						
M (10km)	0.068*	0.026*	0.0095	-0.0054	0.014	0.057**	0.027
	(0.037)	(0.013)	(0.025)	(0.023)	(0.019)	(0.028)	(0.031)
R-squared	0.85	0.90	0.92	0.65	0.90	0.95	0.95
Observations	3627	3141	1989	2679	5439	8757	16875
	C. Height						
M (10km)	0.71	-0.17	1.14	1.50	0.86	1.43**	0.99
	(0.56)	(0.65)	(1.26)	(1.95)	(0.94)	(0.63)	(1.01)
R-squared	0.86	0.84	0.87	0.68	0.84	0.93	0.93
Observations	3627	3141	1989	2679	5439	8757	16875
	D. ln(Height)						
M (10km)	0.0013	-0.0040	0.0074	0.014	0.0072	0.016	0.010
	(0.011)	(0.0065)	(0.0078)	(0.017)	(0.0080)	(0.012)	(0.012)
R-squared	0.70	0.65	0.85	0.55	0.74	0.83	0.86
Observations	3627	3141	1989	2679	5439	8757	16875
	E. BMI						
M (10km)	7.56	2.22	-0.074	-1.80	-1.82	3.50	1.02
	(5.45)	(1.83)	(0.62)	(1.85)	(2.56)	(2.72)	(1.94)
R-squared	-0.00055	-0.0014	0.81	0.48	0.14	-0.00032	0.0012
Observations	3627	3141	1989	2679	5439	8757	16875
	F. ln(BMI)						
M (10km)	0.065**	0.034**	-0.0053	-0.034	-0.00015	0.025*	0.0067
	(0.029)	(0.014)	(0.029)	(0.041)	(0.026)	(0.015)	(0.021)
R-squared	0.093	0.14	0.82	0.68	0.76	0.17	0.63
Observations	3627	3141	1989	2679	5439	8757	16875

Note: All models include year-event and household-event fixed effects. R^2 accounts for the fixed effects. Standard errors in parentheses are adjusted for clustering at the village level: *** p < 0.01, ** p < 0.05, * p < 0.1.

Table II.21: *Effect on z-scores*

Age:	Age of respondent when first observed in wave 1 (2008)						
	0-4	5-9	10-14	15-29	30+	0-14	All ages
Model:	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Outcome	Z-score:						
	A. Weight-for-age						
M (10km)	0.47*	-0.051	0.12	-0.021	0.19*	0.25	0.18
	(0.26)	(0.10)	(0.19)	(0.16)	(0.097)	(0.16)	(0.11)
R-squared	0.46	0.61	0.77	0.73	0.87	0.58	0.70
Observations	3627	3141	1989	2679	5435	8757	16871
	B. Height-for-age						
M (10km)	0.092	-0.050	0.24***	0.10	0.098	0.080**	0.087*
	(0.068)	(0.071)	(0.089)	(0.21)	(0.066)	(0.038)	(0.048)
R-squared	0.44	0.61	0.71	0.70	0.84	0.57	0.67
Observations	3627	3141	1989	2679	5435	8757	16871
	C. Weight-for-height						
M (10km)	0.73**	0.23	-0.084	-0.018	0.075	0.46**	0.25
	(0.32)	(0.15)	(0.23)	(0.11)	(0.12)	(0.22)	(0.16)
R-squared	0.29	0.37	0.44	0.54	0.84	0.35	0.59
Observations	3619	3139	1989	2679	5439	8747	16865
Outcome	$\Pr(z < -1)$:						
	D. Weight-for-age						
M (10km)	-0.065	0.0087	-0.17**	0.098	-0.011	-0.062**	-0.015
	(0.040)	(0.049)	(0.078)	(0.079)	(0.029)	(0.030)	(0.030)
R-squared	0.37	0.45	0.55	0.55	0.59	0.45	0.52
Observations	3627	3141	1989	2679	5439	8757	16875
	E. Height-for-age						
M (10km)	0.0077	0.021	-0.16	0.044	-0.031	-0.019	-0.0092
	(0.016)	(0.014)	(0.10)	(0.047)	(0.036)	(0.020)	(0.014)
R-squared	0.39	0.54	0.52	0.57	0.69	0.49	0.58
Observations	3627	3141	1989	2679	5439	8757	16875
	F. Weight-for-height						
M (10km)	-0.025	0.037	0.052	0.028	-0.038	0.0033	-0.0061
	(0.075)	(0.10)	(0.18)	(0.062)	(0.031)	(0.059)	(0.035)
R-squared	0.078	0.24	0.27	0.30	0.65	0.20	0.34
Observations	3627	3141	1989	2679	5439	8757	16875

Note: All regressions include year-event and individual-event fixed effects. R^2 accounts for the fixed effects. Standard errors in parentheses are adjusted for clustering at the village level: *** p < 0.01, ** p < 0.05, * p < 0.1.

Table II.22 presents the effect of small-scale mining on schooling. The dependent variable is a dummy variable indicating whether the respondent is currently in school.

Table II.22: *Effect on schooling (respondent currently in school)*

Age in wave one	0-13	14-20	0-20
Level equivalent	Primary	Secondary	Both
Model	(1)	(2)	(3)
	A. Boys and girls		
M (10km)	0.088**	-0.12	0.025
	(0.036)	(0.093)	(0.054)
R-squared	0.46	0.50	0.42
Observations	11741	3079	14820
	B. Boys		
M (10km)	0.060**	-0.11	0.011
	(0.029)	(0.074)	(0.041)
R-squared	0.44	0.50	0.40
Observations	5575	1847	7422
	C. Girls		
M (10km)	0.12**	-0.14	0.043
	(0.059)	(0.18)	(0.084)
R-squared	0.48	0.50	0.45
Observations	6166	1232	7398

Note: All models include year-event and individual-event fixed effects. R^2 accounts for the fixed effects. Standard errors in parentheses are adjusted for clustering at the village level: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Appendix II.G Robustness Tests

Table II.23 presents key results from this paper when also controlling for rainfall (current and past year), and access to communications. The variable "Dist. road" captures the distance from the household to the closest major road in kilometers.

Table II.23: *Controlling for roads and rain*

	Output	Inputs		Expenditure		Technology		
Outcome:	Harvest value	Cultiv-ated area	Days worked	Input exp.	Cons-umption	Impr. seeds	Fert-ilizers	Pest-icides
Model:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
M (10km)	-171.2***	-0.99***	-20.5***	-38.9***	91.6***	-0.10*	-0.014	-0.038*
	(36.7)	(0.21)	(6.30)	(12.4)	(34.4)	(0.059)	(0.053)	(0.022)
Dist. to road	0.27	0.0055**	-0.015	-0.0079	-0.24	0.000048	-0.00019	-0.00029
	(0.42)	(0.0028)	(0.083)	(0.15)	(0.15)	(0.00054)	(0.00037)	(0.00030)
Rain	206.7**	0.77	4.08	30.8	42.1	0.089	0.039	0.12
	(95.0)	(0.69)	(16.2)	(31.7)	(42.1)	(0.10)	(0.082)	(0.074)
Rain lagged	-45.1	0.011	-1.90	6.62	-2.39	-0.075	-0.0014	-0.0085
	(47.4)	(0.31)	(6.82)	(27.4)	(20.6)	(0.050)	(0.063)	(0.029)
R-squared	0.41	0.58	0.45	0.45	0.54	0.28	0.47	0.30
Observations	4868	4868	4868	4868	4866	4868	4868	4868

Note: All models include year-event and individual-event fixed effects. R^2 accounts for the fixed effects. Standard errors in parentheses are adjusted for clustering at the village level: *** p < 0.01, ** p < 0.05, * p < 0.1.

Table II.24 presents results obtained from regressing treatment status M_{it} on different measures of rainfall. The variable $Rain = \frac{Precipitation}{Meanprecipitation}$ is calculated as the total 12-month (July-June) precipitation in the current year divided by average precipitation over all such 12-month periods. The variable *Rain lagged* is constructed in the same way, but uses the preceding 12-month period in the numerator. The specifications presented in column 3 and 6 of table II.24 include timing dummies, which indicate the timing of the onset of the wettest quarter in weeks (1-36) relative to the mean onset of the wettest quarter. These dummies are intended to capture variation in the timing of the major rainy season which, in addition to the amount of precipitation, can have important consequences for agricultural outcomes. The data comes from the Rainfall Estimates (RFE) database provided by the National Oceanic and Atmospheric Administration's Climate Prediction Center (NOAA CPC). In addition to the remotely sensed precipitation data, table II.24 also includes subjective valuations of farmer satisfaction with the timing and amount of precipitation during the last major wet season (Masika), which have been collected by the Tanzania NPS. The evidence provided by these exercises indicate that the results of

this paper are not driven by shocks related to rainfall or road constructions, and that adverse weather outcomes that could affect agriculture do a relatively poor job in explaining the emergence of small-scale mining sites.

Table II.24: *Effect of weather on M*

Dependent var:	M(10 km)					
Model:	(1)	(2)	(3)	(4)	(5)	(6)
Rain	-0.031	-0.027	0.030			0.036
	(0.040)	(0.039)	(0.041)			(0.044)
Rain lagged		0.032	0.041			0.058
		(0.031)	(0.040)			(0.040)
Stated amount:						
Far too much				0.013	0.0084	-0.0091
				(0.016)	(0.018)	(0.013)
A bit too much				0.0068	0.0011	-0.019
				(0.015)	(0.014)	(0.014)
A bit too little				-0.041*	-0.038	-0.026*
				(0.023)	(0.023)	(0.015)
Far too little				-0.0079	-0.012	-0.00023
				(0.0092)	(0.012)	(0.011)
Stated timing:						
Far too early					0.010	0.020
					(0.015)	(0.016)
A bit too early					0.021	0.017
					(0.016)	(0.015)
A bit too late					-0.017	-0.022
					(0.016)	(0.018)
Far too late					0.031	0.030
					(0.027)	(0.021)
Timing dummies	No	No	Yes	No	No	Yes
R-squared	0.25	0.25	0.45	0.16	0.17	0.47
Observations	4868	4868	4868	4899	4899	4790

Note: All models include year-event and individual-event fixed effects. R^2 accounts for the fixed effects. Standard errors in parentheses are adjusted for clustering at the village level: *** p < 0.01, ** p < 0.05, * p < 0.1.

Table II.25 presents the results from estimating II.1 using leads of M. The purpose of this exercise is to verify that the estimated effects are not the result of some random noise in the data, and to rule out anticipatory effects occurring in the period before treatment. The estimates presented in II.25 show that the leads, or "placebo" treatments, do not produce statistically significant results. These findings are consistent with the identifying assumptions that underlie the empirical strategy of this paper and therefore does not reject the internal validity of the main results.

Table II.25: *Placebo: leads of M*

	Output	Inputs		Expenditure		Technology		
Outcome:	Value of harvest	Cult. area	Days worked	Input exp.	Cons-umption	Impr. seeds	Ferti-lizers	Pesti-cides
Model:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
M(t+1)	20.8	0.045	1.90	-4.20	-33.4	-0.071	0.0046	-0.048
	(26.1)	(0.36)	(8.83)	(9.73)	(35.7)	(0.11)	(0.026)	(0.030)
R-squared	0.45	0.54	0.51	0.55	0.59	0.29	0.50	0.35
Observations	3318	3318	3318	3318	3318	3318	3318	3318

Note: All models include year-event and individual-event fixed effects. R^2 accounts for the fixed effects. Standard errors in parentheses are adjusted for clustering at the village level: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table II.26 breaks down the total number of eligible households in the study area present in the first NPS wave (2008) by treatment statuses, and by whether they were retained or dropped out in subsequent survey waves. "Switchers" are households that (based on their location in 2008) were not initially exposed to small-scale mining, but became exposed at some point during the study period. "Always treated" are households that always were exposed, and "Never treated" are households that never became exposed. Importantly, the attrition rate is similar for switchers and non-switchers.

Table II.27 reports the result of regressing dummy variables indicating treatment statuses on a dummy indicating whether the household is dropped due to attrition. This analysis again indicates that households that become exposed to small-scale mining (i.e. switchers) do not experience higher attrition rates compared to other households.

