Assessing the Household and Firm-level Impacts of Electricity Development in Cambodia

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Assessing the Household and Firm-level Impacts of Electricity Development in Cambodia

(カンボジアにおける電力開発の家計および企業に対するインパクト評価)

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EXECUTIVE SUMMARY

According to the United States Energy Information Administration (2013), an estimated 1.3 billion people worldwide did not have access to electricity in 2010, the majority of whom live in South Asia and Sub-Saharan Africa. As stated by the World Bank (2018), this means a considerable proportion of the world's population still lack a fundamental key to progress on a broad range of development indicators, including poverty reduction, health, education, food security, gender equality, and livelihoods.

Even where electricity access is available, consumers in developing countries often face the issues of high prices and frequent outages due to inadequate electricity supply. International donors and governments of many developing countries have been putting efforts into increasing electrification rates and lowering costs in the form of subsidies for poor households. According to the World Bank (2018), approximately 118 million people gain access to electricity each year since 2010; however, more efforts are needed not only in the expansion of electricity access, but also in reducing cost and outages in order to achieve Sustainable Development Goal 7 – ensuring access to affordable, reliable, sustainable, and modern energy for all by 2030.

Electrification is widely assumed to have significant welfare gains for households, especially for women. Without electricity, households continue to rely on traditional sources of fuels such as wood, biomass, and kerosene for lighting, cooking, and heating. Besides the fact that households have to spend a lot of time collecting and preparing these fuels, their health conditions are also affected by the indoor air pollution that is caused by the use of those traditional fuels. Availability of electricity, on the other hand, can improve household welfare through various channels such as income, education, health, and gender equality. A review of a strand of previous empirical studies shows that rural electrification has significant positive effects on household income and the education of children (i.e. Chakravorty et al., 2014; Khandker, Barnes, & Samad, 2012, 2013; Khandker, Samad, et al., 2014; Lipscomb et al., 2013; Litzow et al., 2019; Saing, 2018; van de Walle et al., 2017). However, the direct evidence on how electrification improves income and education is not shown in these studies. Since a clear pathway to higher income and more education is through employment opportunities, another strand of literature has tried to fill this gap by studying the effects of electrification on employment structures in developing countries (i.e. Akpandjar & Kitchens, 2017; Dinkelman, 2011; Grogan & Sadanand, 2012; Rathi & Vermaak, 2018; van de Walle et al., 2017). However, findings from these studies have been mixed, suggesting that the pathways between electrification and employment structure are specific to each country's context and that more empirical evidence is needed.

Cambodia has been left with inadequate infrastructure after its three decades of civil war (1968-1998). During the Khmer Rouge regime (1975-1979), many electricity facilities, including generation, transmission, and distribution systems, were destroyed. Peace and stability were restored in 1998 which left Cambodia far behind in terms of electricity development, compared to its neighboring countries in the region. Since the majority of people without access to electricity are concentrated in South Asia and Sub-Saharan Africa, most of the previous studies have also directed their focus on countries in these regions. Cambodia, on the other hand, has received little attention and discussion among academia. Analysis of the initial progress of electricity development in Cambodia would provide important clues to understand how electricity benefits the welfare of people in other low-income countries. Therefore, this dissertation aims to assess the impacts of electricity development in Cambodia.

Before undertaking the three main empirical studies, this dissertation provides an overview of the electricity development in Cambodia in Chapter 2, while Chapter 1 gives an introduction which focuses on the objectives and significance of the dissertation. The analysis in Chapter 3 examines the effects of rural electrification on changes in employment structure in rural Cambodia, which is still in its early stages of electrification and structural change. The study employs the inverse probability of treatment weighting regression adjustment (IPWRA) method to conducts two estimations, one with individual-level repeated cross-section data and the other with district-level panel data, taking advantage of a large and representative sample from the Cambodia General Population Census in 1998 and 2008. The study finds that the movement away from agricultural labor is dominated by an increase in nonfarm self-employment activities. Access to electricity increases the probability of nonagricultural self-employment of both men and women by 10–11 percentage points over a decade. The findings also confirm the existence of small external effects of electrification in rural Cambodia, possibly due to low electrification rates among rural households.

Chapter 4 examines the health benefits of electricity usage by focusing on the extent of electricity consumption rather than on the electrification status. As electricity consumption among rural households varies considerably due to factors such as electricity price and household socioeconomic status, the study adds a significant contribution to the current literature which mainly focuses on comparing electrified to non-electrified households. Analyzing the recent Multi-Tier Framework (MTF) survey for Cambodia conducted in 2017, the study employs electricity price as an instrumental variable to address the endogeneity of electricity consumption. The study finds evidence that electricity consumption reduces the prevalence of respiratory illnesses among rural households in Cambodia. It is also found that the effect of household electricity consumption on respiratory health is heavily concentrated among higher-income households who are more likely to diversify their usage of electricity to use clean cooking fuels. The evidence suggests that the main mechanism through which the use of electricity affects the respiratory health of rural households is through the switch from solid to clean cooking fuels and that this health benefit occurs mainly among higher-income households.

Besides the low level of electricity access and high price, another pressing issue regarding electricity development in Cambodia is the reliability of electricity. Due to limited supply, electricity outages are frequent in Cambodia which can disrupt daily life and business activities. According to the 2013 World Bank Enterprise Survey, electricity was the most commonly cited as the top constraint to the operation and growth of firms in Cambodia. Therefore, Chapter 5 examines the effects of electricity outages on firm performance in

Cambodia. Using the World Bank Enterprise Survey conducted in 2013, the study finds evidence that electricity outages significantly lower the productivity and revenues of firms in Cambodia. In response to outages, Cambodian firms reduce their materials input due to lower marginal productivity of materials. It is also found that most Cambodian firms use a generator in response to outages and that it can significantly mitigate the negative effects of outages despite its relatively high fixed costs.

Based on the evidence presented above, there are three main direct policy implications that can be drawn. Firstly, it is crucial to achieving 100% electricity access in Cambodia. In recent years, the government of Cambodia has done a good job in increasing electricity access from an electrification rate of 26.4% in 2008 to 91.8% in 2018. The remaining households without access to electricity are likely to be located in remote areas where: (1) it is time-consuming and costly for the investment in the expansion of the existing grid system, (2) electricity businesses may not yield the same profits as other regions. While more efforts should be placed on the expansion of the existing grid system to provide electricity access to poor households in the remote areas, another possible policy recommendation is that the government may provide more incentives to attract more private investors to act as electricity providers in remote areas. Although the policies to attract more private investors may be less time-consuming and more cost-effective (in the short run) in bringing electricity access to isolated households than expanding the National Grid to reach all remote areas, it should be noted that the electricity prices from the private providers are generally higher than those from the government. Therefore, the government of Cambodia needs to consider the balance between efficiency, equity, and sustainability for the future planning of the electricity sector. Another possible way to achieve 100% electricity access without subjected poor households to a high electricity price is that the government may consider giving subsidies for remote households to invest in the Solar Home System. Using the Solar Home System, households do not have to pay for monthly electricity bills but have to pay a relatively high initial cost. With subsidies from the government, poor households are likely to adopt the Solar Home

System, but the questions regarding its capacity, durability, and weather dependency remain. More research on the costs and benefits analysis of the Solar Home System in the context of rural Cambodia is necessary.

Secondly, as electricity price is shown to determine how and how much rural households can utilize electricity, the government of Cambodia needs to tackle the relatively high price of electricity in order to encourage a wider diversification of electricity usage, especially among low-income households. Specifically, rural households connected to the isolated system that generates electricity using diesel fuel are subjected to a high price but are not subjected to the subsidy program from the government, unlike those connected to the National Grid. Therefore, a similar subsidy program for low-income households connected to the isolated system should be considered. Alternatively, the government may put more effort into the expansion of the existing grid system to include those areas as mentioned above. Besides the reduction in electricity prices, low-income households should be informed of the health hazards of indoor air pollution and encouraged to adopt cleaner fuels.

Last but not least, the evidence in Chapter 5 shows that the government in Cambodia also needs to improve the reliability of electricity as it is crucial in facilitating growth and attract new investments. Furthermore, the analysis in Chapter 5 finds that the use of a generator is useful for Cambodian firms in reducing the negative impacts of outages on their productivity. The popular use of generators as a response to outages shows that there are also environmental costs from the unreliable electricity supply. In addition, not all firms can afford to invest in a generator; small businesses without generators are still badly affected by outages. Therefore, the government should put more effort into increasing the supply capacity in order to improve electricity reliability. The Electricité du Cambodge may consider investing in more electricity generation plants to increase the supply capacity. Alternately, the government may boost the investment in electricity generation plants from the private sector in the form of tax incentives, abolishing license fees, or even subsidies.

In assessing the impacts of electricity development in Cambodia, this dissertation analyzes all three pressing issues of electricity development (access, affordability, and reliability). Since this dissertation shows empirical evidence on the importance of rural electrification in Cambodia and that the remaining households without access to electricity are likely to be located in remote areas as mentioned above, the next interesting question to answer is whether the benefits of the use of the Solar Home System for isolated households without electricity access outweigh the costs/disadvantages (its capacity, durability, and weather dependency). Due to the limitation of data, the empirical analysis in Chapter 3 cannot differentiate different sources of electricity. Similarly, with the use of electricity price data in Chapters 4 and 5, the analyses mainly focus on the observations connected to the grid line. Since the Solar Home System can be a potential solution to achieving 100% electricity access in the near future without subjecting poor households to a high electricity price, future research may evaluate the costs and benefits of the Solar Home System for households without access to the electricity grid.

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TABLE OF CONTENTS

ABBREVIATIONS

Asian Development Bank (ADB)

Association of Southeast Asian Nations (ASEAN)

Conditional Independence Assumption (CIA)

Cut, Make, and Trim (CMT)

Difference-in-Differences (DID)

Electricité du Cambodge (EDC)

Electricity Authority of Cambodia (EAC)

Heavy Fuel Oil (HFO)

Independent Evaluation Group (IEG)

Independent Power Producers (IPPs)

Instrumental Variable (IV)

Integrated Public Use Microdata Series, International (IPUMS-International)

International Energy Agency (IEA)

Inverse Probability of Treatment Weighting (IPW)

Inverse Probability of Treatment Weighting Regression Adjustment (IPWRA)

Japan International Cooperation Agency (JICA)

Kilowatt-hour (kWh)

Kreditanstalt Für Wiederaufbau (KfW): German Development Bank

Micro and Small Enterprises (MSEs)

Multi-Tier Framework (MTF)

Ordinary Least Squares (OLS)

Organization for Economic Co-operation and Development (OECD)

Power to the Poor (P2P)

Rural Electricity Enterprises (REEs or licensees)

Total Factor Productivity (TFP)

United States Dollar (USD)

World Bank Enterprise Surveys (WBES)

World Health Organization (WHO)

LIST OF TABLES AND FIGURES

List of Tables

List of Figures

CHAPTER 1 - INTRODUCTION

1.1 Background of the Study

According to the United States Energy Information Administration (2013), an estimated 1.3 billion people worldwide did not have access to electricity in 2010, the majority of whom live in South Asia and Sub-Saharan Africa. As stated by the World Bank (2018), this means a considerable proportion of the world's population still lack a fundamental key to progress on a broad range of development indicators, including poverty reduction, health, education, food security, gender equality, and livelihoods.

Even where electricity access is available, consumers in developing countries often face the issues of high prices and frequent outages due to inadequate electricity supply. International donors and governments of many developing countries have been putting efforts into increasing electrification rates and lowering costs in the form of subsidies for poor households. According to the World Bank (2018), approximately 118 million people gain access to electricity each year since 2010; however, more efforts are needed not only in the expansion of electricity access, but also in reducing cost and outages in order to achieve Sustainable Development Goal 7 – ensuring access to affordable, reliable, sustainable, and modern energy for all by 2030.

Electrification is widely assumed to have significant welfare gains for households, especially for women. Without electricity, households continue to rely on traditional sources of fuels such as wood, biomass, and kerosene for lighting, cooking, and heating. Besides the fact that households have to spend a lot of time collecting and preparing these fuels, their health conditions are also affected by the indoor air pollution that is caused by the use of those traditional fuels. Availability of electricity, on the other hand, can improve household welfare through various channels such as income, education, health, and gender equality. A review of a strand of previous empirical studies shows that rural electrification has significant positive effects on household income and the education of children (i.e. Chakravorty et al., 2014;

Khandker, Barnes, & Samad, 2012, 2013; Khandker, Samad, et al., 2014; Lipscomb et al., 2013; Litzow et al., 2019; Saing, 2018; van de Walle et al., 2017). However, the direct evidence on how electrification improves income and education is not shown in these studies. Since a clear pathway to higher income and more education is through employment opportunities, another strand of literature has tried to fill this gap by studying the effects of electrification on employment structures in developing countries (i.e. Akpandjar & Kitchens, 2017; Dinkelman, 2011; Grogan & Sadanand, 2012; Rathi & Vermaak, 2018; van de Walle et al., 2017). However, findings from these studies have been mixed, suggesting that the pathways between electrification and employment structure are specific to each country's context and that more empirical evidence is needed.

While there is active literature on the effects of electrification on income, education, and employment, there has been relatively little research on the impacts of electrification on household members' health. A wave of studies has shown that the reduction of indoor air pollution has a significant effect on respiratory health (Dasgupta et al., 2006; Duflo et al., 2008; Edwards & Langpap, 2012; Hanna et al., 2016; Kurata et al., 2020; Silwal & Mckay, 2015). However, these studies focused solely on different types of cooking fuels/cookstoves rather than on electricity consumption. Barron and Torero (2017) and Litzow et al. (2019) were among the first studies to investigate the impacts of household electrification on health outcomes. While Barron and Torero (2017) found that household electrification substantially reduces indoor air pollution and lowers the incidence of acute respiratory infection among children under six in northern El Salvador, Litzow et al. (2019) did not find a significant effect of electrification on health outcomes. It is obvious that more empirical evidence is needed to show the effects of electricity usage on respiratory health.

A review of the current literature about the impacts of electrification also shows that there has been relatively less research on how electricity affects firms' behaviors. As technological progressions in production have centered on electricity-powered technologies, electricity has become a crucial input for most production processes. However, even where consumers are connected to the electric grid, firms in developing countries are facing unreliable electricity supply where outages are frequent. As electricity has increasingly become an indispensable input for most firms, empirical research to examine the effects of electricity outages and to understand how firms respond to electricity outages is needed because private sector development is essential for economic growth and development in developing countries.

1.2 Why Study Electrification under the Cambodian Context?

Although not one of the countries in South Asia nor Sub-Saharan Africa, Cambodia has been left with inadequate infrastructure after its three decades of civil war (1968-1998). During the Khmer Rouge regime (1975-1979), many electricity facilities, including generation, transmission, and distribution systems, were destroyed. Peace and stability were restored in 1998 which left Cambodia far behind in terms of electricity development, compared to its neighboring countries in the region.

In an effort to expand electricity access in rural areas, the Cambodian government has given the rights to private investors to participate in the country's power sector development as stated in the Electricity Law of the Kingdom of Cambodia in 2001, which is the first guideline regulating all operations involving electric power supply and services throughout Cambodia (Electricity Authority of Cambodia (EAC), 2004). The private investors may obtain licenses from the Electricity Authority of Cambodia for the rights to generate and/or distribute electricity in a given area.

Currently, both state-owned and private enterprises run electricity generation and distribution in Cambodia. A government-owned company named Electricité du Cambodge (EDC) and private independent power producers (IPPs) supply power in the city and provincial towns, while private Rural Electricity Enterprises (REEs or licensees) supply power in rural areas.[1] The involvement of the private sector in generating and distributing electricity

[1] All IPPs have their own electricity generation facilities while some of REEs purchase electricity from other sources and redistribute it (EAC, 2004).

in Cambodia has resulted in variation in electricity prices across the country, with the average price higher than in the neighboring countries.

Besides the low level of electricity access and high price, another pressing issue regarding electricity development in Cambodia is the reliability of electricity. Due to limited supply, electricity outages are frequent in Cambodia which can disrupt daily life and business activities. According to the 2013 World Bank Enterprise Survey, electricity was the most commonly cited as the top constraint to the operation and growth of firms in Cambodia.

Since the majority of people without access to electricity are concentrated in South Asia and Sub-Saharan Africa, most of the previous studies have also directed their focus on countries in these regions. Cambodia has received little attention and discussion among academia even though it started electrification from a very low level of access (5.4% in rural areas in 1998). Thus, research studies regarding electrification in Cambodia are very limited. Analysis of the initial progress of electricity development in Cambodia would provide important clues to understand how electricity benefits the welfare of people in other low-income countries.

1.3 Objectives and Significance of the Study

In view of filling the study gaps described in Section 1.1, the present dissertation intends to provide more empirical evidence on the benefits of electrification, specifically from the Cambodian case. This dissertation consists of three main empirical studies motivated by the three pressing issues of electricity development in Cambodia which are access, affordability, and reliability of electricity. The first empirical study in this dissertation focuses on electricity access. It aims to investigate the effects of electrification on employment structure in rural Cambodia. The motivation behind this study is that the previous research on the effects of electrification on employment structure has shown mixed findings which suggests that the pathways between electrification and employment structure are specific to each country's context. Therefore, this study contributes to the current literature by providing additional evidence from Cambodia which is still in its early stages of electrification and structural change.

The second empirical study is motivated by the fact that most of the previous research on the benefits of electricity focus on electrification status or access to electricity rather than on the extent of electricity usage due to data limitation. By employing the recent Multi-Tier Framework (MTF) survey for Cambodia conducted in 2017 which provides information on household monthly electricity consumption and electricity price, the second empirical study intends to examine the health benefits of electricity consumption in rural Cambodia and the mechanism behind this relationship. While contributing to the current literature by analyzing the extent of electricity consumption, this study also tries to fill the gap in the literature which contains very limited studies on the health benefits of electrification.

The third empirical study turns to the issue of the reliability of electricity in Cambodia. As electricity is important not only for household welfare but also for firm performance and growth, the third study aims to show the effects of electricity outages on firm performance in Cambodia and how firms respond to such constraints. Previous research has shown mixed findings regarding how firms respond to electricity constraints. Thus, this study provides additional evidence from the Cambodian case where outages happen rather frequently and the use of generators is common among firms.

The dissertation attempts to address such questions as: What are the effects of rural electrification on employment structure in Cambodia? How does rural electrification change the employment structure in Cambodia? What effect does electricity usage have on respiratory health in rural Cambodia? How does electricity usage improve respiratory health in rural Cambodia? In other words, what are the pathways through which the use of electricity affects respiratory health in rural Cambodia? What effect do electricity outages have on total factor productivity and revenues of firms in Cambodia? How do firms in Cambodia respond to outages? Does the use of generators during outages mitigate the negative effects of outages on total factor productivity and revenues of firms in Cambodia? After examining these benefits of electrification, this dissertation aims to give useful policy recommendations regarding the three pressing issues of electricity development in Cambodia, i.e. access, affordability, and reliability of electricity.

1.4 Organizational Structure

In terms of organizational structure, this dissertation is laid out in the following manner: Chapter 1 introduces the current state of electrification and the issues surrounding it; provides a summary of gaps in the literature; and presents the objectives, significance, and structure of the dissertation. Chapter 2 gives an overview of the electricity development in Cambodia. Chapter 3 provides empirical evidence of the effects of rural electrification on the employment structure in Cambodia. Chapter 4 shows the causal effects of electricity consumption on respiratory health in rural Cambodia, with the use of electricity tariff to instrument for the electricity consumption. Chapter 5 focuses on electricity outages and their effects on firm performance in Cambodia. Finally, Chapter 6 summarizes the main results from the empirical analyses in the previous chapters. Conclusions, policy implications, and prospects for further study are also presented in this chapter.

CHAPTER 2 - ELECTRICITY DEVELOPMENT IN CAMBODIA

2.1 Background

Electricity was first available in Cambodia in 1906 (Electricity Authority of Cambodia (EAC)). Electricity development in Cambodia was progressing until the start of a three-decade civil war (1968-1998). After the war ended, Cambodia's infrastructure including electricity was in disarray. During the Khmer Rouge regime (1975-1979), many electricity facilities, including generation, transmission, and distribution systems, were destroyed. Peace and stability were restored in 1998 and the *Electricity Law of the Kingdom of Cambodia* was promulgated in 2001 to establish a framework for all operations involving electric power supply and services throughout Cambodia (Electricity Authority of Cambodia (EAC), 2004). One of its most important features was "the principles for the promotion of private ownership of the facilities for providing electric power services" to attract private investors to participate in the country's power sector development (EAC, 2004, p. 6). Currently, both state-owned and private enterprises run electricity generation and distribution in Cambodia. A government-owned company named Electricité du Cambodge (EDC) and private independent power producers (IPPs) supply power in the city and provincial towns, while private Rural Electricity Enterprises (REEs or licensees) supply power in rural areas.[2]

According to the EAC (2009), in 2008 Cambodia imported approximately 20% of its total electricity supply from Vietnam and Thailand. The main sources of electricity generation in Cambodia in 2008 were diesel/heavy fuel oil (HFO) (95%), hydropower (3.1%), coal (1.6%), and wood/biomass (0.3%). As a result of low capacity, high fuel prices and imports, electricity costs in Cambodia are quite high, especially in rural areas. To improve self-sufficiency of power supply and to rely less on diesel/heavy fuel oil, Cambodia has been investing on hydropower and coal-fired plants (Electricité du Cambodge, 2016). By 2018, the total share of imported electricity from the neighboring countries is reduced to 16%, and the main sources

[2] All IPPs have their own electricity generation facilities while some of REEs purchase electricity from other sources and redistribute it (EAC, 2004).

of electricity generation was hydropower (58%), coal (37%), diesel/heavy fuel oil (HFO) (4%), wood/biomass (0.8%), and solar (0.2%) as shown in Figure 2.1 (EAC, 2019).

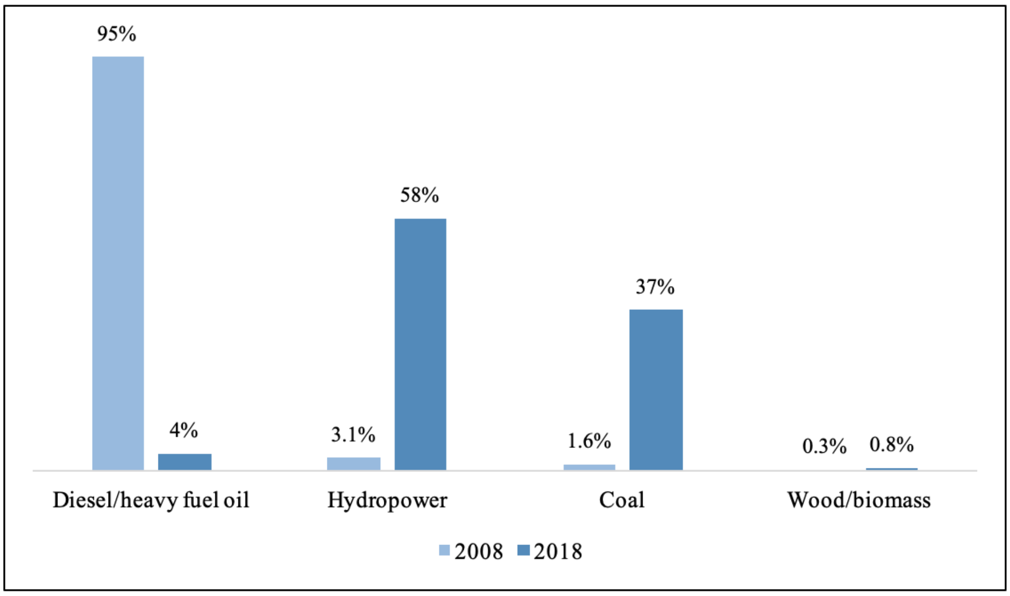

Figure 2.1 *Main sources of electricity generation in 2008 and 2018*

Source: Electricity Authority in Cambodia (EAC) (2009, 2019)

With the assistance of international organizations, Cambodian government have implemented various electricity development projects including Rural Electrification and Transmission Project in 2003 which utilized 150-million-USD loan from the World Bank (World Bank, 2003). In the Greater Mekong Subregion Transmission Project in 2003, 76 million USD loan was financed by Asian Development Bank (ADB) to construct transmission lines from Vietnam to Takeo province and the capital city, Phnom Penh (ADB, 2014). In addition, the ADB approved another 8-million-USD loan in 2007 to build transmission lines from Thailand to Banteay Meanchey, Siem Reap, and Battambang province in order to facilitate importation of power from Thailand (ADB, 2013). In 2007, the German government also approved a 30-million-EUR Rural Electrification and Power Transmission Program with the aim to expand and improve national power grid in Kampot, Takeo, and Kampong Speu province (KfW Development Bank, 2014).