Table II.26: *Attrition: tabulation*

	Switchers?		Always treated?		Never treated?		Total
	No	Yes	No	Yes	No	Yes	
Retained	910 (87.84%)	55 (85.94%)	870 (89.05%)	95 (77.24%)	150 (80.21%)	815 (89.27%)	965 (87.73%)
Dropped	126 (12.16%)	9 (14.06%)	107 (10.95%)	28 (22.76%)	37 (19.79%)	98 (10.73%)	135 (12.27%)
Total	1036 (100%)	64 (100%)	977 (100%)	123 (100%)	187 (100%)	913 (100%)	1100 (100%)

Table II.27: *Attrition: regressions*

Outcome:	Dropped out		
	(1)	(2)	(3)
Switcher	0.019		
	(0.042)		
Always treated		0.12***	
		(0.031)	
Never treated			-0.091***
			(0.026)
R-squared			
Observations	1100	1100	1100

Appendix II.H Testing PML Data Against Verified Mining Locations

Figures II.9 and II.10 plot the location of registered PML applications against confirmed small-scale mining and processing locations. These locations were visited by survey teams between November 2017 and March 2018. Figure II.28 presents a histogram over the distances from each confirmed mining or processing site to the closest registered application in the PML data. Since visited sites only make up a non-random sub-set of all existing mining locations, this exercise cannot confirm or reject whether each registered PLM identifies actual mining activity. However, it provides valuable evidence about the correspondence between the PML data and mining operations on the ground by showing that the vast majority of confirmed locations are located within PML concessions or in their close vicinity.

Figure II.9: *Registered PML applications (red) and visited mining and processing sites (yellow): District of Mara*

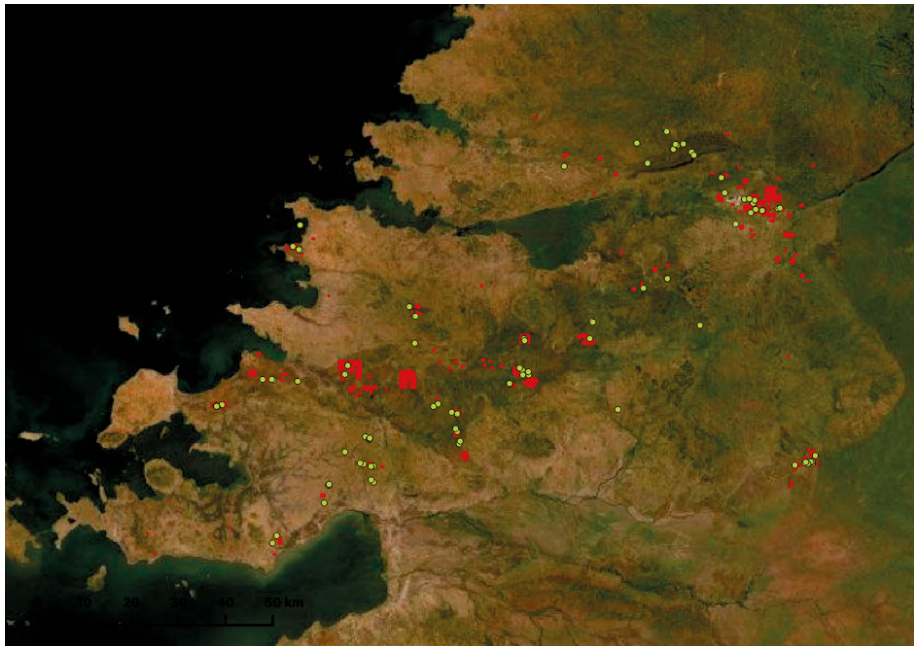


Figure II.10: *Registered PML applications (red) and visited mining and processing sites (yellow): Districts of Geita, Mwanza and Shinyanga*

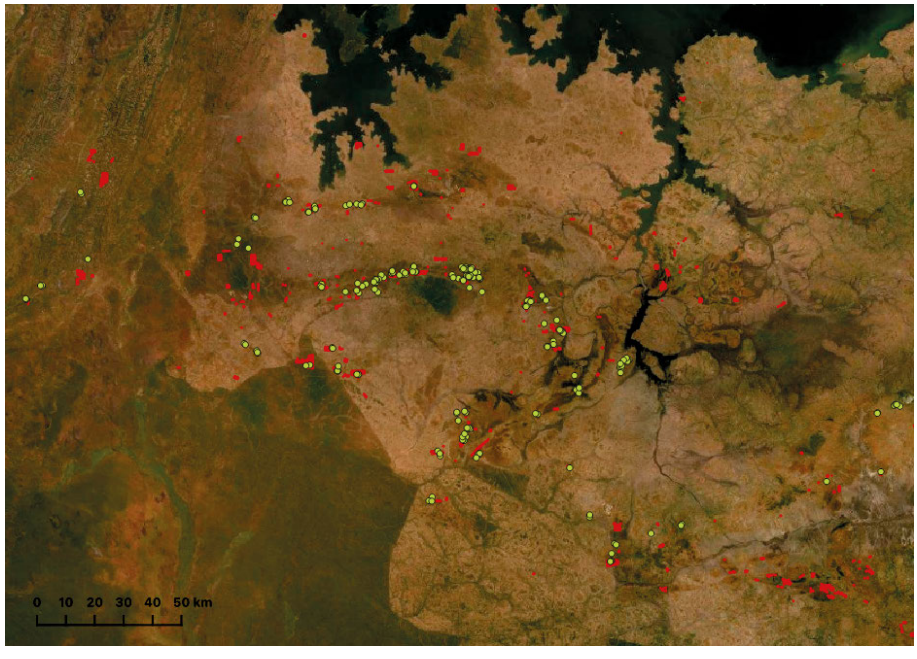
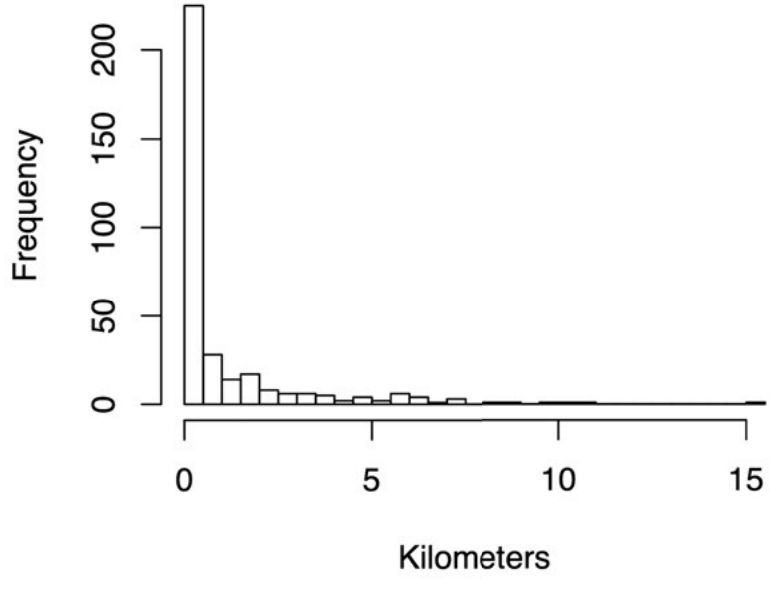


Table II.28: *Distance to closest PML application*



Appendix II.I Accounting for GPS Offsetting

Due to the random noise introduced by GPS offsetting in the NPS data, the true treatment variable (M) may differ from the observed treatment variable ($\hat{\text{M}}$) which is derived from the scrambled GPS coordinates. However, since the error is introduced by a random variable drawn from a known uniform distribution it is possible to calculate the probability with which each observation truly belongs to the treatment group, i.e. the likelihood that $M_{it} = 1$, and the reliability with which it is classified correctly, i.e. the likelihood that $\hat{M}_{it} = M_{it}$. This information is obtained by considering the proportion of all the possible true locations of each household that fall within 10km of a PML. This proportion can be approximated by the following expression (derived from the area of intersection between two circles):

$$P_{it} = \frac{25\cos^{-1}\left(\frac{d_{it}^2-75}{10d_{it}}\right) + 100\cos^{-1}\left(\frac{d_{it}^2+75}{20d_{it}}\right) - \frac{\sqrt{(15-d_{it})(d_{it}-5)(d_{it}+5)(d_{it}+15)}}{2}}{25\pi}$$

where d_{it} is the observed distance between household i in time t and its closest PML using the scrambled coordinates. Thus it is possible to closely approximate both the true probability of treatment $P_{it} \approx \Pr(M_{it} = 1)$ and the reliability $R_{it} = |\hat{M}_{it} + P_{it} - 1| \approx \Pr(\hat{M}_{it} = M_{it})$ using the available geographic information, even if exact coordinates are not provided (however, minor discrepancies could remain due to the additional 5 km offset applied to every 100th cluster and the existence of other PMLs nearby). Figure II.11 plots $\hat{M}_{it}$, P_{it} and R_{it} against d_{it}.

Figure II.11: *Distribution of P_{it} and R_{it} around threshold of treatment*

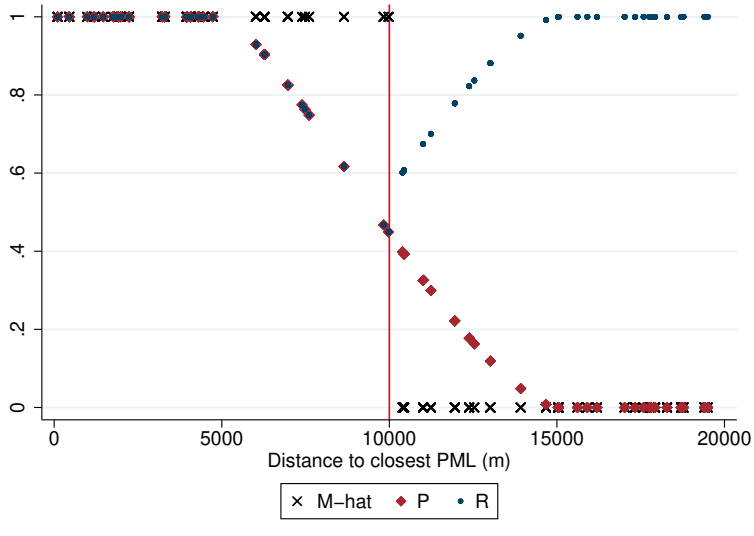


Table II.29 reports the estimated effect of M on the outcome variables when accounting for the degree of confidence in various ways. Panel A presents the results from the main specification, and is included the propose of comparison. Panel B substitutes P_{it} for $\hat{M}_{it}$ as the treatment variable, but makes no additional adjustments to the sample. Panel C restricts the sample to households that are correctly classified with at least 50% probability in every time period. Panel D includes households that are correctly classified with at least 75% probability in every time period. Finally, panel E restricts the sample further to include only households that can be assigned with certainty into the treatment or control group in all three time periods.

Table II.29: *Accounting for potential misclassification*

	Output	Inputs		Expenditure		Technology		
Outcome:	Value of harvest	Cult. area	Days worked	Input exp.	Cons-umption	Impr. seeds	Ferti-lizers	Pesti-cides
Model:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	A. Main specification (for comparison)							
M (10 km)	-155.2***	-1.10***	-16.8**	-35.7***	67.4**	-0.12**	0.017	-0.039**
	(47.1)	(0.20)	(6.72)	(11.6)	(30.6)	(0.051)	(0.048)	(0.018)
R-squared	0.42	0.58	0.44	0.46	0.55	0.29	0.47	0.31
Observations	4977	4977	4977	4977	4975	4977	4977	4977
	B. Using P_{it} as treatment variable							
P	-195.4***	-1.07**	-11.0	-25.8	93.0**	-0.16***	0.073	-0.081***
	(73.8)	(0.49)	(12.4)	(21.6)	(41.9)	(0.055)	(0.068)	(0.030)
R-squared	0.41	0.58	0.44	0.46	0.56	0.29	0.46	0.31
Observations	5199	5199	5199	5199	5195	5199	5199	5199
	C. Dropping households with $R_{it} < 0.5$ in any wave							
M (10 km)	-149.7***	-1.08***	-16.8**	-39.9***	85.7**	-0.14***	-0.019	-0.050***
	(56.9)	(0.24)	(7.78)	(12.2)	(36.1)	(0.040)	(0.052)	(0.018)
R-squared	0.42	0.58	0.44	0.46	0.55	0.29	0.47	0.31
Observations	4935	4935	4935	4935	4933	4935	4935	4935
	D. Dropping households with $R_{it} < 0.75$ in any wave							
M (10 km)	-102.6	-0.99***	-9.86	-29.0**	81.6	-0.14**	-0.028	-0.058***
	(64.2)	(0.26)	(6.98)	(12.4)	(53.5)	(0.055)	(0.071)	(0.021)
R-squared	0.41	0.58	0.45	0.46	0.55	0.30	0.47	0.30
Observations	4719	4719	4719	4719	4719	4719	4719	4719
	E. Dropping households with $R_{it} < 1$ in any wave							
M (10 km)	-128.2***	-1.46***	-21.6***	-14.4	227.8***	-0.13***	-0.052***	-0.075***
	(21.9)	(0.14)	(3.90)	(9.23)	(7.39)	(0.021)	(0.018)	(0.015)
R-squared	0.42	0.59	0.45	0.46	0.55	0.30	0.47	0.31
Observations	4545	4545	4545	4545	4545	4545	4545	4545

Note: All models include year-event and individual-event fixed effects. R^2 accounts for the fixed effects. Standard errors in parentheses are adjusted for clustering at the village level: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

III. The Social Cost of Industrialization: Evidence from the 19th Century Swedish Iron Industry

with Raoul van Maarseveen and Niklas Bengtsson

We would like to express our gratitude to Tessa Bold, Matz Dahlberg, Johannes Haushofer, Mounir Karadja, Jakob Molinder, Göran Rydén, Mara Squicciarini, Anna Tompsett, and the participants of the Urban Economics Association conference, Uppsala Urban Lab seminar and UCBH seminar

III.1 Introduction

The transition from artisanal to industrial production is an ubiquitous feature of economic development. Whether in the context of 19th century Europe, China in the 1970s or developing countries today, the first step toward industrialization often involves the concentration of capital and workers in emergent industrial towns, and the parallel decline of artisanal production. This transition can be beneficial for workers, as industrialization generally leads to higher productivity and increasing wages. However, it could also have adverse consequences for some workers, as it spatially reallocates production and changes the demand for various skills. The net effect of any such industrialization episode for individual workers thus remains unclear. How many workers are permanently displaced by industrialization? In what sectors are the displaced workers reinstated? Do workers migrate to find new jobs? Does industrialization in the longer run lift all boats or does it create a permanent class of "economic losers"?