In areas not connected to the national grid, electricity access is provided through the use of off-grid and mini-grid technologies as well as imports from neighboring countries. The Ministry of Mines and Energy established a Rural Electrification Fund (REF) that provides subsidies for rural electrification projects through either interest-free loans or grants to cover a portion of the project costs (EAC, 2019). The REF has attracted private investors to invest in the power sector in rural areas and has contributed to the expansion of transmission lines in rural areas. For consumers, the REF provides a "Power to the Poor (P2P)" program with the aim to facilitate rural households in the process of acquiring electricity access by providing consumers with interest-free loans for in-house wiring and equipment, connection fees, and deposits required by electricity suppliers (EAC, 2019).

With the aim to speed up electrification, Cambodia, in 2006, has set a target of achieving universal electrification to all villages by 2020 and at least 70% of all households to be connected to the grid by 2030 as stated in the *Rural Electrification by Renewable Energy Policy 2006*. Table 2.1 shows the average electrification rates among the 10 ASEAN countries in 1998, 2008, and 2018. Up until 2008, the proportion of electrified households in Cambodia is still very low at 26.4%. Compared with other countries in the region, the average electrification rates in Cambodia in 1998 and 2008 were the lowest among the 10 ASEAN countries. However, significant progress was made in the Cambodian power sector during the last 10 years resulting in the increase of electrification rate from 26.4% in 2008 to 91.8% in 2018. This shows that Cambodia has already achieved its target that was set in the *Rural Electrification by Renewable Energy Policy 2006*. The efforts from the government in achieving this significant progress include investing in electricity generation plants and the expansion of the existing grid lines. Table 2.2 shows the differences in the share of electrified households in urban and rural areas in 1998 and 2008. Approximately 13.1% of rural households had access to electricity in 2008, up from 5.4% in 1998. The average electrification rates are much higher in urban areas, where the rates were 62.8% and 87.0% in 1998 and 2008, respectively (National Institute of Statistics, 2009).

Table 2.1 Electrification rate among ASEAN countries (% of population)

Countries	**1998**	**2008**	**2018**
Brunei	100	100	100
Cambodia	18.7	26.4	91.8
Indonesia	80.9	92.7	98.5
Lao PDR	37.4	66.0	98.1
Malaysia	N.A.	99.3 *[1]	100
Myanmar	47.0*[2]	50.5	66.2
Philippines	71.3	83.3	94.4
Singapore	100	100	100
Thailand	82.1*[3]	95.5	99.8
Vietnam	83.9	95.2	100

Notes: Data for Malaysia in 1998 are not available.
*[1] Data in 2009.
*[2] Data in 2002.
*[3] Data in 2000.
Source: World Development Indicator

Table 2.2 Share of electrified households in Cambodia 1998 and 2008

	Year	**Number of Households**	**Electrified Households (%)**
Rural	1998	1,797,505	5.4
	2008	2,311,058	13.1
Urban	1998	364,581	62.8
	2008	506,579	87.0
Total	1998	2,162,086	15.1
	2008	2,817,637	26.4

Note: Electricity category includes city power, generator, or both. The data from the Cambodia General Population Census in 2019 is yet to be available.
Source: National Institute of Statistics (2009).

2.2 Electricity Tariff in Cambodia

The electricity generation and distribution in Cambodia are operated by both state-owned and private enterprises. As mentioned earlier, a government-owned company named Electricité du Cambodge (EDC) and private independent power producers supply power mainly in the city and provincial towns, while private Rural Electricity Enterprises (licensees) supply power in rural areas. The involvement of the private sector in the development of the power sector in Cambodia has resulted in variation in electricity tariffs across the country.

The electricity tariff for household consumers is basically determined based on the cost of electricity generated or purchased and the cost of distribution. Thus, the electricity price in Cambodia is not determined by the demand and supply interaction in the market. It is solely dependent on input factors of the supply side (Poch and Tuy, 2012). The electricity prices are set by the electricity suppliers, however, the set prices require prior approval from the Electricity Authority of Cambodia (EAC) to ensure that the provision of electricity services is performed efficiently, sustainably, and transparently (EAC, 2008). Since the electricity tariff is determined by each supplier based on the full-cost recovery principle, the electricity tariff varies significantly from area to area (Poch and Tuy, 2012).

During the late 2000s, most of the licensees generated electricity using diesel/heavy fuels oil (HFO), resulting in a high cost of electricity tariffs in rural areas. In response to fluctuation in fuels (diesel/HFO) costs, the EAC has introduced a Fuel Cost Adjustment mechanism in which the tariff for different slab rates of fuels is pre-determined and fixed by the EAC to ensure transparency to consumers (EAC, 2009, p. 32). With the expansion of the grid system in rural areas, more and more licensees replace the electricity generation operation using diesel/HFO with the electricity bought from the grid system as it results in a lower tariff. There were 29 isolated systems (10 provinces) that generated electricity using diesel fuels by the end of 2016, while the number reduced to only 14 (7 provinces) by the end of 2017 (EAC, 2017, 2018). The electricity tariff for consumers of the isolated systems that generated electricity using diesel fuels in 2017 ranged from about 1000-3100 Riels/kWh (EAC, 2018).

There are four types of the grid system in Cambodia: (1) “National Grid”—the high voltage grid system, consisting of all high voltage lines and connected grid substations, (2) Medium Voltage Grid connected to Vietnam system, (3) Medium Voltage Grid connected to Thailand system, and (4) High Voltage Grid connected to Laos. According to the EAC (2018), the electricity tariff for consumers of licensees importing electric power supply from Vietnam, Thailand, and Laos is varied, due to different costs of electricity from the importing countries and also different costs of infrastructure and volumes of sale. The electricity tariff for consumers of the licensees importing electricity supply from the neighboring countries in 2017 ranged from about 600-1210 Riels/kWh.

Another group of licensees is those that connected to the National Grid. Starting from 2016, the electricity tariff for consumers of the licensees connected to the National Grid is determined by the EAC through the implementation of a subsidy program of the Rural Electrification Fund (REF). As a result of the subsidy program, the electricity tariff for consumers of the licensees connected to the National Grid has been reduced from about 1050-1100 Riels/kWh to 790 Riels/kWh (EAC, 2018). The licensees connected to the National Grid comprised of about 79% of all licensees in 2017.

Also connected to the National Grid, the state-owned electricity company, Electricité du Cambodge (EDC) provides a slightly different tariff for their consumers who are mainly people residing in Phnom Penh city and 16 provincial towns (EAC, 2018). In 2017, the electricity tariff for consumers in Phnom Penh city and the 16 provincial towns is 770 Riels/kWh, with the exception of Svay Rieng (650 Riels/kWh). By the end of 2017, the EDC also expands its supply to consumers outside provincial towns in the provinces of Kratie, Stung Treng, Preah Vihear, and Ratanakiri, with the tariff of 790 Riels/kWh (EAC, 2018).

The subsidy program from the government in 2016 has resulted in a lower and identical electricity tariff for some households which are supplied by licensees connected to the National Grid. Nevertheless, a significant number of households, which are supplied by the licensees importing electricity from different neighboring countries and the isolated systems generating electricity using diesel fuels, are subjected to a wide range of electricity tariffs. As a result, there is a significant variation in electricity tariff across Cambodia as shown in Table 2.3.

Compared to other countries in the region, the electricity price in Cambodia is relatively high. According to the IEA (2017), even the low-income households with a monthly electricity consumption of less than 10 kilowatt-hours (kWh), that are subjected to a subsidy from the government, still have to pay an electricity price that is higher than the average residential tariff in Indonesia, Malaysia, Thailand, and Vietnam. Moreover, rural households are generally subjected to an even higher electricity price than urban households. High electricity price can hamper the extension of electricity access as poor households cannot afford it. Therefore, it is fairly important that along with the expansion of electricity access, the electricity is affordable to the public especially to poor households.

Table 2.3 Electricity tariff in Cambodia

Electricity Price				
Licensees not connected to the National Grid		Licensees connected to the National grid		
Isolated system generated electricity using diesel fuel	Licensees importing electricity supply from the neighboring countries (Laos, Thailand, and Vietnam)	Subsidized by the Rural Electrification Fund	EDC	
			Phnom Penh and 16 provincial towns	Svay Rieng
1000-3100 Riels/kWh	600-1210 Riels/kWh	790 Riels/kWh	770 Riels/kWh	650 Riels/kWh

Source: Electricity Authority in Cambodia (EAC) (2018)

2.3 Electricity Outages in Cambodia

Power outages happen rather frequently in Cambodia especially during the dry season due to inadequate supply. Table 2.4 shows the estimated frequency and duration of outages per year from 2008 to 2013 by the causes of outages. The data in 2013 is the record by April 2013.

Table 2.4 Frequency and duration of electricity outages in Cambodia from 2008 to 2013

Years		Power lack	Technical issues	Total
2008	Frequency	101	7	108
	Duration (minutes)	11,002	473	11,475
2009	Frequency	41	4	45
	Duration (minutes)	3,987	584	4,571
2010	Frequency	12	7	19
	Duration (minutes)	920	929	1,849
2011	Frequency	49	12	61
	Duration (minutes)	3,980	1,256	5,236
2012	Frequency	64	13	77
	Duration (minutes)	6,379	1,235	7,614
2013*	Frequency	55	18	73
	Duration (minutes)	4,694	2,227	6,921

Notes: *Data for 2013 is the record by April 2013.
Source: Japan International Cooperation Agency (JICA) (2014)

Table 2.4 shows that the lack of power supply is the main cause of electricity outages in Cambodia. According to the Japan International Cooperation Agency (JICA) (2014), the improvement in the incidence of outages in 2009 and 2010 was because of the import of electricity from Vietnam which significantly reduced the number of outages caused by the shortage of electricity supply. However, the electricity import from Vietnam has an upper limit. The rise in the local electricity demand led to the continuing increase of the incidence of power outages in 2011 and the years afterward as seen in Table 2.4. The improvement in the reliability of the electricity supply is important for Cambodia. Reducing the frequency and duration of outages can attract new investments as well as reducing the constraints to the operation and growth of the current businesses (JICA, 2012).

CHAPTER 3 – RURAL ELECTRIFICATION AND CHANGES IN EMPLOYMENT STRUCTURE IN CAMBODIA [3]

3.1 Introduction

Electricity is a basic necessity for most people in the developed world, while millions still lack access in developing countries. The United States Energy Information Administration (2013) estimated that approximately 1.3 billion people (i.e., 19% of the world's population) did not have access to electricity in 2010. Recent studies on various developing countries have provided evidence of the positive effects of electricity on household income and the education of children (Chakravorty et al., 2014; Khandker, Barnes, & Samad, 2012, 2013; Khandker, Samad, et al., 2014; Lipscomb et al., 2013; Litzow et al., 2019; Saing, 2018; van de Walle et al., 2017). However, these studies provide no direct evidence on how electrification improves income and education.

One important pathway to higher income and more education is a move to occupations with higher earnings or a diversification of income sources. Extant studies on the effects of electrification on employment structures in developing countries have shown mixed findings (Akpandjar & Kitchens, 2017; Dinkelman, 2011; Grogan & Sadanand, 2012; Rathi & Vermaak, 2018; van de Walle et al., 2017), which suggest that the pathways between electrification and employment structure are specific to each country's context. Thus, this study aims to provide another evidence of the effects of electrification on changes in employment structure in rural Cambodia, which is still in its early stages of electrification and structural change.