In this paper, we study these questions in the context of the industrial transformation of the Swedish iron industry at the end of the 19th century. The iron industry was one of the first to adopt modern large-scale production techniques, and is therefore often seen as the harbinger of the second industrial revolution (Mokyr, 1992). To track the developments in the iron industry, we digitized annual production reports covering all iron producers operating in Sweden between 1860 and 1890. During this period, pressures exerted by technological advances and trade liberalization caused hundreds of furnaces and forges to close down, while production moved to increasingly large-scale industrial producers. The output of the Swedish iron industry increased threefold between 1860 and 1890, while the number of iron production sites declined by more than half.

We combine the production report data with population censuses from the North Atlantic Population Project covering the entire Swedish population in 1880, 1890 and 1900. The linked census data allow us to track individual workers and their descendants across both time and space. We exploit variation in the timing and location of site closures to estimate the effects of the industrial transformation on individual ironworkers. The occupations listed in the census data enable us to identify ironworkers in 1880 and link these workers to iron production sites at the parish level. We then use the production reports data to identify the subset of ironworkers that were displaced between 1880 and 1890 due to the closure of iron production sites in their parish. Finally, we estimate the worker consequences of site closures by comparing the outcomes of "displaced" and "non-displaced" ironworkers in the subsequent 1890 and 1900 censuses.

We find that the industrial transformation of the iron industry significantly affected the ironworkers. Ironworkers displaced by the closure of ironworks were 23 - 25 percentage points less likely to be employed in the iron industry

in 1890 compared to non-displaced ironworkers. At the same time, displaced ironworkers were 25 percentage points more likely to migrate to a different parish, which is more than double the migration rate among the non-displaced groups. While migration may have alleviated some of the negative effects of displacement, the displaced ironworkers nonetheless tended to end up in lower-paid professions. On average, displaced ironworkers lost roughly 105 - 123 SEK in annual earnings (from a mean of 1012 SEK) compared to their non-displaced counterparts, which implies a relative earnings loss compared to other workers of around 10%. Other occupational groups in the same parish seem to have been largely unaffected by the closures.

Interestingly, we find no evidence that the effects diminish over time. The effects on occupational change, migration and income are very similar when outcomes are measured in 1890 and when outcomes are measured in 1900. However, in the long run the negative displacement effects are increasingly concentrated among the group of workers who did not choose to migrate. Around half the displaced ironworkers migrated to a different parish between 1880 - 1900, and despite suffering an income loss at the time of the 1890 census, we find that their incomes are no longer significantly different from non-displaced workers by 1900. Thus, our estimates suggest that regional migration played an important role in this era in adjusting to the shock.

Furthermore, we analyze the effects of displacement on the outcomes of the children of displaced workers to study the intergenerational spillovers. Although the children of displaced ironworkers are significantly less likely to work in the iron industry and more likely to migrate compared to children of non-displaced workers, we find that their average annual earnings are not statistically different from children of non-displaced workers. We thus conclude that this episode of industrialization created a relatively transitory group of "economic losers" with long-lasting effects for the individual workers, but without significantly affecting the subsequent generation.

We interpret these estimates as causal. The causal interpretation relies on the identifying assumption that the outcomes of ironworkers observed in 1880 would have evolved similarly, if it were not for the industrial transformation causing some sites to close and spatially reallocating iron production. One concern is that site closures may indicate broader trends of economic decline in certain parishes, which could have independent effects on the outcomes. To account for this possibility, we estimate a triple-difference design where we also compare the outcomes of non-ironworkers between parishes and find that the non-ironworkers show the same trajectory regardless of whether the iron industry closes. Another concern is that workers may engage in anticipatory sorting, which could influence the characteristics of workers employed at a site before closure. To address this possibility, we first restrict the sample to workers who are living in their parish of birth and thus are less likely to have sorted based on short-term prospects. Second, we restrict the analysis to sites that closed later than 1885, which makes it less likely that workers already

have anticipated the closure when first observed in 1880. In both cases we find similar results. Finally, we look at site-level employee counts and find that they start to decline only around two years before closure, which limits concerns over sorting.

Our paper contributes to several strands of the economics literature. First, our paper contributes to a literature studying the effects of technological change on individual workers. Innovations in agriculture have displaced workers globally since the early 19th century and continue to do so in the developing world today (Olmstead and Rhode, 2001). The shift from artisanal spinning and weaving to industrial textile production led to widespread displacement of workers in England (Mantoux 1928) and triggered the so-called Luddite movement; a technology-skepticism that survives to this day (Mokyr 1992). While the displacement effects of such episodes have generally been counterbalanced by the reinstatement of labor through productivity gains in the long run (Acemoglu and Restrepo, 2019), the effects on displaced workers in the short run might be substantial. However, despite the longstanding literature studying such episodes of large-scale technology-driven displacement, their consequences for individual workers remain unclear. In this paper, we advance the literature by studying one historical displacement shock in detail, and use worker-level data to estimate its effects on earnings and migration.

Surprisingly, we find that the earning losses suffered by workers are quite similar to the earnings losses found in the modern plant closure literature (Jacobson et al., 1993; Eliason and Storrie, 2006; Couch and Placzek, 2010; Seim, 2019). This is despite the absence of unemployment programs in the late 18th century, which have proven important to mitigate the impacts of contemporary displacement shocks (Edin et al., 2019). Key to our understanding of this result is the role of local migration. Workers that moved to the new and expanding production sites saw no significant decrease in their earnings in the long run. This point does not appear to be emphasized in work using contemporary data, with the exception of Huttunen et al. (2018) who also highlight an important role for internal migration in coping with worker displacement in Norway.

Furthermore, our study contributes to an emerging literature on the social and intergenerational effects of worker displacement. Several papers find negative effects on worker health (Browning and Heinesen, 2012; Eliason and Storrie, 2009), spousal health (Marcus, 2013; Bubonya et al., 2017), and parental health and family separations (Mörk et al., 2020), which suggest that displacement can permanently harm human capital. When it comes to intergenerational effects, the evidence is mixed. Some papers find that children of displaced fathers have lower annual earnings (Oreopoulos et al., 2008), worse health and nutritional outcomes (Schaller and Zerpa, 2019; Pieters and Rawlings, 2020) and lower educational performance (Rege et al., 2011; Stevens and Schaller, 2011), while other papers find small or insignificant effects (Bratberg et al., 2008; Hilger, 2016; Mörk et al., 2020). Our paper adds to this literature

by finding that the displacement of fathers during the industrialization of the Swedish iron industry in the 19th century did not appear to have significant scarring effects for the next generation in terms of occupational earnings.

Finally, our paper contributes to the literature on the social and economic impact of industrialization, economic growth and urbanization more generally (Michaels et al., 2012). Many developing countries still rely predominantly on artisanal production methods in their manufacturing industries and will presumably make the step from artisanal production to large-scale production in the future. Our paper provides the first evidence of the consequences of industrialization on the displaced workers. In particular, our findings highlight the importance of spatial mobility in mitigating the negative consequences of industrialization and highlight the importance of policies that facilitate migration in response to adverse shocks. For instance, existing evidence suggests that simple policies, such as providing transportation, can stimulate out-migration from poor areas (Bryan et al., 2014). Conversely, our results suggest that policies that limit internal migration, such as China's Hukou system, might increase the economic and social costs of industrialization.

The remainder of the paper continues as follows. Section III.2 provides an overview of the historical context, the data and the empirical approach. Section III.3 presents the main findings whereas section III.4 discusses the effectiveness of the migration response. Finally, section III.5 concludes.

III.2 Historical Context, Data and Methodology

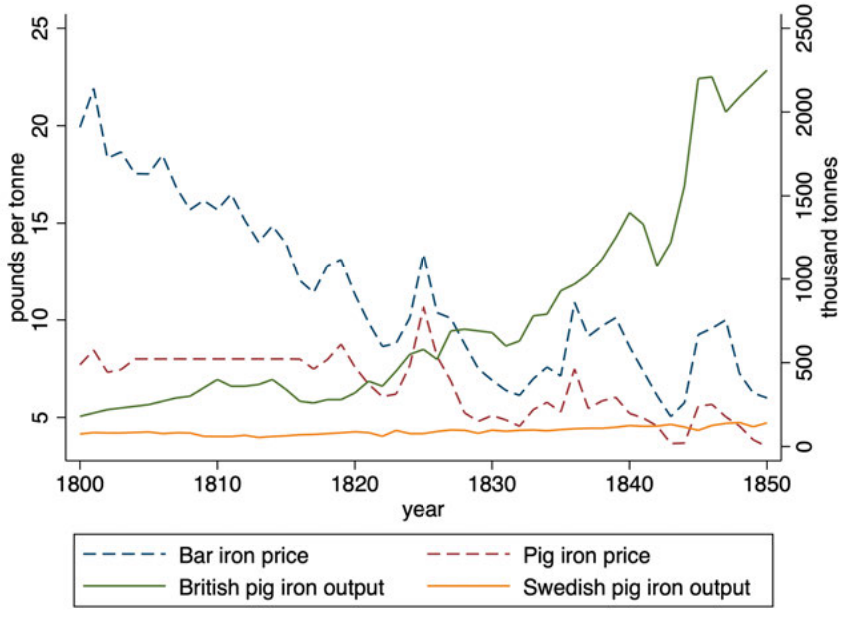
III.2.1 Background

In 1850 the Swedish iron industry consisted of hundreds of small blast furnaces and finery forges scattered across the countryside. Production was carried out by skilled artisans and craftsmen applying techniques that had been used for centuries, with the majority of production sites in operation since at least the 17th century. By the year 1900, this traditional industry had almost completely been replaced by large ironworks organized as modern factories and the real output of Swedish iron more than quadrupled (BiSOS, 2019). The transformation of the iron industry marks the beginning of a period of rapid industrialization in Swedish economic history and is typical of the economic changes associated with the second industrial revolution.

The transformation of the Swedish iron industry is generally considered to be the consequence of technological developments beginning in Great Britain (Eriksson, 1957). In 1784 the British inventor Henry Cort patented an improved version of the so-called "puddling process" for converting crude pig iron into malleable bar iron, which revolutionized British iron production in terms of quality and cost (Artur Attman, 1958). While Swedish iron producers recognized the benefits of this process at an early stage (see Rydén, 2017), it could not be transmitted to Swedish conditions due to the lack of any

significant deposits of coal, which was required to reach the higher temperatures demanded by the new process. This development raised concern in the export-oriented Swedish iron industry, which around 1800 exported around one quarter of its total output to the British market. The rise of British iron production in the first half of the 19th century is shown in figure III.1. While British pig iron output was comparable to that of Sweden in 1800, by 1850 it exceeded Swedish output by more than an order of magnitude. Simultaneously, declining production costs caused the price of bar and pig iron in the British markets to fall.

Figure III.1: *Swedish and British iron industry 1800-1850*



Note: Bar and bar iron prices for the British market are derived from Gayer et al. (1953). British pig iron output is derived from Riden (1977). Swedish pig iron output is from Schön (1988), and provided by Olsson (2007). The iron industry produces other goods in addition to pig iron, such as bar iron, cast iron and steel, but, as the main intermediary product, pig iron provides a useful proxy for the real output of the industry overall.