Cambodia ranks lowest in terms of per-capita income among the countries analyzed in previous research on electrification and employment. Hence, the demand for non-food items is still limited. Cambodia has also experienced three decades of civil war (from 1968 to 1998) and started electrification from a very low level of access (5.4% in rural areas in 1998).

[3] This chapter was published in journal *World Development* in January 2021. It is available online at: https://doi.org/10.1016/j.worlddev.2020.105212

Analysis of the initial progress of electricity expansion in Cambodia would provide important clues to understanding how electricity benefits the welfare of people in other low-income countries.

Besides providing additional evidence, this study contributes to the current literature by looking further into the movement out of agriculture toward three different types of nonagricultural employment: self-employment, wage employment, and unpaid work. Understanding such structural changes in the labor market is important because non-farm employment plays a vital role in lifting people out of poverty. Recent research, including that of Hoang et al. (2014), Lanjouw and Shariff (2004) and Seng (2015), has shown that participation in the rural non-farm sector substantially increases incomes and reduces the vulnerability of farm households in developing countries, including Cambodia. In addition, by looking into nonagricultural self-employment and unpaid employment, we provide evidence on the important contributions of the informal sector in a rural economy.

Estimating the effects of electrification can be challenging since it is clear that electrification projects are not random and access to electricity is chosen by households. To mitigate the problem of non-random placement, the inverse probability of treatment weighting regression adjustment (IPWRA) method is used to conducts two estimations, one with individual-level repeated cross-section data and the other with district-level panel data. By comparing the results of individual-level and district-level analyses, we also can capture the extent of the external effects of rural electrification.

Our estimation results show that the movement away from agricultural labor is dominated by an increase in nonfarm self-employment activities. Access to electricity increases the probability of nonagricultural self-employment of both men and women by 10–11 percentage points over a decade. We also confirm the existence of small external effects of electrification in rural Cambodia, possibly due to low electrification rates among rural households.

The remainder of this chapter is structured as follows: Section 3.2 provides a literature review; Section 3.3 outlines the empirical strategies; Section 3.4 presents an explanation of the data; Section 3.5 discusses the empirical results; and Section 3.6 offers the conclusions.

3.2 Literature Review

Many previous studies have investigated the effects of electricity expansion in developing countries. Most have examined effects on poverty and/or children's education (Chakravorty et al., 2014; Khandker, Barnes, & Samad, 2012, 2013; Khandker, Samad, et al., 2014; Lipscomb et al., 2013; Litzow et al., 2019; Saing, 2018; van de Walle et al., 2017) and have found positive effects. However, results on employment structures have been mixed (Akpandjar & Kitchens, 2017; Dinkelman, 2011; Grogan & Sadanand, 2012; Rathi & Vermaak, 2018; van de Walle et al., 2017).

Dinkelman (2011) and Grogan and Sadanand (2012) found significant positive effects of rural electrification on female employment but not on male employment in South Africa and Nicaragua, respectively. Dinkelman (2011) provided evidence that electrified areas have shown an increase in the use of electric lighting and electric appliances for cooking, reducing the use of wood-fueled cooking. With the use of electricity for home production, South African women are able to work outside the home or run their own micro-enterprises. Grogan and Sadanand (2012) found that electrified households in rural Nicaragua spend less time on firewood collection as households are able to work longer hours. The authors suggest that extra income generated from longer working hours enables households to buy firewood instead of collecting it. Compared to South Africa, the use of household electric appliances is not as prevalent among rural Nicaraguan households.

Contrary to the findings above, van de Walle et al. (2017) reported that electrification enables men to shift from casual wage work to regular wage work but this change has not occured for women in India. While electrification may enable the use of electric stoves and other time-saving appliances in South Africa, rural Indian households continue to use bio-fuels and firewood for cooking and kerosene for lighting along with electricity (Mathur & Mathur, 2005; Rehman et al., 2005). The social norms in India that prevent women from working outside the home may help explain van de Walle et al.'s (2017) results.

Furthermore, van de Walle et al. (2017) found no significant effects of electrification on agricultural and nonagricultural self-employment for both men and women in India. Meanwhile, Akpandjar and Kitchens (2017) found that access to electricity has led to increases in small businesses, wage-earning occupations, and skill compositions and decreases in agricultural employment for both men and women in Ghana.

A recent cross-country analysis of South Africa and India by Rathi and Vermaak (2018) revealed some major differences from previous studies focusing only on India. The authors found that access to electricity in India increases paid employment for women while it decreases paid employment for men. The authors explained that access to modern technology via electricity frees up women's time from household chores to perform income-generating activities. On the contrary, men may drop out of the labor force as a result of extra income from female family members. The authors also stated that male farmers might withdraw from their secondary jobs as a result of improved agricultural productivity when electric pumps are used.

Rathi and Vermaak's (2018) findings contradict those of van de Walle et al. (2017), who found that electrification in India increases regular wage work for males but not for females. In South Africa, Rathi and Vermaak (2018) found that access to electricity increases the probability of employment for both men and women. However, the effect is not statistically significant at conventional levels. The authors explained that even if electrification allows for more time for income-generating activities as suggested by Dinkelman (2011), the employment rate does not increase due to South Africa's lack of absorptive capacity for labor. Nonetheless, it should be noted that the findings of Rathi and Vermaak (2018) focus primarily on paid employment. Although rural electrification might not translate into wage employment, previous studies suggest the time-saving effect of electrification can result in self-employment activities in the form of home-based microenterprises.

Although the countries examined in the previous studies are all developing countries, they are located on different continents with different income levels. The mixed findings suggest that the pathways between rural electrification and employment structure are specific to each country's context. From the review and other evidence, we hypothesize four possible mechanisms that change the employment structure through changes in electricity access. First, electricity access changes the pattern of time use as less is required to collect firewood, perform household chores, or operate agricultural machinery. Second, the use of electrical tools or machinery such as sewing machines allows households to diversify their income sources, mainly in the form of home-based small-scaled businesses. Third, access to information is improved by watching TV, listening to radio, and the use of mobile phones (Aker & Mbiti, 2010). This mechanism has not been investigated in previous studies, probably because it is more relevant for migrant work and participation in market transactions. Fourth, the use of electricity may also provide an incentive for local or foreign entrepreneurs to establish factories in rural areas, creating new employment opportunities. Which of the four mechanisms dominates the process of structural change in a country depends on electricity access and quality; income levels and demand structures; economic and institutional environments; and government policies.

In Cambodia, the income level is low and electrification is limited in rural areas. The high cost and low quality of electricity means the expansion of wage employment opportunities is unlikely to happen in rural areas. Thus, the main channels of changes in employment structure in rural areas must be the flexible use of work time and better access to information. Since the focus of this study is not on migration but on changes in employment structure in rural areas, we hypothesize that family-based, small-scale businesses such as grocery stores or food shops provide the main sources of new work opportunities brought about by electricity access. We expect that nonfarm self-employment and unpaid family workers are the categories of employment that expand through rural electrification.

3.3 Empirical Strategies

First, we want to estimate the effect of electrification on employment in different categories by using pooled cross-section data at the individual level. The usual estimation equation is:

$$Y_{idt} = \boldsymbol{X}'_{idt}\boldsymbol{\beta} + \gamma Z_{idt} + \theta_{dt} + \varepsilon_{idt} \qquad (3.1)$$

where Y_{idt} is a dummy variable for different categories of employment for individual i in district d in year t; $\boldsymbol{X}_{idt}$ is a vector of individual and household characteristics; Z_{idt} is a dummy variable for electricity connection; θ_{dt} is a district-year fixed effect; ε_{idt} is an error term; and $\boldsymbol{\beta}$ and γ are parameters to be estimated. The household characteristics include dummy variables of house ownership, living in a house with three or more rooms, having a toilet, and having access to piped water. The individual characteristics include age, age squared, years of education, years of education squared, a female dummy variable, dummy variables of marital status (married, divorced, and widowed), dummy variables of religion (Buddhist, Muslim, and Christian), and a vector of birth-cohort fixed effects [4] that can control for events or shocks experienced by people in the same age group. For instance, political turmoil, natural disasters, and economic shocks can halt or slow the process of electrification in Cambodia. These types of events have different effects on age cohorts such as between those still in school and those who have just reached working age.

The effect of electrification on employment is estimated by the coefficient γ by ordinary least squares if electrification Z_{idt} is exogenous to other factors affecting employment choice. Obviously, this exogeneity assumption cannot be supported. Even with the availability of an electricity grid within a village, households make their own decisions on whether to acquire a connection to electricity. Unobservable characteristics such as the entrepreneurial talent of a household member might affect both the electricity connection and employment choice of each household. Furthermore, as stated by Saing (2018), one of the primary objectives of electricity development in Cambodia is to extend the existing grid (and off-grid) supply network of the

[4] We group individuals according to their birth year with an interval of five years in each birth cohort.

EDC and REEs. Therefore, communities near already electrified ones are more likely to become connected. Moreover, the government has encouraged the private sector to invest in providing electricity services to rural areas since 2001 (EAC, 2004). Naturally, private investors choose to invest in areas with relatively high income levels and potential for future economic development. Therefore, electricity grids are more likely to expand to more developed rural communities with a broad range of nonagricultural activities, indicating a possibility of reverse causality.

To deal with the endogeneity problem, some previous studies have used an instrumental variable (IV) approach. The IVs employed in previous studies include land gradient (Dinkelman, 2011; Duflo & Pande, 2007; Grogan & Sadanand, 2012), distance to electricity line (Khandker, Barnes, & Samad, 2012), and proportion of electrified households in the area (Khandker, Samad, et al., 2014). However, it is questionable whether these IVs can be valid when applied to Cambodia. First, land gradient can be associated with agricultural productivity and agricultural employment growth in Cambodia since the majority of rural Cambodians (84.9%) are involved in agriculture, fishing, and forestry.[5] Second, placement of electricity lines can be endogenous since they are more likely to be placed through economically active areas where there are higher-income households. This is especially true in the case of rural Cambodia, where electricity is operated by private enterprises with the aim of maximizing profits. Similarly, a high proportion of electrified households in the community would create spillover effects of electrification to the whole community through greater employment opportunities or general equilibrium price effects, which may violate the exogeneity assumption for a valid IV as observed by van de Walle et al. (2017).

As the IVs are not appropriate in the case of Cambodia, we implement two estimation strategies to assess the effect of rural electrification on the employment structure. The first is the IPWRA to estimate the effect of electrification on employment in different categories with pooled cross-section individual-level data. The second takes advantage of the representative

[5] Authors' calculation using the average share from a 10% representative sample of census data in 1998 and 2008.

nature of our samples and constructs district-level panel data with average characteristics in each district. We then estimate the effect of electrification with a method combining difference-in-differences (DID) and IPWRA (DID-IPWRA). We explain the details of each estimation strategy in turn.

3.3.1 Individual-level analysis

The inverse probability of treatment weighting (IPW) method uses weights based on the propensity score to create a synthetic sample in which the distribution of observed covariates is independent of electricity access (Austin, 2011). Weights are given by $w_i = \frac{z_i}{p_i} + \frac{1-z_i}{1-p_i}$, where p_i is the propensity score of individual i and z_i is an indicator of individual i belonging to the treatment group. In our estimation, the treatment group is those with access to electricity. Thus, individuals in electrified households are given the weight of $w_i = \frac{1}{p_i}$ while individuals in non-electrified households are given the weight of $w_i = \frac{1}{1-p_i}$. The IPWRA method combines the IPW method with regression adjusted for observed covariates.

First, we need to estimate the propensity score, p_{idt}, of individual i in district d in time t, which can be written as:

$$p_{idt} = Pr\,(Z_{idt} = 1 \mid \boldsymbol{V}_{idt}\ , \theta_{dt}), \qquad 0 < p_{idt} < 1. \tag{3.2}$$

In our specification, $\boldsymbol{V}_{idt}$ represents individual and household characteristics including birth cohort fixed effects. θ_{dt} is a vector of district-year fixed effects to capture shocks common to individuals living in a particular district in a particular year. District-specific time trends can partially control for the possibility of simultaneous changes in other factors, such as changes in other types of infrastructure and economic activity, affecting the implementation of electrification projects over the decade.