The challenges arising from the expansion of the puddling process generated dedicated efforts to close the technological gap in the first half of the 19th century, but the Swedish iron industry struggled to keep up with the mounting foreign competition (Arthur Attman, 1986). The first major breakthrough was made in 1845 when the Swedish metallurgist Gustaf Ekman devised a new charcoal-based method for producing bar iron inspired by British techniques. The so-called "Swedish Lancashire process" improved productivity in iron making to such an extent that Swedish producers could again begin to compete with their British counterparts. The significance of this achievement

is noted by Eli Filip Heckscher (1954), who describes it as the foremost development in "one of the most glorious pages in Swedish economic history". A second major breakthrough came with the so-called "ingot steel processes", which include the Bessemer process invented in 1856 and the Siemens–Martin process invented in 1865. These innovations created the foundation for the rise of the modern Swedish steel industry, which happened at the same times as the transformation of the iron industry described in this paper.[1]

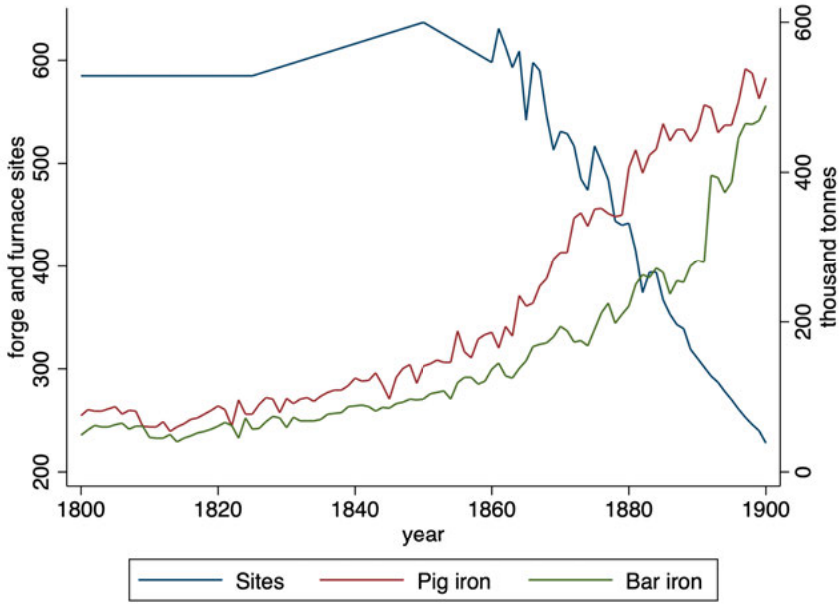
In addition to the technological improvements, the advance of liberal economic thought around the mid 19th century also brought important policy changes that began to erode some pre-industrial institutions that had restricted the growth of the Swedish iron industry. Most importantly, all ironworks had been subject to explicit output restrictions due to a monopolistic policy dating back to the 1700s, when Swedish iron dominated the European iron trade (E. Heckscher, 1949). The so-called "smidesregleringen" was gradually lifted through the legalization of pig iron exports in 1835, increased production quotas for bar iron in 1838, and was finally abolished in 1846 (Isacson, 1997; Olsson, 2007). Other ancient policies sought to protect the traditional iron industry by rationing forest resources for charcoal production, and by regulating in detail how the work was organized (Boëthius, 1958). The so-called "hammarsmedsordningarna" and "masmästarordningen" dating back to 1637 and 1649 were both abolished in 1858 (Isacson, 1997), which finally removed the greater part of the regulations that, according to Eli Filip Heckscher (1954), had imposed "insuperable obstacles to industrial reorganization" in the Swedish iron industry.

The liberalizing reforms facilitated the emergence of new organizational structures that accompanied the technological transition. By the end of the 19th century, the earlier cooperatives of craftsmen had been almost entirely replaced by hierarchical firm structures that clearly separated the roles of capital owners, industrial engineers and manual workers. It is likely that a combination of these technological and institutional changes contributed to the expansive phase that the Swedish iron industry entered by the mid 19th century, which is visible in figure III.2. The output of Swedish pig iron and bar iron

[1]The traditional view recounted here, as represented by historians like Eli Filip Heckscher (1954) and Artur Attman, 1958; Arthur Attman, 1986, emphasizes technological breakthroughs in the second half of the 19th century as the starting point of a new era in Swedish iron making: marking a clear departure from old artisanal traditions in favor of scientific metallurgy and industrial-scale production. However, this narrative is somewhat simplified. In particular, in a study on the 19th century technological transformation of iron production in the district of Gästrikland, Rydén (1998) argues that the traditional view has exaggerated the disruptive effect of specific technologies (such as the Swedish Lancashire process), while ignoring continuous productivity improvements going back to the 18th century.

increased four-fold between 1850 and 1900.[2] Simultaneously, historical data from Statistics Sweden (BiSOS C) indicate that the total number of workers employed in the iron industry increased by roughly 50%.

Figure III.2: *Production in the Swedish iron industry: 1800-1900*



Note: Swedish bar and pig iron output over the period 1800-1900 are derived from a composite series constructed by Olsson (2007) using a number of sources. The number of operational furnaces and finery forges, i.e. "production sites", per year between 1860 and 1900 is from Statistics Sweden: Bidrag till Sveriges officiella statistik, Bergshantering 1858–1910 (BiSOS C), whereas the data for 1800, 1825 and 1850 is based on Åberg (1999)

The new technologies generally required larger facilities and continuous production to operate efficiently, which meant that iron producers needed to scale up their operations in order to stay competitive. The simultaneous expansion of railway networks made larger-scale production possible by allowing charcoal to be transported over great distances, the cost of which had exerted a centrifugal force on the geographical distribution of iron production in previous decades. The transformation of the Swedish iron industry in the latter half of the 19th century thus involved the emergence of large-scale ironworks, but also the disappearance of hundreds of producers that were unable to make the necessary adjustments. This decline of the old Swedish iron in-

[2]Between 1850 and 1900 the total output of pig iron increased from 141 to 526 thousand tonnes, while the output of bar iron increased from 97 to 489 thousand tonnes. This translates to an annual growth rate of around 2.6% for pig iron and 3.2% for bar iron. In the preceding period 1800 to 1850 real output growth was more limited, amounting to annual growth rates of around 1.2% for pig iron and 1.3% for bar iron

dustry is commonly referred to as "the great death of the forges" (or “den stora bruksdöden”), and is among the more well-documented events of 19th century Swedish economic history.

Figure III.2 illustrates this development by plotting the number of production sites over time. The number of sites declined by about two-thirds in four decades between 1860 and 1900, from roughly 600 sites to around 200 sites. The majority of sites had been operating for centuries, which sets this episode apart from the general pattern of high turnover that can be observed in many other industries during the industrial revolution.[3] At the same time, the average number of workers per site increased sixfold as the expanding iron industry increasingly concentrated to fewer and larger sites that could accommodate the scale required by new production methods. The simultaneous expansion and concentration of the iron sector meant that, while most sites were abandoned, those that survived often turned into small industrial towns as they attracted workers from the surrounding countryside. In 1913, Boëthius (1958) notes that only 37 ironworks represented over 90 percent of the Swedish output of iron and steel.

III.2.2 Data

In order to study the transformation of the Swedish iron industry we use data from a series of annual production reports (“bergmästarrelationer”). These production reports were compiled by the administrators of each mining district and submitted to the National Board of Trade. The production reports contain detailed annual accounts on the mining and metal processing industries in each district, and include site-specific information on the activities of individual mines and ironworks (including all blast furnaces and finery forges) over the past year. Therefore, unlike an annual survey or census, which would observe sites operating at a particular point time, the production reports include every production site that existed in Sweden during this period even if they only operated for a very short time. We have digitized the original handwritten reports stored in the Swedish National Archives in Stockholm and constructed a panel data set of year-site observations covering the universe of the Swedish iron and steel production sites between 1860 and roughly 1894.[4]

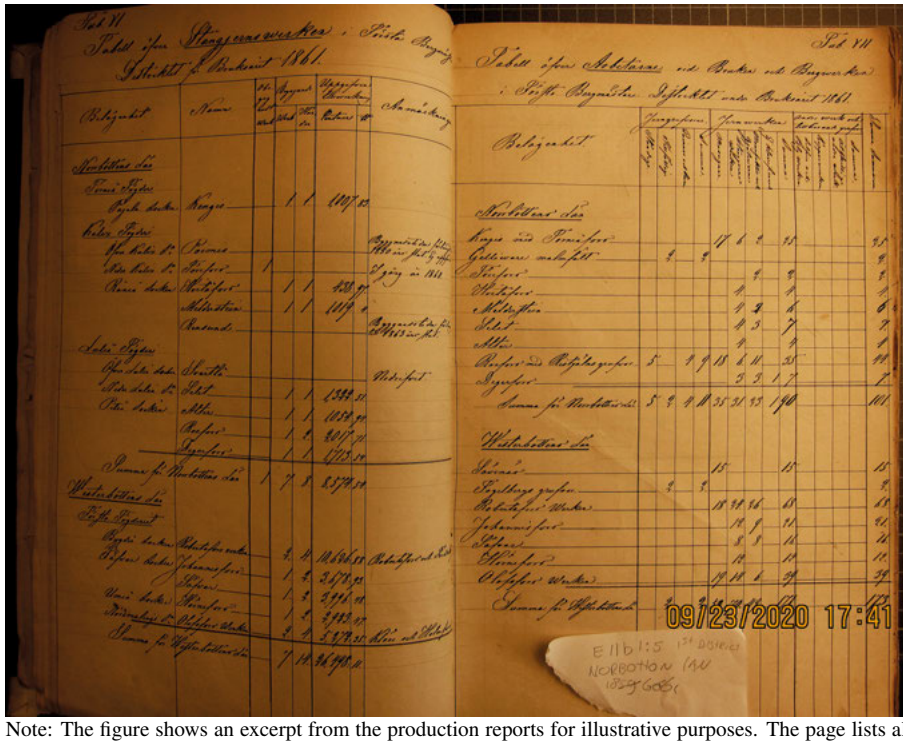
The digitized data set contains information on the output of each production site for every year of its operation, as well as employee counts for certain

[3]For instance Juhász et al. (2020) find a 93% turnover rate in the cotton industry in France between 1800-1840. Of course, the turnover of plants in the Swedish iron industry during this period also includes plants that were not victims of industrialization. For example, some modern large-scale ironworks closed down in the 1870s recession (including Kung Oscarshyttan in Uppland and Bångbro bruk in Kopparberg). However, the overwhelming number of site closures observed in this period are broadly attributed to the industrial transformation and destruction of the old iron industry

[4]The final reporting year varies slightly depending on the district

years. Figure III.3 below illustrates a page from the production reports, including the output and employee count of all finery forges operating in the Northern mining district in 1861. For the purposes of this paper, the production reports offer crucial data on the periods of activity for ironworks that operated during the latter half of the 19th century. For descriptive purposes we also combine this data with a historical list of iron production sites ("Harmens register"), which allows us to observe the first recorded year of production for 85% of the sites in our sample. In our sample of sites observed between 1860 and 1894, the median site first entered the historical records in 1673, with the 10th and 90th percentile first mentioned in 1628 and 1775 respectively. This highlights that the majority of production sites had been operating for well over a century prior to the closures in the latter half of the 19th century.

Figure III.3: *Extract from production reports*



Note: The figure shows an excerpt from the production reports for illustrative purposes. The page lists all finery forges that operated in the Northern mining district in 1861.

To observe the individual worker outcomes we use data from the Swedish population censuses of 1880, 1890 and 1900. The historical census records have been digitized by the North Atlantic Population Project (NAPP) and contain individual-level data on various demographic characteristics, including occupation, family structure, current place of residence, and place of birth. The NAPP has matched individual census records across censuses based on

personal information provided in the census, and successfully linked 64% (55%) of males aged 25 - 45 between the 1880 and 1890 (1880 and 1900) censuses.[5] The census data thus allows us to track the outcomes of individual workers and their children over time between 1880 and 1900.

To identify ironworkers in the census data, we rely on the occupational descriptions from the census (originally provided by the parish priest) that have been coded into five-digit HISCO codes by the NAPP. Due to incomplete information in the occupational descriptions in the census, it is not always possible to distinguish ironworkers from workers employed in related industries. For instance, certain occupations such as "metal smelter" commonly refers to ironworkers, but could also apply to workers in other metal industries. However, the dominance of iron within the Swedish metal processing sector in this period means that this problem is not likely to be severe.[6] In other cases, the census record lists potential ironworkers as “factory workers” or simply “workers” without further specifying the type of industry, which could lead us to exclude workers who were actually employed in the iron industry. In these cases, we take a conservative approach and only include workers whose employment clearly refers to the smelting and forging of metals. The occupational codes used to classify ironworkers are listed in table III.1 below.

Table III.1: *Occupations classified as iron industry workers*

Occupation	Observations
Forgemen	306
Hammersmiths	654
Metal annealers, temperers and hardeners	10
Metal melters and reheaters, and workers in metal melting mills	154
Metal rollers	1210
Metal smelter and furnacemen	2622
Other (specialised) metal workers	202
Other blacksmiths, hammermen and forgeing-press operators	3298
Other metal workers nec	388
Total	8844

Number of observations based on the occupational codings in 1880, for individuals who are linked across the 1880 and 1890 census.

The census data does not include explicit information about individual income or social status, but we can approximate the average annual earnings of individual workers using the information on occupations. We combine the Swedish census data with Norwegian data on average annual earnings by oc-

[5]The linkages are made on the basis of name, age, and parish of birth. The Swedish parishes are on average fairly small (around 2000 inhabitants), which greatly aids the linking procedures. For more detailed information we refer the reader to the documentation on the NAPP website.
[6]In 1890 iron accounted for roughly 85% of employment in the mining and metal processing sector according to the National Statistics. See BISOS C, Bergshantering 1890.

cupation in 1900 provided by Abramitzky et al. (2012). The annual earnings reported in the Norwegian data are comparable to annual earnings in Sweden for the select occupations where data is available in both countries (see appendix III.A), but offers the advantage of a much larger number of occupations compared to the Swedish data available for this period. The process used to link the Norwegian earnings data to occupations in the Swedish census data is described in appendix III.B. Since the earnings data from Abramitzky et al. (2012) represents a cross-sectional sample of occupations it cannot be used to capture changes in wages within occupations over time. However, it provides a unified measure of workers' position in the occupational hierarchy, as indicated by average annual earnings around 1900. Therefore, as long as the relative earnings of occupations remained more or less stable between 1880 and 1900, the data allows us to quantify the relative impact of occupational changes over time for individuals and groups of workers.[7]

III.2.3 Methodology

Since the digitized Swedish census data starts in 1880 and the mining books extend to 1894, the focus of this paper will be on the period between 1880 and 1890. In the baseline analysis, we compare the outcomes of ironworkers and their offspring living in parishes where the ironworks close down to the outcomes of ironworkers living in parishes where at least some ironworks continue to operate. We cross-reference all the closure dates reported in the mining books between 1880 and 1890 using external sources, and exclude closures that actually represent a transition from iron production into other closely related types of manufacturing not included in our mining book data. Figure III.5 in the appendix shows a map of parishes where iron production continued uninterrupted between 1880 and 1890, and where iron production ceased.

Throughout the analyses, we focus on three worker outcomes: (1) whether the worker continues to be employed in the iron industry, (2) the migration responses, and (3) the changes in the average annual income as imputed from worker occupations. To estimate the effect of displacement, we estimate equation III.1, where i refers to the individual and j refers to the parish of residence in the 1880 census. The first two terms, $\text{occupation}_{i,1880}$ and $\text{region}_{i,1880}$, represent occupation and region (Län) fixed effects measured in 1880. The coefficient δ captures the general difference in worker outcomes between "treatment" parishes (where the iron production closes down between 1880 and

[7]The assumption of constant relative earnings over time is bound to be violated to some extent. Bagge et al. (1933) suggest that average earnings between 1880 and 1890 grew by somewhat different rates in the categories of metal industries (19.5%), textile industries (15.1%), forestry (18.5%) and agriculture (16.5%). However, despite the existence of some differential changes in occupational earnings, we expect the data from Abramitzky et al. (2012) to provide a reasonably stable approximation of the relative social status of occupations over this period.

1890) and "control" parishes (where iron production did not close down between 1880 and 1890). Finally, the coefficient γ captures the corresponding difference in outcomes specifically for ironworkers.

$$\begin{aligned}\text{Worker\_outcome}_{i,1890/1900} = \text{occupation}_{i,1880} + \text{region}_{i,1880} + \\ \delta(\text{plant\_death}_{j,1880-1890}) + \\ \gamma(\text{iron\_worker}_{1880} \times \text{plant\_death}_{j,1880-1890}) + \varepsilon_i \quad \text{(III.1)}\end{aligned}$$

The coefficient γ can be interpreted as the causal effect of site closures on ironworker outcomes under two important assumptions. First of all, we assume that the individual characteristics of workers employed in the iron industry in 1880 are similar across treated and control parishes, so that initial sorting (conditional on the occupation and region fixed effects) does not explain differences in outcomes in 1890 or 1900. Second, we assume that site closures are exogenous with respect to other local shocks, which means that there are no unobserved factors that affect ironworkers differently compared to non-ironworkers and that affect the probability of site closures between 1880 and 1890. The appropriateness of these two assumptions will be discussed further in the result section.

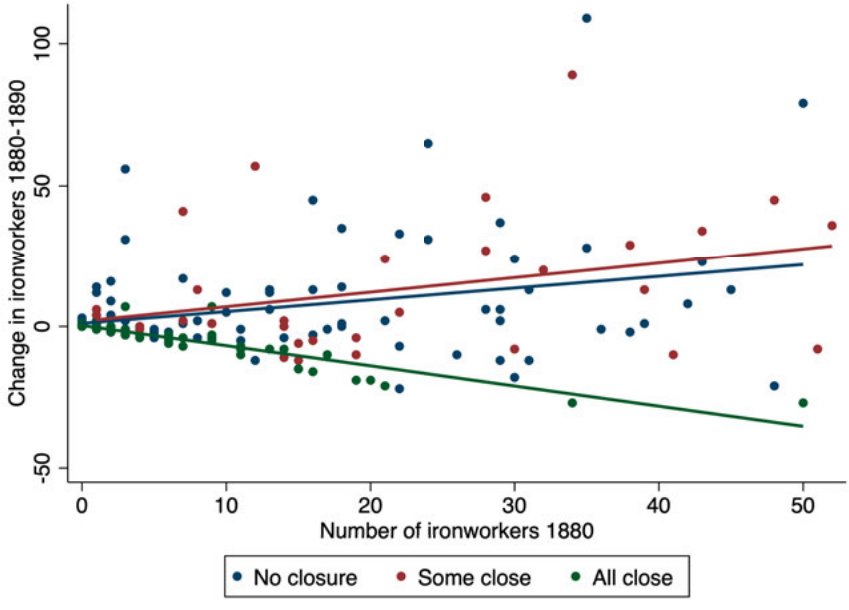
Since the empirical framework compares worker outcomes across parishes, it is important to select a relevant control group. The closest counterfactual for the outcomes of workers in parishes where iron production closed down between 1880 and 1890 may be offered by workers in parishes that also produced iron in 1880, but where production continued at least until 1890. However, in this case is not clear whether any observed differences would reflect losses among displaced workers or gains among workers in the control group, since many of the surviving production sites are simultaneously industrializing and expanding. Therefore, it may be useful to instead evaluate the outcomes of ironworkers in treated parishes against a broader control group that also includes parishes that are not producing iron. In order to address this issue we use three different control groups that include: (1) parishes where the iron industry remained active throughout the period between 1880 and 1890, (2) parishes that produced iron at some point between 1860 and 1894 (i.e. any parish that appears in the production reports at any point), and (3) all parishes in Sweden.[8] The results are quite stable across the three types of control regions, highlighting that the comparison group does not matter a great deal for the interpretation.

Finally, we verify that the census data accurately identify ironworkers and that iron production closures identified from the mining book are visible as

[8]Not all of Sweden has employees in the iron industry, but a few parishes have employees in the same occupations but in other types of metal manufacturing listed in table III.1 (f.i. Zinc and Lead) that can also serve as control group. Furthermore, the different control groups each help to identify the δ estimate in equation III.1 based on different groups

displacement in the census figures. Figure III.4 plots the change in employment in the iron industry between 1880 and 1890 according to the census for three types of parishes, those where all iron production sites close (green), those where some close and some remain open (red) and those all remain open (blue). The iron industry employment shows a strong decline in the parishes where the iron production sites close. This suggests that the plant closures we observe in the iron industry reports line up well with the aggregate changes in employment we observe in the census data.

Figure III.4: *Change in number of ironworkers between 1880 - 1890 according to the census by plant closure status*



III.3 Results

III.3.1 Effect on Worker Outcomes

We start by analyzing the effect of worker displacement on the probability that a worker remains employed in the iron industry after the displacement shock. Table III.2 shows the estimates obtained by estimating equation III.1 on a dummy variable indicating whether the worker is employed in the iron industry when observed in 1890. Consistent with our expectations, site closures significantly reduce the likelihood of working in the iron industry in 1890. In parishes where iron production continues, around 62% of the ironworkers observed in 1880 also remain employed in the iron industry in 1890. By contrast, this probability is 23 - 25 percentage points lower in parishes where iron production ceased. The closure of iron production sites is associated with a sharp and significant drop in the likelihood of continued employment in the iron industry, indicating that workers switched to different occupations following displacement.

The fact that many individuals remain employed in the iron industry even though the production sites in their parish of residence closed suggest that migration might play an important role. Migration was significant during this period, with 25% of the adult males moving to a different parish between

Table III.2: *Occupation 1880-1890*

Outcome:	Working in Iron Industry			
Sample:	Male workers observed in 1880 and 1890			
Parishes:	All	All	Ever iron produced	Producing Iron 1880
Model:	(1)	(2)	(3)	(4)
plant death	-0.00637***	-0.00339***	-0.00692***	-0.0105***
	(0.00143)	(0.00123)	(0.00201)	(0.00263)
plant death × ironworker 1880		-0.225***	-0.244***	-0.250***
		(0.0593)	(0.0590)	(0.0593)
R-squared	0.310	0.312	0.363	0.366
Observations	529387	529387	110846	86495

Standard errors in parentheses are adjusted for clustering at the parish level: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. Sample restricted to those between ages 18-59 at the time of the 1880 census. The lists of occupations considered as ironworkers are displayed in table III.1.

1880 and 1890.[9] Table III.3 shows the effect of site closures on a dummy variable indicating whether the worker moved to a different parish between 1880 and 1890. The rates of out-migration are substantially stronger among ironworkers in the regions where the iron production sites close. The closure of the iron industry between 1880 and 1890 leads to a 25 percentage point increase in the likelihood that an individual migrates, which represents a doubling of the baseline migration rate. No such differences are visible among workers outside the iron industry, with the out-migration for non-ironworkers actually slightly lower in parishes where the iron industry disappeared, suggesting that the difference in out-migration is specific to the iron industry workers.

Iron industry workers thus responded to the upheaval in their industry both by migrating to other parishes and by moving out of the iron industry. The question is how effective these responses were as adaptation mechanisms to mitigate the impact of displacement. Table III.4 reports the effect of iron site closures on log income at the time of the 1890 census. On average, displaced ironworkers earn around 9 - 10% less in 1890 compared to their non-displaced counterparts. The difference is stable across the three comparison groups, and non-ironworkers in the parishes where the iron industry closed between 1880 and 1890 do not appear to suffer similar earnings losses. The results are similar when using income in levels instead of logs as shown in table III.1 in the appendix.

[9]These figures still exclude international migration, which was also substantial during this period (see Karadja and Prawitz, 2019).

Table III.3: *Migration between 1880 - 1890*

Outcome:	Migration			
Sample:	Male workers observed in 1880 and 1890			
Parishes:	All	All	Ever iron produced	Producing Iron 1880
Model:	(1)	(2)	(3)	(4)
plant death	-0.0196**	-0.0228***	-0.00864	-0.000150
	(0.00855)	(0.00845)	(0.00998)	(0.00848)
plant death × ironworker 1880		0.248***	0.253***	0.257***
		(0.0491)	(0.0490)	(0.0490)
R-squared	0.143	0.143	0.115	0.111
Observations	529387	529387	110846	86495

Standard errors in parentheses are adjusted for clustering at the parish level: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. Sample restricted to those between ages 18-59 at the time of the 1880 census. Migration is defined as a change of parish between the 1880 and 1890 census.

Given that the income measure does not capture changes in wages within occupations, the income losses would be larger if the iron production site closures also decrease the general wage levels in the area.[10] At the same time, it should be noted that in absolute terms the real income of displaced ironworkers may still have increased somewhat between 1880 and 1890, despite the shift into lower-paid occupations. After accounting for the relative earnings loss, and assuming that earnings grew at the same rate as average annual real wage in this period (1.6% according to Prado, 2010), the earnings of displaced workers would still have increased by about 6.5% over the ten-year period between 1880 and 1890 (compared to 17.2 percent for other workers).

One concern might be that differences in outcomes between the displaced and non-displaced ironworkers may reflect broader trends in these regions. In general, the δ coefficient in equation III.1 should capture such differences. However, this coefficient is estimated based on all non-ironworkers, which might not form a reasonable counterfactual for ironworkers. To investigate whether broader trends within the manufacturing sector may explain our results, we repeat the analyses above for workers in the manufacturing sector that work with non-metallic inputs, such as carpenters and tailors. The results are displayed in tables III.2 - III.4 in the appendix. There are no significant effects of the iron plant closures on the migration behavior and on the income of non-metallic manufacturing workers. Hence, the results for the iron-workers

[10]However, it seems unlikely that any decline in the general wage levels would have been substantial, given the absence of out-migration among non-ironworkers in the parishes where the iron industry closed.