Table 3.1 reports the results of the logit estimation of the propensity score while Table A3.1 in the Appendices presents the summary statistics of variables used in our individual-level estimations. The validity of the propensity score method depends on the conditional independence assumption (CIA), requiring that outcomes are independent of the treatment assignment conditional on the propensity scores (Rosenbaum & Rubin, 1983). To confirm whether the CIA is valid in our specification, we provide balancing tests before and after implementing the propensity score weighting in Table 3.3 in Section 3.5 below.

Table 3.1 Logit regression to estimate propensity score (treatment = electrified households)

Variables	**Coefficient**	**Standard Error**
Household Characteristics		
Toilet	1.6264***	0.0521
Piped water	1.9950***	0.1162
House with 3 or more rooms	0.7957***	0.0470
Own the house	-1.0053***	0.0966
Household size	0.0222***	0.0050
Individual Characteristics		
Years of schooling	0.0936***	0.0126
Years of schooling squared	0.0024***	0.0008
Age	0.0531***	0.0089
Age squared	-0.0005***	0.0001
Female	0.0853***	0.0101
Married	-0.1061***	0.0209
Divorced	-0.1537***	0.0386
Widowed	-0.1399***	0.0370
Buddhist	0.7240***	0.1498
Muslim	1.3125***	0.2730
Christian	1.4604***	0.2664
Birth-cohort fixed effects	Y	
District-specific time trends	Y	
Treatment	84,974	
Controls	719,762	
Number of observations	804,736	
Pseudo R-squared	0.2901	
Log likelihood	-192649.41	

Note: ***Significant at the 1 percent level.
**Significant at the 5 percent level.
*Significant at the 10 percent level.

Hirano and Imbens (2001) have explored the method of combining weighting based on the propensity score with a regression adjustment to allow for flexible specification of both the propensity score and the regression functions. Subsequent research has called the combination method a "doubly robust estimator" by proving that only one of the two models need to be correctly specified to obtain a consistent estimator (Funk et al., 2011; Vansteelandt & Daniel, 2014; Waernbaum, 2012). Our study utilizes the doubly robust estimator, or the IPWRA to further reduce the possibility of model misspecification.

The functional form for the conditional expectations of the employment outcome is assumed to be linear as shown below:

$$Y_{idt} = \boldsymbol{X}'_{idt}\boldsymbol{\beta} + \theta_{dt} + \varepsilon_{idt} \quad (3.3)$$

It should be noted that $\boldsymbol{X}_{idt}$ in Equation (3.3) is different from $\boldsymbol{V}_{idt}$ in Equation (3.2). While $\boldsymbol{V}_{idt}$ in Equation (3.2) aims to capture the treatment assignment, $\boldsymbol{X}_{idt}$ in Equation (3.3) aims to control for factors influencing the outcomes. Specifically, the vector $\boldsymbol{X}_{idt}$ additionally includes the number of children younger than 5. We estimate Equation (3.3) separately for treatment and control groups, each weighted by the inverse of the estimated propensity score, $\widehat{w}_i = \frac{Z_i}{\hat{p}_i} + \frac{1-Z_i}{1-\hat{p}_i}$. Then, the average difference between the predicted outcomes gives the IPWRA estimate of the average treatment effect of electrification.

3.3.2 District-level analysis

The second estimation uses district-level panel data, constructed from individual observations by calculating average characteristics in each district. Analyzing the effect of electrification on employment structure at the district level enables us to capture the external effects of electrification. As explained by van de Walle et al. (2017), the external effects of household electrification include shared lighting, safer streets, evolving social norms, and general equilibrium effects on wages and employment opportunities. By examining both individual and district-level estimates, Akpandjar and Kitchens (2017) found that the effects of electrification at the district-level are larger than the individual-level estimate because of the external effects of electrification.

With the constructed panel data at the district level, we can also improve upon our individual-level analysis by incorporating DID to the IPWRA to account for potential time-invariant unobservable factors such as social norms of females outside employment. Following Akpandjar and Kitchens (2017), after aggregating the individual-level data to the district level, we define treatment and control districts as those whose relative increases in the share of households with electricity between 1998 and 2008 were in the top and bottom quartile, respectively.[6]

Let p_d be the propensity score of district *d,* and we estimate the propensity score by the following equation:

$$p_d = Pr\,(Z_d = 1 \mid \boldsymbol{V}_d), \qquad 0 < p_d < 1 \tag{3.4}$$

where Z_d is a dummy variable for the treatment district. In our propensity score specification, $\boldsymbol{V}_d$ consists of the variables measured in the base year (1998): average shares for households (within the district) with a toilet, with piped water, with three or more rooms, and that own the house; averages for household size, years of education, and years of education squared; a gender ratio; a natural log of district population and a natural log of distance to nearest provincial town; dummy variables indicating districts located along the national border and districts located in mountainous or plateau areas; and the share of electrified households in the base year. We include the share of electrified households in the base year because it can be either negatively correlated with the variable indicating the relative increase in electrification due to the catch-up effect, or positively correlated due to better prospect for economic development. Other geographic variables such as distance to the nearest provincial town or location along the national border are included to capture the pattern of electrification created by the government policy of promoting the expansion of existing networks and the import of electricity from neighboring countries.

[6] The districts in the second and third quartiles are dropped from the sample in the district-level estimation.

Our outcome specification follows the DID framework. Since we have only two time periods, we estimate the following first-differenced equation of the outcome model:

$$\Delta Y_d = \Delta \boldsymbol{X}'_d \boldsymbol{\beta} + \Delta \varepsilon_d \tag{3.5}$$

where ΔY_d is the change in the share of different categories of employment in district d between 1998 and 2008; and $\Delta \boldsymbol{X}_d$ is the vector of changes in several district characteristics between 1998 and 2008 including average shares for households with a toilet, piped water, three or more rooms, and own the house; averages for household size, years of formal schooling, and years of formal schooling squared; a gender ratio; a natural log of district population; averages for age of adults and age of adults squared; average shares for people aged 60 or older and for individuals having infants aged less than 5; and the variables capturing shares of different types of marital status and religions. It should again be noted that $\boldsymbol{X}_d$ in Equation (3.5) is different from $\boldsymbol{V}_d$ in Equation (3.4). While the $\boldsymbol{V}_d$ in Equation (3.4) aims to capture the treatment assignment, the $\boldsymbol{X}_d$ in Equation (3.5) aims to control for factors influencing the outcomes. From the weighted regression estimates of Equation (3.5) separately for the treatment and control groups, we calculate the predicted values of the corresponding estimated outcome model. The average difference between the predicted outcomes across the treatment and control groups gives the average treatment effect of electrification.

3.3.3 Potential threats to validity of our estimates

There are a few concerns about our estimation strategy. First, the district-level analysis relies on the assumption that all households pursue income-generating activities in the same district where they dwell. Although it is undeniable that some individuals are pursuing income-earning activities outside of their residential district, the census data in rural Cambodia in 2008 shows that an overwhelming majority of workers (97.8%) works in the same district where they dwell. However, due to the unavailability of such information in the 1998 census, we cannot provide additional analysis where we exclude those individuals working outside of their residential district.

Second, over a decade, people may migrate to the area where the opportunity for employment is better. If this is the case, electrification may provide jobs for new migrants, while original residents may not benefit from electrification. In order to exclude this possibility, we conduct the estimation with the sample of individuals excluding migrants within ten years in Table 3.4 below. We find smaller but similar estimates, which suggest that work-related migration is not a major factor driving our results.

Third, the district-level variation in electrification might not fully identify the individual-level change in employment to warrant causation since districts might be too large. That is one of the reasons why both individual and district-level analyses are conducted in this study. If the individual access to electricity also leads to similar changes in employment as in the analysis of district-level panel data, then the district-level analysis can warrant causation.

3.4 Data

This study employs the 10% representative sample of the Cambodian General Population Census conducted in 1998 and 2008, obtained from IPUMS-International (Minnesota Population Center, 2018).[7] Cambodia has conducted three population censuses since its first democratic election in 1993, but the data of the most recent 2019 census have not been made public yet. The number of observations in each census is 223,518 households (or 1,141,254 individuals) in 1998 and 289,562 households (or 1,340,121 individuals) in 2008.

The smallest administrative area identified in these data is district with 161 in the 1998 census data and 168 in the 2008 census data.[8] The increase in the number of districts is a result of the Royal Sub-decree on Administrative Area changes issued in January 2008, wherein seven districts were created and the borders of others were changed.[9] As a result, Koh Kong

[7] The IPUMS archive contains samples of censuses from many countries. It is publicly available at: https://international.ipums.org/international/.

[8] The number 161 represents the number of districts in the dataset. In several cases, more than one district is combined into a single district.

[9] National Institute of Statistics (2009) explains the changes in administrative areas as follows. "Many administrative changes were introduced by the Royal Government after the 2008 census was taken like re-naming certain provinces and districts, shifting of communes from one district to another within a province, formation of new districts and cities within a province by regrouping communes, shifting of a few communes (wholly and

province (three districts), Preah Sihanouk province (three districts), and 18 other rural districts are excluded from the analysis below.[10]

As well as analyzing repeated cross-section of individual-level data, we also construct a panel dataset of district aggregate variables using the censuses. Additional data on distance to the provincial town, measured using a Distance Calculator [11], are added to the district-level panel dataset.

The two censuses employed different definitions of urban areas. In the 1998 census, urban areas included provincial town of each province, four districts of the Phnom Penh Municipality, and the entire towns of Sihanoukville, Kep, and Pailin. In the 2008 census, urban areas were identified using commune-level data with certain conditions: "(a) population density exceeding 200 per km^2; (b) percentage of male employment in agriculture below 50 percent; and (c) total population of the commune should exceed 2,000" (National Institute of Statistics, 2009, p. 7). As our analysis focuses on rural areas, we employ a common definition of urban areas for comparison purposes. As this study employs both individual and district-level analysis, the definition classifying a whole district into an urban or rural area is preferable for our purposes. As well, the commune-level data is not available for us to employ the 2008 census definition. Therefore, we use the 1998 census definition of urban areas. We also exclude the three districts in Phnom Penh Municipality that the 1998 census classified as rural.[12] After considering these factors, a total of 34 districts and 23 provincial towns are excluded from the sample, leaving 111 rural districts for our analysis.

partly) from Koh Kong province to Preah Sihanouk province, and converting province headquarter districts into Krongs" (p. 8).

[10] The 18 rural districts include one rural district in Phnom Penh city.

[11] Distance Calculator is an online tool to calculate the distance between two cities, villages, or airports in a country: https://distancecalculator.globefeed.com/Country_Distance_Calculator.asp

[12] As the country's capital city, Phnom Penh's rapid development is an exception. With close proximity to developed infrastructure, goods, and services, the three districts would show atypical results and thus should be excluded from the analysis.

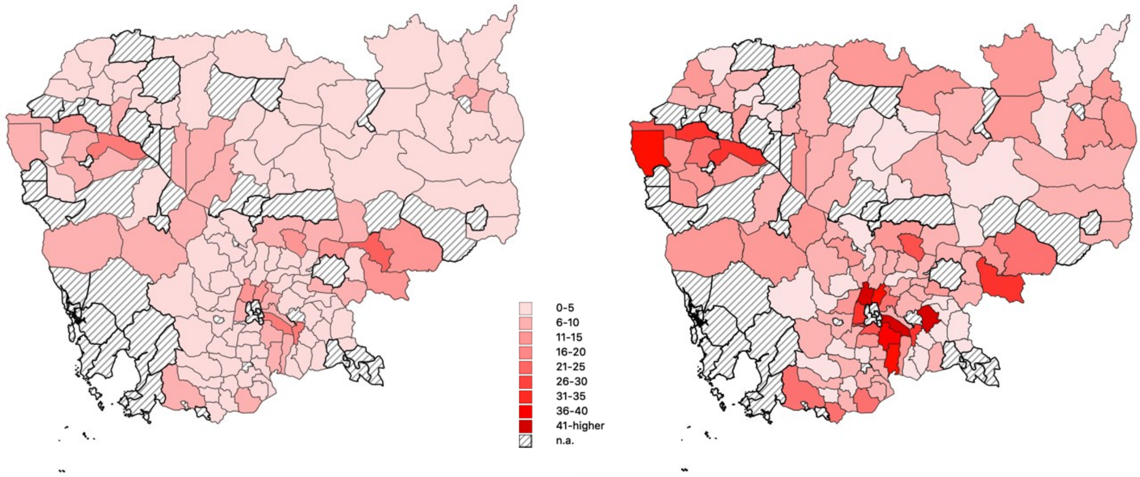

Figure 3.1 *District-level electrification rates in rural Cambodia in 1998 and 2008*

Notes: The numbers represent the proportion (%) of electrified households in each district. Areas without a line pattern are included in the analysis. Areas with a line pattern represent urban districts and districts whose areas were changed in the Royal Sub-decree on Administrative Area changes in 2008 that are excluded from the analysis.