Table III.4: *Log income in 1890*

Outcome:	Log income			
Sample:	Male workers observed in 1880 and 1890			
Parishes:	All	All	Ever iron produced	Producing Iron 1880
Model:	(1)	(2)	(3)	(4)
plant death	0.00583	0.00715	0.0116	0.0213**
	(0.00844)	(0.00852)	(0.00897)	(0.00961)
plant death × ironworker 1880		-0.0987***	-0.0899***	-0.0985***
		(0.0253)	(0.0278)	(0.0271)
R-squared	0.420	0.420	0.463	0.463
Observations	512003	512003	107095	83947

Standard errors in parentheses are adjusted for clustering at the parish level: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. Sample restricted to those between ages 18-59 at the time of the 1880 census. The income data is described in Appendix III.B.

do not appear to reflect broader trends in the manufacturing industry between the regions, but instead seem specific to the iron industry.

It is possible to take this analysis one step further and to separately estimate equation III.1 for every single occupation interacted with the plant closure indicator, rather than just for the iron industry workers. Tables III.5 - III.8 in the appendix shows the result of this exercise for the three outcome measures. As can be seen, the migration response, occupational change and income losses are strongest for those employed in the iron industry in 1880 compared to the other occupations, again suggesting that the changes within the affected parishes are specific to the iron industry and are not driven by broader changes in regional development.

Finally, we utilize the linked 1880 and 1900 censuses to analyze whether the effects on occupational change, migration and income persist over the longer run. The displacement indicator is likely to be less accurate in this instance, as we do not have full information on iron site closures between 1890 and 1900. Therefore, some of the ironworkers in the control group may themselves also have become displaced when observed in 1900. Nonetheless, the effects of worker displacement on occupational changes, migration and income remain clearly visible in the 1900 census as shown in tables III.9 - III.12 in the appendix. This suggests that workers have not been able to fully adapt to the original displacement shock even in the longer run. The effects of displacement on migration and occupational change between 1880 and 1900 are very similar to the effects on migration and occupational change between

1880 - 1890, suggesting that most of the migration response and occupational changes took place shortly after the plant closures.

III.3.2 Effect on the Next Generation

One important question that remains is whether the displacement affected the outcomes of subsequent generations. In order to investigate this, we study a sample consisting of the sons of workers observed in 1880.[11] To ensure that there is sufficiently large sample of children old enough to have observable labor market outcomes, we focus on the outcomes measured in the 1900 census. We restrict the sample to children who were between the ages 0 and 16 at the time of the 1880 census, and who were under the age of 20 at the time of the plant closure. We estimated the model in equation III.2 which is very similar to equation III.1, but with the occupation and ironworker status on the right-hand side based on the occupation of the household head in 1880.

$$\begin{aligned}\text{Childhood\_outcome}_{i,1900} = \alpha_i * \text{occupation father}_{i,1880} + \beta_i * \text{region}_{i,1880} + \\ \delta * \text{plant\_death}_{j,1880-1890} + \\ \gamma * \text{father iron\_worker}_{1880} \times \text{plant\_death}_{j,1880-1890} + \varepsilon_i \quad \text{(III.2)}\end{aligned}$$

Tables III.5 to III.7 show the effect of worker displacement on the outcomes of children. There is a small negative effect of site closures on the probability that the children are employed as ironworkers. Whereas 23% of the sons of non-displaced ironworkers work in the iron industry by 1900, only 18% of the sons of displaced ironworkers do so.

At the same time, we do find a significant 22 - 25% increase in migration among the children of displaced workers, which is similar to the effects on the parents. Given the relatively high baseline mobility of the children of ironworkers during this time period (44% lives in a different parish in 1900 compared to 1880), this means that the overwhelming majority of children of the displaced workers no longer live in their parish of birth. Hence, the migration response seems to be an important and lasting effect in response to the industry closures. At the same time, no such migration response is visible for the children of non-ironworkers, suggesting that the effects are not driven by wider regional trends in migration patterns.

Finally, table III.7 presents the estimates of the worker displacement on the income of their children in 1900. The coefficient on log income is comparatively small and statistically insignificant across all specifications, suggesting that the worker displacement does not strongly affect the occupational outcomes of their children. Even though the estimates are somewhat imprecise

[11] While it would be interesting to also estimate the models on the labor market outcomes of daughters, the labor force participation of women during this period is around 5%, meaning that occupations are observed for only a very small sub-sample.

due to the relatively small sample of 130 male children of displaced workers (out of which 101 report an occupation)[12], the estimates are nonetheless significantly different from the parental earning losses estimates in table III.11.

Table III.5: *Employment of children in the iron industry in 1900*

Sample:	Male children observed in 1880 and 1900			
Parishes:	All	All	Ever iron produced	Producing Iron 1880
Model:	(1)	(2)	(3)	(4)
plant death	-0.000200	0.000741	-0.00638*	-0.0141***
	(0.00249)	(0.00240)	(0.00342)	(0.00445)
plant death × ironworker 1880		-0.0476	-0.0661	-0.0740*
		(0.0425)	(0.0418)	(0.0416)
R-squared	0.0571	0.0572	0.0874	0.0907
Observations	198893	198893	47071	36842

Standard errors in parentheses are adjusted for clustering at the parish level: *** p < 0.01, ** p < 0.05, * p < 0.10. Sample restricted to those between ages 0-16 at the time of the 1880 census. The lists of occupations considered as ironworkers are displayed in table III.1.

Table III.6: *Migration of children 1880 - 1900*

Sample:	Male children observed in 1880 and 1900			
Parishes:	All	All	Ever iron produced	Producing Iron 1880
Model:	(1)	(2)	(3)	(4)
plant death	-0.0212	-0.0262*	0.00795	0.00552
	(0.0154)	(0.0154)	(0.0152)	(0.0163)
plant death × ironworker 1880		0.253***	0.220***	0.227***
		(0.0582)	(0.0570)	(0.0583)
R-squared	0.121	0.121	0.104	0.0997
Observations	198893	198893	47071	36842

Standard errors in parentheses are adjusted for clustering at the parish level: *** p < 0.01, ** p < 0.05, * p < 0.10. Sample restricted to those between ages 0-16 at the time of the 1880 census. Migration is defined as a change of parish between the 1880 and 1890 census.

[12]The percentage not reporting an occupation is very similar among the children of the displaced workers (22%) and the children of the non displaced workers (20%), suggesting that differences in labor force participation are unlikely to drive the results.

Table III.7: *Log income of children in 1900*

Sample:	Male children observed in 1880 and 1900			
Parishes:	All	All	Ever iron produced	Producing Iron 1880
Model:	(1)	(2)	(3)	(4)
plant death	-0.0259**	-0.0256**	-0.0192	-0.0220*
	(0.0110)	(0.0111)	(0.0125)	(0.0124)
plant death × ironworker 1880		-0.00971	-0.0328	-0.0399
		(0.0365)	(0.0371)	(0.0364)
R-squared	0.141	0.141	0.152	0.151
Observations	122518	122518	28686	23040

Standard errors in parentheses are adjusted for clustering at the parish level: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. Sample restricted to those between ages 0-16 at the time of the 1880 census. The income data is described in Appendix III.B.

III.4 Effectiveness of the Migration Response

The results in the previous section highlighted that migration appears to be an important part of the adjustment process following the iron closure. One question is how effective migration was as a strategy to mitigate the impact of the original displacement shock. While the group that chose to migrate is naturally self-selected, the results may nonetheless provide some indications whether migration can insulate workers against displacement shocks. Around 43% of the displaced ironworkers migrated to a different parish by 1890, which further rises to 54% by 1900. Table III.8 below decomposes the estimated effect of displacement by migration status in 1890. As would be expected, the effect of displacement on the likelihood of working in the iron industry is smaller among those who migrated, suggesting that some displaced workers find other jobs in the iron industry in the new parish of residence. The effects on income and log income are negative for both groups, but the estimates are not significantly different from each other.

This changes when we analyze worker outcomes in 1900. The effect of displacement on income is now smaller and statistically insignificant for those ironworkers who migrated to a different parish. Furthermore, the differences between workers that migrated and did not migrate are now statistically significant. Taken together, the findings suggest that, at least in the long run, migration appears to have been a viable way to mitigate the impact of the original displacement shock. Nonetheless, since the negative effects of displacement on income are visible for both migrants and non-migrants when measured in

1890, it appears that this adjustment may take some time. This aligns well with the more recent literature on worker displacement.

Table III.8: *Effects of worker displacement on outcomes in 1890 by migration status*

Sample:	Non-migrants			Migrants		
Outcome 1890:	Ironworker	Log Income	Income	Ironworker	Log Income	Income
plant death	-0.0105***	0.0213**	20.11**	-0.0108***	0.0213**	20.08**
	(0.00268)	(0.00962)	(9.213)	(0.00268)	(0.00962)	(9.204)
plant death ×	-0.306***	-0.117***	-123.7***	-0.178**	-0.0734**	-93.79***
ironworker 1880	(0.0760)	(0.0329)	(30.73)	(0.0772)	(0.0345)	(33.67)
R-squared	0.372	0.463	0.505	0.373	0.463	0.505
Observations	83854	83854	83854	83824	83824	83824

Standard errors in parentheses are adjusted for clustering at the parish level: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. Sample restricted to those between ages 18 - 59 at the time of the 1880 census. The income data is described in Appendix III.B. The sample is restricted to parishes with iron production in 1880 to save space. The results are virtually identical when using different control groups.

Table III.9: *Effects of worker displacement on outcomes in 1900 by migration status*

Sample:	Non-migrants			Migrants		
Outcome 1900:	Ironworker	Log Income	Income	Ironworker	Log Income	Income
plant death	-0.0239***	-0.0151	-10.17	-0.0237***	-0.0150	-10.11
	(0.00615)	(0.0124)	(8.957)	(0.00614)	(0.0125)	(8.966)
plant death ×	-0.408***	-0.166***	-143.9***	-0.147	-0.0501	-50.53
ironworker 1880	(0.0490)	(0.0375)	(25.77)	(0.0895)	(0.0356)	(36.25)
R-squared	0.271	0.326	0.378	0.273	0.327	0.378
Observations	56322	56322	56322	56330	56330	56330

Standard errors in parentheses are adjusted for clustering at the parish level: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. Sample restricted to those between ages 18 - 49 at the time of the 1880 census. The income data is described in Appendix III.B. The sample is restricted to parishes with iron production in 1880 to save space. The results are virtually identical when using different control groups.

III.5 Conclusion

The transition from artisanal to industrial production is an important milestone in economic development, but its consequences for individual workers remain poorly understood. We study the industrial transformation of the Swedish iron industry in the late 19th century, and find that many ironworkers were

negatively affected by the mass closure of the old iron production sites. Ironworkers who were displaced by site closures between 1880 and 1890 often left the iron industry and tended to end up in lower-paid professions. We estimate that displaced workers on average ended up with 10% lower earnings relative to non-displaced workers. While these losses do not completely offset the general improvements in wages in this period, the large downward movement within the income distribution implies that displaced ironworkers missed out on much of the real wage growth that took place between 1880 and 1890.

Many ironworkers responded to displacement through migration. We find that displaced ironworkers were 25 percentage points more likely to migrate to a different parish compared to non-displaced workers, which we interpret as an attempt to cope with the local labor market shocks. This response appears to have been effective in the long run. We find that the initial earnings losses associated with displacement are similar for migrants and non-migrants, but one decade later the earnings of displaced ironworkers that migrated are similar to those of non-displaced ironworkers. Furthermore, we find no negative effects on the earnings of children of displaced workers. Therefore, while industrialization negatively affected the displaced workers, it appears that it did not generate long-term scarring effects for the subsequent generations.

It should also be noted that migration is likely to be a costly response, as it often involves leaving family and social networks behind. Not only are displaced iron-workers more likely to migrate in general, they are also more likely to permanently leave their parish of birth, which could imply particularly large social costs. These social and economic costs of the migration response are difficult to measure but may constitute an important part of the overall welfare effects of displacement, which calls for more research.

The occupational earning losses we find are comparable to the earnings losses found in the contemporary plant closure literature, which is remarkable due to the lack of reeducation and training programs in this time period to mitigate the costs of unemployment. One explanation may be the importance of regional migration as an adaptation mechanism. However, as noted by Söderberg, 2000, the social consequences of the destruction of the old Swedish iron industry must be interpreted in light of the general industrial expansion happening at the same time. This sets the event studied in this paper apart from many similar examples of mass displacement, such as the steel crises that affected the English midlands, the Rhur area in Germany, the Rust Belt in the US, as well as the Swedish Bergslagen in the 1970s and 1980s.

Since this is the first paper to quantitatively study the individual worker consequences of displacement during the industrial revolution, there are no estimates from other countries to compare our results to. The findings of this paper provide a rational motivation for early social mobilization against technological change, such as the Luddite movement in Great Britain, as we find that displaced workers suffer permanent income losses. At the same time, the unions and political parties that grew out of the industrial revolution in Scan-

dinavia were less technology-averse compared to the United Kingdom. Historical records indicate that opposition to technology was seldom explicit in Swedish union-orchestrated demonstrations in the early 20th century (Molinder et al., 2021). As such, the direct negative consequences of industrialization for Swedish workers may have been relatively mild compared to other European countries.

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- Sweden 1890 Census: The Swedish National Archives, Umeå University, and the Minnesota Population Center. National Sample of the 1890 Census of Sweden, Version 1.0. Minneapolis: Minnesota Population Center [IPUMS], 2010.
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Appendices

Appendix III.A Comparing Norwegian and Swedish Income Data

In this paper, we use Norwegian data on average annual earnings by occupation in 1900 to quantify the economic significance of changes in occupational status. The use of Norwegian data in the Swedish context is not ideal, since the relative earnings of different occupational groups could differ between the two countries (which could also affect their relative rankings). However, given that data on the annual earnings of Swedish workers is not available at a sufficiently detailed level, we use Norwegian data as the second-best option. This said, the Norwegian data likely offers a good approximation due to the large structural similarities and high level of integration between the Swedish and Norwegian economies at the time (Sweden and Norway were in a political, economic and monetary union until 1905). Table III.10 reports the average annual earnings of different categories of Norwegian workers in 1900 provided by Abramitzky et al. (2012), as well as the average annual earnings of similar categories of Swedish workers in 1900 provided by Bagge et al., 1933. Table III.10 suggests that, for those worker categories where a comparison is possible, the Norwegian and Swedish data appear to be well aligned.

Table III.10: *Annual earnings in 1900 by occupation: Swedish and Norwegian data*

	Norwegian data		Swedish data	
Category	Description	Kr	Description	Kr
Metal workers	Metal smelter and furnacemen; Metal casters and workers in metal casting plants; Metal annealers, temperers and hardeners; Metal melters and reheaters, and workers in metal melting mills; Metal rollers	1294	Metal manufacturing and engineering industries	1229
	Hammersmiths; Forgemen; Other blacksmiths, hammermen and forgeing-press operators	1202		
	Other metal workers n.e.c.	1103		
Textile workers	Textile workers, specialisation unknown	701	Workers in textile industries	655
Farmers	general farmers and farmers nfs	1470	Farmers (owner-occupiers)	1457*
	Farm workers, specialisation unknown	655	Male agricultural day-laborers	544
	Husbandmen or cottars	425	Farm servants (statare)	472

Note: The Norwegian data is from Abramitzky et al. (2012) (converted to Swedish Kronor using the exchange rate for year 1900 provided by Klovland (2004)). The Swedish data is from Bagge et al., 1933 who collected information on wages between 1860 and 1930. The reported income if statare is adjusted for in-kind payments. The annual earnings of male agricultural day-laborers is calculated by multiplying the daily wage rate (markegång rate) by 297 (assuming a six day working week).
* To calculate the annual earnings of owner-occupier farmers we divide the total value of the 1900 harvest (after correcting for input costs following Abramitzky et al. (2012)) by the number of farm owners in Sweden in 1900 obtained from "Bidrag till Sveriges officiella statistik" (BiSOS) 1851–1917.

Appendix III.B Imputation of Wage Data

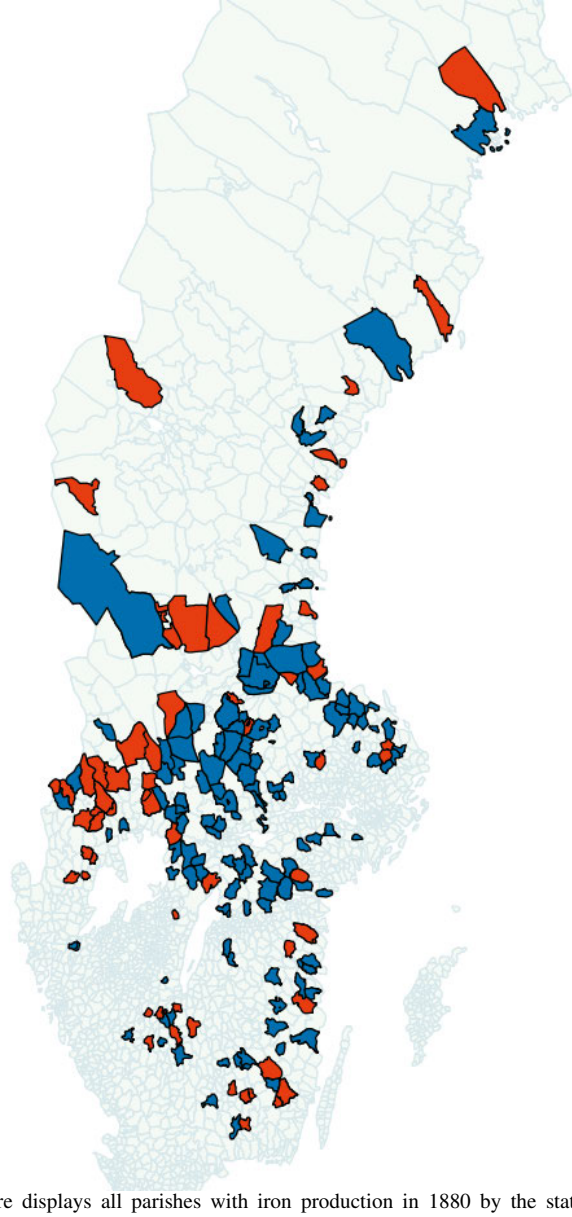
The linkage of the historical occupation to wages is derived from data the provided by Abramitzky et al. (2012). This data is coded according to the same historical 5-digit occhisco classification is also used by IPUMS International for the digitalized Swedish censuses, which means that the historical occupations are standardized according to the same 5-digit occupational clas-

sification. For 73% of the observations, we directly observe the income data from Abramitzky et al. (2012), out of which a substantial fraction (73%) are farming households. For the remaining 27%, we average the wages from occupations within the same 1-/2-/3- digit historical ISCO classification with available wage data, weighting the occupation by the frequency at which they are observed. Using the 3-digit classification pushes the matching rate up to 95% and with the 2-digit classification to 99%. Finally, we use wages on the 1-digit ISCO classification level to obtain a 100% matching rate on wages. The occupation for which we rely on the 1-digit occupational structure are not very obviously selected, with the 5 largest occupations being accountants, charcoal burners, hotel managers, musicians and "other jewelry workers". However, the results are virtually identical if we restrict attention to the occupations for which wages are known at the 3-digit level.

To investigate the applicability of the Norwegian wage structure for the Swedish context, we compared the Norwegian wages with the wage levels which are known for a select number of Swedish occupations in appendix III.A. Finally, for some individuals the occupation is classified as missing, but we know from the occupational string that these individuals were living of church charity or begging. For these individuals, we assign the income to be the lowest observed income among the occupations, which are domestic servants.

Appendix III.C Iron Production Locations

Figure III.5: *Iron production site closures 1880-1890*



Note: Figure displays all parishes with iron production in 1880 by the status of their iron production in 1890. Blue indicators that all iron production sites survived, whereas red indicated that all production sites closed. Parishes where some sites closed and some remained open are not displayed on the map.

Appendix III.D Additional Outcomes

III.D.1 Effect of Displacement on 1890 Income of Ironworkers

Table III.1: *Income in 1890*

Outcome:	Income			
Sample:	Male workers observed in 1880 and 1890			
Parishes:	All	All	Ever iron produced	Producing Iron 1880
Model:	(1)	(2)	(3)	(4)
plant death	3.353	5.004	9.774	20.08**
	(7.587)	(7.679)	(8.522)	(9.202)
plant death ×		-122.6***	-104.5***	-111.1***
ironworker 1880		(24.25)	(26.28)	(25.85)
R-squared	0.495	0.495	0.506	0.505
Observations	512003	512003	107095	83947

Standard errors in parentheses are adjusted for clustering at the parish level: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$ Sample restricted to those between ages 18-60 at the time of the 1880 census. The income data is described in Appendix III.B.

III.D.2 Effects of Plant Closures on Craftsmen in 1890

Table III.2: *Migration between 1880-1890*

Outcome:	Migration			
Sample:	Male workers observed in 1880 and 1890			
Parishes:	All	All	Ever iron produced	Producing Iron 1880
Model:	(1)	(2)	(3)	(4)
plant death	-0.0196**	-0.0180**	-0.00361	0.00442
	(0.00855)	(0.00854)	(0.00981)	(0.00874)
plant death ×		-0.0354**	-0.0292	-0.0120
craftsman 1880		(0.0149)	(0.0207)	(0.0155)
R-squared	0.143	0.143	0.114	0.110
Observations	529387	529387	110846	86495

Standard errors in parentheses are adjusted for clustering at the parish level: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. Craftsmen are defined as three occupational groups, namely "Boot and shoe makers and repairers", "Tailors and tailoresses", "Carpenters".

Table III.3: *Income in 1890*

Outcome:	Income			
Sample:	Male workers observed in 1880 and 1890			
Parishes:	All	All	Ever iron produced	Producing Iron 1880
Model:	(1)	(2)	(3)	(4)
plant death	3.353	4.091	8.793	18.56**
	(7.587)	(7.832)	(8.650)	(9.288)
plant death ×		-16.67	-12.56	-5.158
craftsman 1880		(11.50)	(12.25)	(12.91)
R-squared	0.495	0.495	0.506	0.504
Observations	512003	512003	107095	83947

Standard errors in parentheses are adjusted for clustering at the parish level: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. Craftsmen are defined as three occupational groups, namely "Boot and shoe makers and repairers", "Tailors and tailoresses", "Carpenters".

Table III.4: *Log income in 1890*

Outcome:	Log income			
Sample:	Male workers observed in 1880 and 1890			
Parishes:	All	All	Ever iron produced	Producing Iron 1880
Model:	(1)	(2)	(3)	(4)
plant death	0.00583	0.00697	0.0110	0.0202**
	(0.00844)	(0.00869)	(0.00908)	(0.00967)
plant death ×		-0.0259**	-0.0176	-0.0103
craftsman 1880		(0.0108)	(0.0114)	(0.0120)
R-squared	0.420	0.420	0.463	0.463
Observations	512003	512003	107095	83947

Standard errors in parentheses are adjusted for clustering at the parish level: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. Craftsmen are defined as three occupational groups, namely "Boot and shoe makers and repairers", "Tailors and tailoresses", "Carpenters".

III.D.3 Effects of Plant Closure by Occupation

Table III.5: *Estimates of γ for each occupation separately for probability of working in the iron industry.*

	gamma
Metal smelter and furnacemen	-.3212057
Other blacksmiths, hammermen and forgeing-press operators	-.0838042
Factory labourers (unspecified)	-.0409795
Sawyers and other titled wood/sawmill operatives	-.0098577
Day labourers (e.g., journalier)	-.0042322
Labourers nfs	.0004746
Military, rank unknown	.0018223
Worker nfs	.0019844
Seamen	.0024938
General farmers and farmers nfs	.0030728
Foremen and supervisors, nec	.0031168
Tailors and tailoresses	.0034527
Painters, construction	.0037315
Teachers (primary)	.0038176
Husbandmen or cottars	.0039149
Boot and shoe makers and repairers	.004046
Farm workers, specialisation unknown	.0045755
Bookkeepers and bookkeeping clerks	.0046891
Foresters and wood wardens	.0048584
Dealer, merchant etc. (wholesale and retail trade)	.0078011
Carpenters	.0082665
Millers and related workers	.0120077
Blacksmiths	.0502774
Total	-.0145946

Note: estimates obtained by estimating equation III.1 separately for all occupation with at least 50 observations in the communities where the iron plants close between 1880 and 1890.