Source: Authors' calculations are based on 10% representative samples of Cambodian general population census in 1998 and 2008.

The data available in both censuses include individual characteristics such as age, gender, marital status, religion, education, economic activity, employment sector, and migration status. Additionally, the data include information on housing and facilities such as the main sources of lighting, cooking fuel, and drinking water; number of rooms; and toilet. The electricity status is inferred from having electricity as the source of lighting. It should be noted that the number of hours in a day that electricity is available differs from place to place. For instance, in some rural areas, electricity is available 24 hours a day while in others, it is only available from 5 p.m. to 10 p.m. However, information on the duration of available electricity is not included in the census.

We limit the individual sample to those aged 15 or older as that is the minimum age for employment in Cambodia. Although the retirement age is 60, we do not limit the sample to those under 60 because older people can still be self-employed or perform unpaid work. In addition, we restrict the sample to individuals who are in the labor force, which includes those who are currently unemployed. As our study aims to capture the effects of electrification on employment structure, the main analysis uses individual-level data; however, we also analyze a limited sample of household heads as a robustness check. The main sample of the pooled-cross section data of individual-level analysis includes 804,736 individuals while the main sample of district-level panel data includes 111 districts. Since we exclude the second and third quartiles in the DID-IPWRA specification, there are 28 districts in the treatment group and 28 districts in the control group.

3.5 Empirical Results

3.5.1 Descriptive statistics

Table 3.2 compares the characteristics of electrified and non-electrified households. The summary statistics show remarkable differences, confirmed by results of t-tests of mean differences in the use of a toilet, piped water, years of formal education, and gender. On average, approximately 56% of electrified households have a toilet while roughly 13% of non-electrified households do not. Similarly, about 18% of electrified households use piped water while only 2% of non-electrified households use piped water. Individuals in electrified households completed, on average, 5.6 years of formal education while those in non-electrified households completed, on average, 3.5 years. This indicates that better-educated people are more likely to be connected to electricity. In addition, on average, approximately 49% of people with access to electricity are female, while 54% of people without access to electricity are female, reflecting that females are less likely to have a connection to electricity than males.

Table 3.2 Characteristics of electrified and non-electrified households

Variables	1998	2008	Δ	Non-electrified	Electrified	Δ
Outcome Variables						
Nonagri. total emp.	0.103	0.146	0.043***	0.090	0.450	0.360***
Nonagri. self-emp.	0.047	0.052	0.005***	0.033	0.195	0.162***
Nonagri. wage emp.	0.046	0.077	0.032***	0.049	0.191	0.142***
Nonagri. unpaid emp.	0.010	0.017	0.007***	0.008	0.063	0.055***
Agricultural total emp.	0.856	0.844	-0.012***	0.888	0.520	-0.372***
Household Characteristics						
Toilet	0.064	0.250	0.186***	0.126	0.562	0.436***
Piped water	0.017	0.049	0.032***	0.018	0.178	0.159***
House with 3 or more rooms	0.031	0.047	0.016***	0.031	0.121	0.090***
Own the house	0.978	0.965	-0.013***	0.976	0.921	-0.055***
Household size	5.602	5.199	-0.403***	5.350	5.528	0.178***
Number of children aged less than 5	0.515	0.355	-0.160***	0.435	0.318	-0.117***
Individual Characteristics						
Years of schooling	3.190	4.107	0.917***	3.500	5.580	2.080***
Age	35.407	36.787	1.380***	36.188	36.340	0.152***
Female	0.540	0.525	-0.015***	0.536	0.492	-0.044***
Married	0.711	0.720	0.009***	0.718	0.708	-0.009***
Divorced	0.030	0.022	-0.007***	0.026	0.021	-0.005***
Widowed	0.055	0.043	-0.012***	0.050	0.035	-0.016***
Buddhist	0.969	0.969	0.000	0.970	0.963	-0.007***
Muslim	0.017	0.018	0.001***	0.016	0.027	0.011***
Christian	0.003	0.003	0.001***	0.003	0.006	0.003***
Observations	339,549 339,519	465,187 465,180		719,762 719,736	84,974 84,963	

Notes: The lower row in observations represents the number of observations for outcome variables including nonagricultural self-employment, nonagricultural wage employment, and nonagricultural unpaid workers. The upper row in observations represents the number of observations for the remaining variables.
***Significant at the 1 percent level.
**Significant at the 5 percent level.
*Significant at the 10 percent level

In terms of outcome variables, there again are remarkable differences between people with and without access to electricity. On average, approximately 89% of people without access to electricity are employed in the agricultural sector while 52% of people with access to electricity are employed in agriculture. Roughly 45% of people with access to electricity are employed in the nonagricultural sector compared to only 9% of people without access to electricity. In addition, about 20%, 19%, and 6% of people with access to electricity are employed in nonagricultural self-employment, wage employment, and unpaid employment, respectively, while roughly 3%, 5%, and 1% of people without access to electricity are employed in these three nonagricultural employment categories, respectively. These results provide evidence that people with electricity are more likely to engage in nonagricultural income-generating activities.

Figure 3.2 shows the employment structure in Cambodia. The vast majority of the rural population engages in the agricultural sector, decreasing only slightly to 84.9% in 2008 from 88.2% in 1998, while employment in the industrial and service sectors showed minor increases over the same period, to 4.9% from 2% and to 10.2% from 9.8%, respectively (National Institute of Statistics, 2009). In comparison, urban areas saw declines in agriculture and service employment but an increase in the industry sector. The low levels of employment in the industrial and service sectors in rural areas indicate that rural Cambodia in the late 2000s was still in the early phases of development in the nonfarm sector.

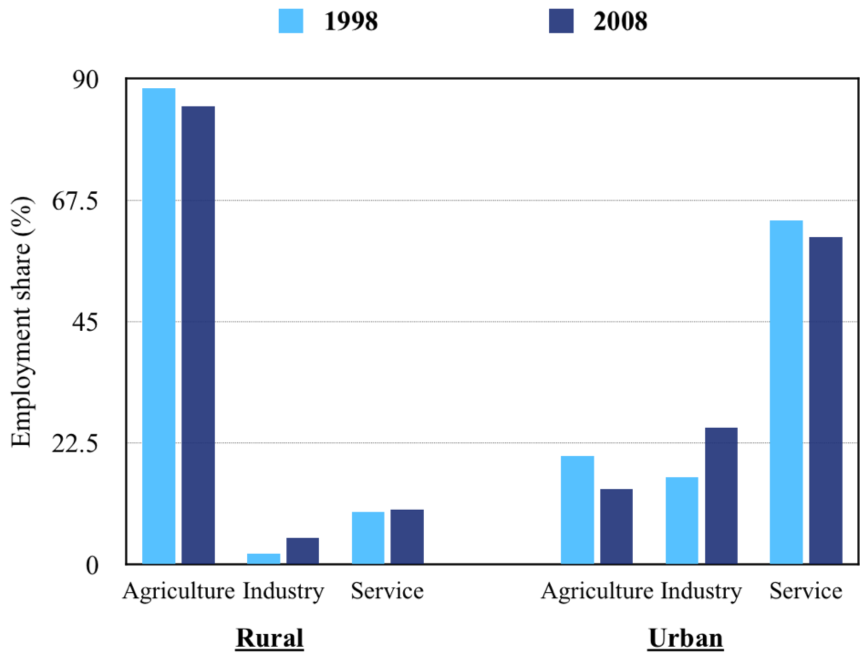

Figure 3.2 *Employment Structure in Cambodia in 1998 and 2008*

Notes: Statistics include individuals aged 5 and over.

Source: National Institute of Statistics (2009)

3.5.2 Econometric analysis

3.5.2.1 Results of individual-level estimation

As discussed earlier, to address the issue of non-random placement of electricity in our sample, the IPWRA method is employed to balance the covariates. Table 3.3 reports the covariate balance summary before and after implementing propensity score weighting that includes standardized differences and variance ratio of measured covariates. Different from the simple statistical tests of differences in means in Table 3.2, the standardized difference compares the difference in means in units of the pooled standard deviation and is not influenced by sample size (Austin, 2011).[13]

[13] For the formula of standardized differences, see Austin (2011).

The standardized differences and variance ratios of measured covariates before weighting are mostly greater than those after weighting and propensity score weighting resulted in standardized differences closer to 0 and variance ratios closer to 1. These results imply that the distributions of these covariates of the two groups—people with and without access to electricity—are similar after weighting.

Table 3.4 reports the results of individual-level estimation by IPWRA. Each row corresponds to a different outcome variable of employment categories while each column is the result of estimation with different sub-samples of interests. Column 1 reports our main analysis, which includes all working-age individuals in the labor force. We examine the results when restricting the sample to only household heads in Column 2 and different sub-samples of interest such as female and male adults in Columns 3 and 4, respectively. We also test for the potential problem of selective migration by restricting the sample to non-migrants in Column 5. Robust standard errors adjusted for clustering at the district level are presented in parentheses.

Table 3.3 Covariate balance summary before and after propensity score weighting

Covariates	Standardized difference		Variance ratio	
	Raw	Weighted	Raw	Weighted
Household Characteristics				
Toilet	1.0340	-0.0123	2.2419	0.9788
Piped water	0.5552	-0.0082	8.0467	0.9591
House with 3 or more rooms	0.3427	-0.0189	3.5100	0.9142
Own the house	-0.2524	-0.0030	3.1352	1.0162
Household size	0.0787	-0.0136	1.1072	1.0066
Individual Characteristics				
Years of schooling	0.6043	-0.0368	1.2797	1.0094
Years of schooling squared	0.5821	-0.0244	2.0317	0.9784
Age	0.0106	0.0126	0.9143	1.0405
Age squared	-0.0061	0.0177	0.8891	1.0618
Female	-0.0877	-0.0020	1.0050	1.0002
Married	-0.0207	0.0043	1.0197	0.9959
Divorced	-0.0299	0.0004	0.8283	1.0021
Widowed	-0.0768	-0.0035	0.7027	0.9853
Buddhist	-0.0385	-0.0168	1.2221	1.0923
Muslim	0.0735	0.0129	1.6440	1.0972
Christian	0.0507	0.0079	2.2133	1.1455

The results in Column 1 indicate that electrification has statistically significant and economically large effects on the employment structure of the labor market. People with electricity access are 18.5 percentage points less likely to work in agriculture. Relative to the mean of 84.9%, access to electricity is associated with a 22% relative decrease in agricultural employment. On the other hand, individuals with electricity access are 17.6 percentage points more likely to work in nonagricultural jobs. Relative to the mean of 12.8%, access to electricity is associated with a 138% relative increase in nonagricultural employment.

To further investigate the movement out of agriculture, we examine different categories within nonagricultural employment. We find that individuals with electricity access are 10.8

percentage points more likely to engage in nonagricultural self-employment activities. Relative to the mean of 5%, this suggests there is a 216% relative increase in nonagricultural self-employment. In addition, access to electricity increases nonagricultural wage employment by 3.5 percentage points, a 55% relative increase. Similarly, we also find that access to electricity increases nonagricultural unpaid employment by 3.3 percentage points, which is a 236% relative increase. By comparing the magnitudes of each estimated coefficient within the category of nonagricultural employment, we confirm that a large portion of the movement out of agriculture is toward self-employment activities, illustrating the importance of growth in nonfarm self-employment in the early stages of structural change.

Table 3.4 Results of individual-level analysis (IPWRA)

Outcome Variables	**Baseline**	**All Heads**	**Females**	**Males**	**Non-migrants**
	(1)	**(2)**	**(3)**	**(4)**	**(5)**
Agricultural employment	-0.1852***	-0.1827***	-0.1835***	-0.1853***	-0.1627***
	(0.0078)	(0.0077)	(0.0082)	(0.0083)	(0.0078)
Nonagricultural employment	0.1764***	0.1810***	0.1733***	0.1780***	0.1561***
	(0.0073)	(0.0076)	(0.0075)	(0.0078)	(0.0073)
Nonagricultural self-employment	0.1076***	0.1406***	0.1017***	0.1132***	0.0969***
	(0.0048)	(0.0061)	(0.0052)	(0.0055)	(0.0048)
Nonagricultural wage employment	0.0354***	0.0397***	0.0209***	0.0514***	0.0288***
	(0.0032)	(0.0031)	(0.0029)	(0.0042)	(0.0028)
Nonagricultural unpaid workers	0.0330***	0.0005**	0.0504***	0.0129***	0.0303***
	(0.0020)	(0.0002)	(0.0031)	(0.0012)	(0.0020)
Observations (individual)	804,736	327,456	427,663	377,073	710,497
	804,699	327,446	427,651	377,048	710,473

Notes: Robust standard errors clustered at the district level are presented in parentheses. The upper row of observations represents the number of observations in regression of agricultural employment and nonagricultural employment while the lower row represents the number of observations in regression of nonagricultural self-employment, nonagricultural wage employment, and nonagricultural unpaid workers. Non-migrants are defined as individuals who have lived in the current village for 10 or more years.
***Significant at the 1 percent level.
**Significant at the 5 percent level.
*Significant at the 10 percent level.

Columns 2, 3, and 4 present the results when we restrict the sample to household heads, female adults, and male adults. Although the overall results are similar, the electrification effects on certain employment categories are more concentrated within certain sub-samples. For example, in Column 2, which is restricted to heads of households, the magnitude of the coefficient for nonagricultural self-employment is bigger than the baseline and the magnitude for nonagricultural unpaid workers is smaller than the baseline. Because household heads are likely to be the main income earners, household heads are more likely to be self-employed and unlikely to be unpaid workers. Columns 3 and 4 show that men are more likely to engage in nonagricultural wage employment than women while women are more likely to work as nonagricultural unpaid workers. Meanwhile, the results indicate that the effect of electrification on nonagricultural self-employment is similar between male and female sub-samples in rural Cambodia.

As people can migrate to areas where there is potential for employment, our estimation results may include the effect of changes in the composition of the workforce due to migration. To address this issue, in Column 5 we restrict the sample to individuals who have resided in the current locality for more than or equal to ten years. The results are in line with our baseline results, albeit smaller in magnitude. Nevertheless, the results are qualitatively similar to the baseline specification, indicating that the effect of selective migration is minor and thus is not a threat to our estimation results.

3.5.2.2 Results of district-level estimation

Table 3.5 reports the results of the district-level analysis for which we provide estimation results for fixed effects panel estimation and DID-IPWRA. In the fixed effects specifications, the full panel sample of 111 districts in two time periods is used to derive within estimators. The treatment variable in the fixed effects estimation is the change in the electrification rate of each district over the two time periods. In DID-IPWRA specifications, we follow Akpandjar and Kitchens (2017), and only 56 districts either in the top or bottom quartile are chosen for the treated and control groups. Column 1 reports the results of fixed effects estimation without district-level controls while Column 2 includes the control variables. Columns 1 and 2 present robust standard errors clustered at the district level. Time fixed effects are included in both specifications. Column 3 reports our main findings of the DID-IPWRA method.

Comparing the coefficients of the fixed effects regressions to the DID-IPWRA, we can see that the signs and magnitudes are very similar after adjusting the DID-IPWRA coefficients to the difference in average changes in electrification rates between the treatment and control districts. Column 3 shows that nonagricultural self-employment increases by 12.9 percentage points, nonagricultural wage employment increases by 2.8 percentage points, and nonagricultural unpaid work rises by 2.5 percentage points. It should be noted that the coefficient of nonagricultural wage employment in the fixed effects specification in Column 2 is much larger in magnitude but is not statistically significant at conventional levels.

In the comparison between individual-level and district-level analyses in Tables 3.4 and 3.5, the electrification effects on the movements out of agriculture and into nonagricultural self-employment are somewhat larger in the district-level analysis. As mentioned in Section 3.3.2, the larger effects of electrification in a regional-level analysis arise from the external effects of electrification. Our results from both individual and district-level analyses indicate the existence of small external effects of electrification in rural Cambodia. The small external effects are understandable as the average proportion of electrified households in rural districts was only 12.3% in 2008. This level is very low compared to the average of 46.8% in Ghana in Akpandjar and Kitchens' (2017) study.

Table 3.5 Results of district-level analysis (fixed effects and DID-IPWRA)

Outcome Variables	**Fixed Effects**		**DID-IPWRA**
	(1)	**(2)**	**(3)**
Agricultural employment	-0.5461*** (0.1548)	-0.1870** (0.0941)	-0.2403*** (0.0029)
Nonagricultural employment	0.5400*** (0.1334)	0.1805** (0.0772)	0.1980*** (0.0020)
Nonagricultural self-employment	0.1391*** (0.0548)	0.0955*** (0.0201)	0.1294*** (0.0007)
Nonagricultural wage employment	0.3735*** (0.0803)	0.0619 (0.0740)	0.0278*** (0.0015)
Nonagricultural unpaid worker	0.0285*** (0.0096)	0.0251*** (0.0091)	0.0249*** (0.0002)
District characteristics	N	Y	Y
Time fixed effects	Y	Y	Y
Observations (district)	222	222	56

Notes: Unit of observation is district-year. The total number of observations in each time period is 111. All regressions are weighted with district population in 1998; standard errors (presented in parentheses) are robust, clustered at district level except in Column 3. In the DID-IPWRA model, treatment and control districts are determined as those whose relative increases in share of households with electricity between 1998 and 2008 was in the 75th–100th percentile and 0–25th percentile, respectively. It should be noted that not all households in the treatment districts are electrified and a small portion of households in the control districts also have electricity access. The mean of the change in the proportion of electrified households in the treatment districts is 19.377% while the mean of the change in the proportion of electrified households in the control districts is 0.459%. Thus, the DID-IPWRA results presented in Column 3 are adjusted for the difference in the changes in electrification by 18.918%.

***Significant at the 1 percent level.
**Significant at the 5 percent level.
*Significant at the 10 percent level.

3.6 Conclusion

This study uses the Cambodia General Population Census in 1998 and 2008 to investigate the effects of electrification on changes in employment structure in rural Cambodia using two different estimation strategies, one with individual-level pooled cross-section data and the other with district-level panel data. Both estimation methods rely on the IPWRA to deal with endogenous electricity placement. The estimates of all our specifications show consistent results on signs and magnitudes of the effects of rural electrification on the employment structure in Cambodia.

A significant contribution of this study is that it looks into employment categories, which is the main channel through which electrification affects people's welfare. Specifically, we fill a research gap by examining the effects of electrification on the employment structure that has resulted in mixed findings in previous studies. As well as categorizing employment structure into agricultural and nonagricultural sectors, we examine the movement out of agriculture by further looking into three types of nonagricultural employment: self-employment, wage employment, and unpaid work. It is important to understand structural changes in the labor market because nonfarm employment plays a vital role in lifting people out of poverty (Hoang et al., 2014; Lanjouw & Shariff, 2004; Seng, 2015). Additionally, we provide evidence on the important contributions of the informal sector such as self-employment and unpaid employment in the rural economy during the early transition to non-agricultural activities.

We find evidence that rural electrification moves people out of agricultural employment toward nonagricultural employment by 17–18 percentage points over a decade. We also find that the movement out of agriculture is dominated by an increase in self-employment activities. Access to electricity increases the probability of nonagricultural self-employment of both men and women by 10–11 percentage points while it increases the probabilities of nonagricultural wage employment and unpaid work only by 2-5 and 1-5 percentage points, respectively. Thus, in the early stages of electrification in rural Cambodia, we confirm that structural changes start from the movement of the workforce out of agriculture to nonfarm self-employment activities and that this movement is facilitated by rural electrification. We also find the evidence of small external effects of electrification on the movements out of agriculture into nonagricultural self-employment.

A significant policy implication is the importance of expanding electricity access in rural Cambodia. Compared to other developing countries, access to electricity in Cambodia is still limited. Therefore, the expansion of access to electricity is crucial for long-term rural development and poverty eradication in Cambodia. At the same time, the government of Cambodia needs to tackle the relatively high cost of electricity, low levels of capacity, and unreliability of electricity that can hinder the enabling of more income-generating activities. How these factors interact to limit rural development and poverty alleviation is the topic of subsequent chapters.

CHAPTER 4 - THE EFFECT OF ELECTRICITY CONSUMPTION ON RESPIRATORY HEALTH IN RURAL CAMBODIA

4.1 Introduction

Electricity is regarded as a basic necessity for most people in the developed world. However, millions still lack access to electricity in the developing economies. It was estimated that approximately 1.3 billion people (i.e., 19% of the world's population) did not have access to electricity in 2010 (United States Energy Information Administration, 2013). Even where households are connected to the electric grid, electricity supply tends to be unreliable and too costly for most rural households. Without access to electricity or the adequate use of it, household members are exposed to indoor air pollution caused by the use of candles and kerosene lamps for lighting and/or solid fuels for cooking. Indoor air pollution is the third major risk factor for global disease concern, after high blood pressure and smoking (Lim et al., 2013). According to the World Health Organization (2002), indoor air pollution is estimated to cause about one-third of the cases of acute respiratory infection which is one of the dominant causes of child mortality in the world.

The direct channel through which household electrification can improve respiratory health is the reduction of indoor air pollution as a result of switching from candles and kerosene lamps to electric lighting as well as from traditional cookstoves to electric cookstoves (Barron & Torero, 2017; IEG, 2008). Household electrification also has indirect impacts on respiratory health through a rise in income and access to information on TV. A rise in income, in turn, allows households to adopt cleaner cooking fuels such as electricity, liquefied petroleum gas (LPG)/cooking gas, or biogas which can reduce indoor air pollution. Access to information on TV can also raise awareness of the clean cooking products and smoke hazards which can influence households to adopt cleaner cooking fuels.

Despite the claimed benefits of household electrification in reducing the incidence of respiratory health, the empirical evidence on the impacts of household electrification on respiratory health has remained scarce. A wave of studies has found a significant effect of the reduction of indoor air pollution on respiratory health (Dasgupta et al., 2006; Duflo et al., 2008; Edwards & Langpap, 2012; Hanna et al., 2016; Kurata et al., 2020; Silwal & Mckay, 2015), although they focused solely on the effect of different types of cooking fuels/cookstoves rather than on electricity consumption. The previous studies examining the effects of rural electrification has centered their findings on income, consumption, and children's education (Chakravorty et al., 2014; Khandker, Barnes, & Samad, 2012, 2013; Khandker, Samad, Ali, & Barnes, 2014; Saing, 2018; van de Walle et al., 2017), and on employment structure (Akpandjar & Kitchens, 2017; Chhay & Yamazaki, 2021; Dinkelman, 2011; Grogan & Sadanand, 2012; Rathi & Vermaak, 2018). Barron and Torero (2017) and Litzow et al. (2019) were among the first studies to investigate the impacts of household electrification on health outcomes.

Barron and Torero (2017) found that household electrification substantially reduces indoor air pollution and lowers the incidence of acute respiratory infection among children under six in northern El Salvador. The authors suggested that the results were partly driven by reductions in kerosene use. It should be noted that Barron and Torero (2017) focused mainly on the effect of receiving discount vouchers for the fee of electricity connection rather than the actual electrified households. The author also found that the share of households using cooking gas in northern El Salvador rose significantly during the study period, although the regression coefficient was not statistically significant at conventional levels. In contrast, Litzow et al. (2019) did not find a significant effect on health outcomes. The difference between Barron and Torero (2017) and Litzow et al.'s (2019) findings may be due to the fact that Litzow et al.'s (2019) study focused on being ill in general rather than being sick with respiratory illnesses.