Table III.6: *Estimates of γ for each occupation separately for probability of migration.*

	gamma
Other blacksmiths, hammermen and forgeing-press operators	.3071771
Metal smelter and furnacemen	.2855957
Labourers nfs	.1532894
Bookkeepers and bookkeeping clerks	.1301142
Blacksmiths	.1076954
Millers and related workers	.0376488
Husbandmen or cottars	.0229289
Worker nfs	.0185562
Carpenters	.0171508
Teachers (primary)	.0153584
Dealer, merchant etc. (wholesale and retail trade)	.0097882
General farmers and farmers nfs	.0057026
Foresters and wood wardens	.0044715
Day labourers (e.g., journalier)	-.0008961
Foremen and supervisors, nec	-.0095637
Seamen	-.0223469
Tailors and tailoresses	-.0445002
Factory labourers (unspecified)	-.050493
Boot and shoe makers and repairers	-.0545428
Painters, construction	-.0622196
Farm workers, specialisation unknown	-.0897436
Military, rank unknown	-.0928522
Sawyers and other titled wood/sawmill operatives	-.1192087
Total	.0247439

Note: estimates obtained by estimating equation III.1 separately for all occupation with at least 50 observations in the communities where the iron plants close between 1880 and 1890.

Table III.7: *Estimates of γ for each occupation separately for 1890 log income.*

	gamma
Metal smelter and furnacemen	-.1411351
Other blacksmiths, hammermen and forgeing-press operators	-.0876114
Dealer, merchant etc. (wholesale and retail trade)	-.0851558
Seamen	-.0707601
Husbandmen or cottars	-.0654878
Factory labourers (unspecified)	-.0579437
Blacksmiths	-.0490396
Carpenters	-.0379942
Millers and related workers	-.0370944
Boot and shoe makers and repairers	-.0306444
Worker nfs	-.0271859
Tailors and tailoresses	-.0087069
Painters, construction	-.0079238
Sawyers and other titled wood/sawmill operatives	-.0062354
Bookkeepers and bookkeeping clerks	-.005761
Foremen and supervisors, nec	-.0021034
Farm workers, specialisation unknown	.010238
Foresters and wood wardens	.0191371
Military, rank unknown	.0201311
Labourers nfs	.0296351
Teachers (primary)	.0309602
Day labourers (e.g., journalier)	.0437726
General farmers and farmers nfs	.0700754
Total	-.0216015

Note: estimates obtained by estimating equation III.1 separately for all occupation with at least 50 observations in the communities where the iron plants close between 1880 and 1890.

Table III.8: *Estimates of γ for each occupation separately for 1890 income.*

	gamma
Metal smelter and furnacemen	-151.2554
Dealer, merchant etc. (wholesale and retail trade)	-137.8477
Other blacksmiths, hammermen and forgeing-press operators	-119.6495
Factory labourers (unspecified)	-110.9953
Seamen	-76.16467
Husbandmen or cottars	-57.65844
Blacksmiths	-55.22545
Millers and related workers	-51.86971
Boot and shoe makers and repairers	-33.76601
Painters, construction	-24.89331
Worker nfs	-15.88531
Sawyers and other titled wood/sawmill operatives	-12.15184
Carpenters	-12.05427
Bookkeepers and bookkeeping clerks	-8.811954
Tailors and tailoresses	4.34342
Farm workers, specialisation unknown	17.32788
Military, rank unknown	19.45932
Foremen and supervisors, nec	20.65549
Foresters and wood wardens	36.61045
Labourers nfs	44.02872
Teachers (primary)	48.33202
Day labourers (e.g., journalier)	53.82156
General farmers and farmers nfs	63.80629
Total	-24.34103

Note: estimates obtained by estimating equation III.1 separately for all occupation with at least 50 observations in the communities where the iron plants close between 1880 and 1890.

III.D.4 Effects of Displacement on Ironworkers in 1900

Table III.9: *Occupational changes 1880-1900*

Outcome:	Working in Iron Industry			
Sample:	Male workers observed in 1880 and 1900			
Parishes:	All	All	Ever iron produced	Producing Iron 1880
Model:	(1)	(2)	(3)	(4)
plant death	-0.00638**	-0.00346	-0.0129***	-0.0232***
	(0.00283)	(0.00282)	(0.00453)	(0.00604)
plant death × ironworker 1880		-0.209***	-0.251***	-0.261***
		(0.0570)	(0.0581)	(0.0609)
R-squared	0.200	0.201	0.258	0.266
Observations	355165	355165	74406	58283

Standard errors in parentheses are adjusted for clustering at the parish level: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. Sample restricted to those between ages 18-49 at the time of the 1880 census. The lists of occupations considered as ironworkers are displayed in table III.1.

Table III.10: *Migration between 1880-1900*

Outcome:	Migration			
Sample:	Male workers observed in 1880 and 1900			
Parishes:	All	All	Ever iron produced	Producing Iron 1880
Model:	(1)	(2)	(3)	(4)
plant death	-0.0126	-0.0163	0.00599	0.0114
	(0.0122)	(0.0122)	(0.0107)	(0.0101)
plant death × ironworker 1880		0.264***	0.255***	0.263***
		(0.0483)	(0.0483)	(0.0485)
R-squared	0.147	0.147	0.117	0.116
Observations	355165	355165	74406	58283

Standard errors in parentheses are adjusted for clustering at the parish level: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. Sample restricted to those between ages 18-49 at the time of the 1880 census. Migration is defined as a change of parish between the 1880 and 1900 census.

Table III.11: *Log income in 1900*

Outcome:	Log income			
Sample:	Male workers observed in 1880 and 1900			
Parishes:	All	All	Ever iron produced	Producing Iron 1880
Model:	(1)	(2)	(3)	(4)
plant death	-0.0130	-0.0115	-0.0129	-0.0151
	(0.00997)	(0.0100)	(0.0111)	(0.0124)
plant death ×		-0.108***	-0.0980***	-0.105***
ironworker 1880		(0.0226)	(0.0225)	(0.0230)
R-squared	0.303	0.303	0.333	0.326
Observations	341445	341445	71705	56403

Standard errors in parentheses are adjusted for clustering at the parish level: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. Sample restricted to those between ages 18-49 at the time of the 1880 census. The income data is described in Appendix III.B.

Table III.12: *Income in 1900*

Outcome:	Income			
Sample:	Male workers observed in 1880 and 1900			
Parishes:	All	All	Ever iron produced	Producing Iron 1880
Model:	(1)	(2)	(3)	(4)
plant death	-11.46	-9.928	-9.339	-10.13
	(7.279)	(7.343)	(8.048)	(8.954)
plant death ×		-106.7***	-87.42***	-94.63***
ironworker 1880		(20.68)	(20.11)	(20.63)
R-squared	0.377	0.377	0.386	0.378
Observations	341445	341445	71705	56403

Standard errors in parentheses are adjusted for clustering at the parish level: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. Sample restricted to those between ages 18-49 at the time of the 1880 census. The income data is described in Appendix III.B.

Appendix III.E DD and Triple Differences Estimates

The main specification described in equation III.1 can be shown to be numerically equivalent to a modified triple differences (DDD) estimator that controls for occupation-specific and region-specific differential trends. Therefore, one alternative way to state the key identifying assumption underlying our causal claims is that; conditional on occupation-specific and region-specific trends, outcomes would have evolved similarly over time for ironworkers in parishes where the iron production ceased (treatment) and where it did not stop (control) if it were not for the closure of iron production sites. If this assumption holds, then any observed relative changes in outcomes between workers in control and treatment parishes (after adjusting for occupation and region effects) can be attributed to the treatment. The central identifying assumption underlying our preferred specification is thus closely related to the standard parallel trends assumption commonly referred to in the context of DD and DDD estimators, but offers the additional flexibility of also allowing for differential region- and occupation-level dynamic effects. However, this added flexibility also means that, in contrast to canonical DD and DDD estimators, our estimated treatment effects do not represent unconditional differences in expectation between the potential and realized outcomes of treated individuals (ATT), as per the Neyman-Rubin potential outcomes framework. Therefore, in this section we reproduce the main results using a standard triple differences strategy, and show that it allows us to reach the same conclusions. We estimate the regression model:

$$\begin{aligned} y_{i,t} = \alpha_i &+ \delta \left(\text{plant\_death}_j \times \mathbf{1}(year = 1890)\right) \\ &+ \gamma \left(\text{plant\_death}_j \times \mathbf{1}(year = 1890) \times \text{ironworker\_1880}_i\right) \\ &+ \theta \left(\mathbf{1}(year = 1890) \times \text{ironworker\_1880}_i\right) + \varepsilon_{i,t} \end{aligned}$$

where $y_{i,t}$ now represents the outcome of individual i in time $t \in \{1880, 1890\}$. The parameter γ specified in this model is the DDD estimator, which can be described as follows:

$$\begin{aligned} \gamma = &((\bar{Y}_{1890}^{T,ironworker1880} - \bar{Y}_{1880}^{T,ironworker1880}) - \\ &(\bar{Y}_{1890}^{T,not\ ironworker1880} - \bar{Y}_{1880}^{T,not\ ironworker1880})) \\ &- ((\bar{Y}_{1890}^{C,ironworker1880} - \bar{Y}_{1880}^{C,ironworker1880}) - \\ &(\bar{Y}_{1890}^{C,not\ ironworker1880} - \bar{Y}_{1880}^{C,not\ ironworker1880})) \end{aligned}$$

where $\bar{Y}_t^{T,ironworker1880}$ indicates the mean of outcome Y for workers in year t belonging to a treated parish T (as opposed to a control parish C) who were ironworkers in the 1880 (as opposed to having another occupation in 1880). Treated parishes are parishes where iron production closed down between 1880 and 1890. If the difference in changes in outcome $Y_{i,t}$ between ironworkers and non-ironworkers would have been the same across treated and

control parishes in the absence of treatment (i.e. if iron production sites did not close), then γ captures the causal effect of the site closures on the outcomes of ironworkers in the treated parishes.

We also estimate a simple difference-in-differences estimator (corresponding to the estimates presented in column 1 of the main tables), which is given by:

$$Y_{i,t} = \hat{\alpha}_i + \hat{\delta}\left(\text{plant\_death}_j \times \mathbf{1}(year = 1890)\right) + \hat{\varepsilon}_{i,t}$$

where the difference-in-differences estimator $\hat{\delta}$ is given by

$$\hat{\delta} = (\bar{Y}^T_{1890} - \bar{Y}^T_{1880}) - (\bar{Y}^C_{1890} - \bar{Y}^C_{1880})$$

If the changes in outcome Y_t would have been the same across treated and control parishes in the absence of treatment (i.e. if iron production sites did not close), then $\hat{\delta}$ captures the causal effect of the site closures on the outcomes of workers in the treated parishes. Table III.1 below replicates the main results for ironworker status. Table III.2 replicates the main results for migration. Table III.3 replicates the main results for log income.

Table III.1: *Occupational changes 1880 - 1890*

Outcome:	Working in Iron Industry			
Sample:	Panel of male workers observed in 1880 and 1890			
Parishes:	All	All	Ever iron produced	Producing Iron 1880
Model:	(1)	(2)	(3)	(4)
plant death	-0.00664***	-0.00121	-0.0131***	-0.0186***
	(0.00169)	(0.000883)	(0.00191)	(0.00234)
plant death × ironworker 1880		-0.249***	-0.271***	-0.272***
		(0.0602)	(0.0610)	(0.0611)
R-squared	0.000586	0.159	0.167	0.167
Observations	1058774	1058774	221692	172990

Standard errors in parentheses are adjusted for clustering at the parish level: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. Sample restricted to those between ages 18-60 at the time of the 1880 census. The lists of occupations considered as ironworkers are displayed in table III.1.

Table III.2: *Migration between 1880 - 1890*

Outcome:	Migration			
Sample:	Panel of male workers observed in 1880 and 1890			
Parishes:	All	All	Ever iron produced	Producing Iron 1880
Model:	(1)	(2)	(3)	(4)
plant death	-0.0885***	-0.0921***	-0.0356**	-0.0307**
	(0.0139)	(0.0138)	(0.0161)	(0.0131)
plant death × ironworker 1880		0.263***	0.276***	0.276***
		(0.0497)	(0.0510)	(0.0511)
R-squared	0.245	0.245	0.187	0.182
Observations	1058774	1058774	221692	172990

Standard errors in parentheses are adjusted for clustering at the parish level: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. Sample restricted to those between ages 18-60 at the time of the 1880 census. Migration is defined as a change of parish between the 1880 and 1890 census.

Table III.3: *Log income in 1890*

Outcome:	Log income			
Sample:	Panel of male workers observed in 1880 and 1890			
Parishes:	All	All	Ever iron produced	Producing Iron 1880
Model:	(1)	(2)	(3)	(4)
plant death	-0.000612	0.00101	-0.0115	-0.0187*
	(0.00888)	(0.00912)	(0.00976)	(0.0101)
plant death × ironworker 1880		-0.0961***	-0.0692**	-0.0649*
		(0.0351)	(0.0351)	(0.0352)
R-squared	0.00154	0.00170	0.00536	0.00761
Observations	1041390	1041390	217941	170442

Standard errors in parentheses are adjusted for clustering at the parish level: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. Sample restricted to those between ages 18-60 at the time of the 1880 census. The income data is described in Appendix III.B.

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