With the limited empirical research on this topic, this study provides empirical evidence of the effect of electricity consumption on respiratory health among rural households in Cambodia, utilizing the recent Multi-Tier Framework (MTF) survey for Cambodia conducted in 2017.[14] To address the endogeneity of electricity consumption, electricity price is employed as an instrumental variable, taking advantage of the unique situation in rural Cambodia in

[14] As there are more sources of air pollution in urban areas, this study limits its scope to rural areas.

which electricity generation and distribution are operated by various private enterprises (licensees) and that prices are determined based on input factors of the supply side.

A distinction of this study is the use of continuous variable 'amount of electricity consumption in kWh' with the aim to explicitly capture the effect of electricity usage. Specifically, this study investigates respiratory health benefits across different amounts of electricity usage as a way to contribute to the current literature of rural electrification which has mainly centered on the differences between electrified and non-electrified households. In addition, this study explores the mechanism behind the effect of electricity usage on respiratory health by examining three target sub-samples including those who do the cooking, children aged under six, and adults aged over 50.

This study finds that household electricity usage decreases the prevalence of acute respiratory infection among Cambodian rural households. Specifically, a one kWh increase in household electricity consumption reduces the probability of having respiratory illnesses by 0.2 percentage points. Moreover, this study finds the respiratory health benefits from electricity consumption are heavily concentrated among higher-income households who are more likely to diversify their use of electricity to use clean cooking fuels. Among the upper-income quantile, a larger and significant coefficient is found for two sub-samples: those who do the cooking and adults aged over 50. A one kWh increase in electricity consumption among households in the upper-income quantile leads to a reduction in the probability of having respiratory illnesses among those who do the cooking by 0.47 percentage points and among adults aged over 50 by 0.3 percentage points.

The evidence suggests that the pathway through which different amounts of electricity consumption affects respiratory health is through the switch from solid to clean cooking fuels and that this health benefit happens mainly among higher-income households. The role of the reductions in kerosene use as suggested in the study by Barron and Torero (2017) is not prominent in this study because the use of electric lighting–the main use of electricity among newly-electrified households–may not differ substantially between households consuming different amounts of electricity.

The remainder of this chapter is structured as follows: Section 4.2 presents an explanation of the data and sample characteristics; Section 4.3 outlines the empirical strategies; Section 4.4 discusses the empirical results; and Section 4.5 offers the conclusions.

4.2 Data and Sample Characteristics

4.2.1 Data source

This study employs the Multi-Tier Framework (MTF) survey for Cambodia conducted in 2017. The MTF survey is a global baseline survey on household access to electricity and clean cooking fuels, which goes beyond the binary approach in identifying electricity access. Covering the top 30 to 40 countries with energy access deficit, the MTF survey was funded by the World Bank with support from the Energy Sector Management Assistance Program (ESMAP).

Completed on August 2017, the MTF data collection in Cambodia happened mostly in June–July 2017. With the aim of being representative of the country, the selection of the household survey sample was based on two-stage stratification. A total sample of 3,315 households (1,669 rural households) were surveyed in Cambodia, following the stratification criteria of equal allocation between urban and rural areas and 50:50 ratio of electrified and non-electrified households.

The MTF survey consists of three different sub-surveys: household, village, and facility (education, health, government, and religion). The MTF household survey includes a wide range of information ranging from socioeconomic status to supply and demand of electricity, use of cooking solutions, and health impacts. The MTF village survey includes useful information on village infrastructure, energy/fuel prices, and categories of electricity providers in the village. The MTF facility survey is not utilized in this paper.

The MTF survey data contains a total of 14,791 individuals in 3,315 households in 270 villages. Although the unit of analysis is individual, the information on electricity price is obtained from the MTF village survey which asked the village chief about the availability of electricity in the village and electricity price per kWh.[15] Among the 270 surveyed villages, 16 villages are not connected to electricity and 17 villages have missing data. After considering the electricity prices stated in the EAC's annual reports, seven villages whose surveyed prices are too high or too low (out of the range reported in the EAC's annual reports) are dropped from the analysis. This results in the remaining 230 villages, among which 100 of them are located in rural areas.

Among the 100 rural villages, only households connected to the electricity, which is 72% of surveyed households, are included in the analyses. This is due to the fact that this study focuses specifically on the differences in the amount of electricity consumption rather than comparing electrified to non-electrified households. Individuals aged over 65 are also excluded from the analysis as they are more prone to bad health conditions in general. After the data cleaning process, the number of observations used in the final analysis is 3,088 individuals in 734 rural households.

4.2.2 Sample characteristics

Table 4.1 provides descriptive statistics of all variables used in the main analysis. The average age of household heads is approximately 47, the average education of household heads is about 5 years, and roughly 26% of the households are female-headed. Moreover, the household income per capita (adjusted using the OECD-modified equivalent scale), on average, is 374,370 Riels per month, approximately US $94 at a 2017 USD/KHR exchange rate. About 21% of the households do the cooking inside the dwelling without a separate kitchen. Additionally, approximately 81% of rural households have a television while just about 8% of them own a refrigerator. The average duration of the weekly power outage is on

[15] The electricity price obtained from the household-level survey (obtained by using the monthly electricity bill divided by electricity consumption) is not suitable to use in the analysis. That is because poor households connected to the National Grid using electricity less than a pre-determined threshold are subjected to a subsidy program that they can pay at a lower price per kWh. The household-level electricity price is not determined exogenously; it reflects the amount of electricity consumption and real financial burden of each household that can affect the health outcomes of household members.

average 60 minutes. About 15% of the villages have a market while approximately 19% of them are accessible by car or truck on a paved road all year long. Furthermore, villages are on average 13 kilometers away from a hospital and have connected to electricity for approximately 6 years.

The average price of electricity is roughly 726 Riels/kWh while rural households consume, on average, approximately 43 kWh of electricity per month. Figure 4.1 shows a negative slope which is the relationship between electricity price and household electricity consumption. The higher the price, the less likely that households are able to use more of electricity.

Table 4.1 Summary statistics

Variables	Mean	S.D.	Min.	Max.
Outcome Variable				
Acute respiratory infection	0.033	0.179	0	1
Variable of Interest				
Electricity consumption (kWh)	43.455	42.571	0	319
Instrumental Variable				
Electricity price	726.422	211.925	600	2100
Individual Characteristics				
Age	26.877	18.032	0	65
Education	4.713	3.799	0	15
Female	0.511	0.500	0	1
Household Characteristics				
Age of household head	47.136	11.985	20	83
Education of household head	5.013	3.648	0	14
Female-headed household	0.265	0.441	0	1
Household size	5.123	1.815	1	12
Cook inside the house	0.212	0.409	0	1
Ln adjusted income per capita	12.833	1.352	0	18.364

Variables	Mean	S.D.	Min.	Max.
Car	0.063	0.243	0	1
Refrigerator	0.079	0.270	0	1
TV	0.813	0.390	0	1
Outage	60.007	128.100	0	2160
Village Characteristics				
Piped water is the main source of water supply	0.211	0.408	0	1
Share of landless households	7.920	12.547	0	70
Market	0.148	0.355	0	1
Paved road	0.189	0.392	0	1
Years since electricity became available	6.038	4.026	1	20
Distance to hospital	13.405	10.762	0	50

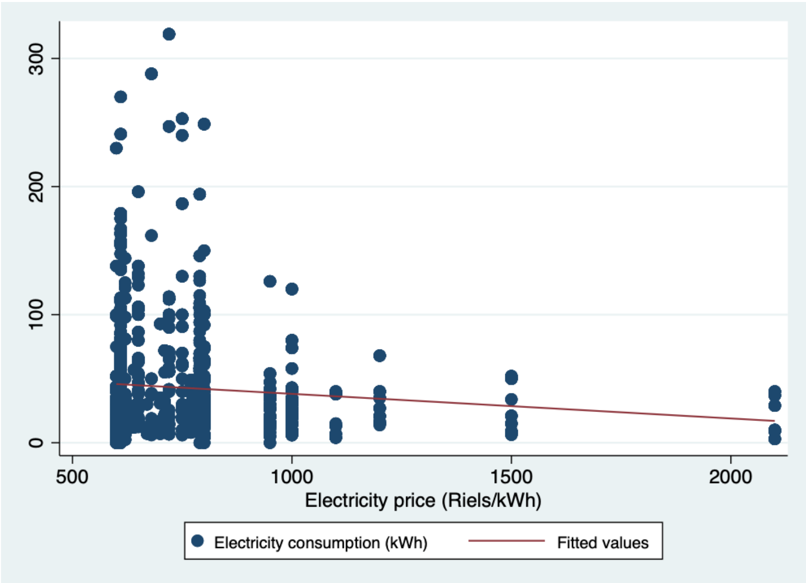

Figure 4.1 *The Relationship between Electricity Price and Household Electricity Consumption*

Source: The MTF Survey in Cambodia (2018)

4.2.3 Describing the incidence of acute respiratory infection

Following the Health Equity and Financial Protection Indicators, this study determines whether an individual is suffering from the acute respiratory infection if he/she reports being sick with a cough and rapid breathing in the past 2 weeks preceding the survey.[16] Table 4.2 shows the incidence of acute respiratory infection among various sub-samples including children aged under six, those who are responsible for cooking, adults aged over 50, two income-based quantiles, and two electricity consumption-based quantile.[17] The average incidence rate of acute respiratory infection of the whole sample is approximately 3.3% while the rate rises to 6.1%, 4.5%, and 4.8% for the sample of children aged under six, those who cook for their family, and adults aged over 50, respectively.[18] Although the acute respiratory infection rates between the two income-based quantiles are quite similar, they are significantly different between the two electricity consumption quantiles. In short, Table 4.2 points out that the sample of children, those who do the cooking, older adults, and households consuming less electricity have a higher incidence of acute respiratory infection.

[16] A limitation of this study is that it relies on self-reported symptoms since the direct measure of respiratory health is not available in the survey.

[17] The income and electricity consumption samples are divided into two quantiles using its median (the adjusted income per capita is used for the income sample).

[18] Individuals aged over 65 are excluded from all the analyses except the analysis of the adult aged over 50 sample.

Table 4.2 The incidence of acute respiratory infection among various sub-samples

Samples	# of observations	Mean (the sample)	Mean (the rest of the sample)	Difference
Whole sample	3088	0.033	-	-
Children aged under 6	374	0.061	0.029	0.032***
Those who cook (aged 15-65) †	686	0.045	0.030	0.015**
Adults aged over 50	620	0.048	0.032	0.016**
Income > median	1,543	0.034	0.032	0.002
Electricity consumption (kWh) > median	1,537	0.024	0.043	-0.018***

Note: † Each household reports one person as the most frequently responsible for cooking, 84% of whom are female.
*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

4.3 Empirical Strategies

The estimation equation to estimate the effect of electricity consumption on individual's respiratory health can be written as:

$$y_{ijk} = \boldsymbol{X'}_{ijk}\,\boldsymbol{\beta_1} + \gamma E_{jk} + \theta_p + \varepsilon_{ijk} \qquad (4.1)$$

where y_{ijk} is the respiratory health outcome for individual *i* in household *j* in village *k,* $\boldsymbol{X}_{ijk}$ is a vector of observed individual, household, and village characteristics, E_{jk} is a continuous variable representing monthly electricity consumption of household *j* in village *k* (measured in kWh), θ_p is a province fixed effect, and ε_{ijk} is an error term.[19] The observed individual characteristics in vector $\boldsymbol{X}_{ijk}$ include age, age squared, years of education, and gender while the observed household characteristics consist of age, years of education, and gender of household head, whether the household cooks inside the dwelling, household income per capita (adjusted using the OECD-modified equivalent scale), dummy variables for the ownership of

[19] To reduce the number of missing values on the variable "electricity consumption" due to households reported "don't know" as their answer, a proxy is used for those households by using the monthly electricity bill divided by village-level electricity price. There is no significant difference in regression results before and after this replacement.

a car, a refrigerator, and a TV, and the duration of a weekly power outage (in minutes). The village characteristics include the share of landless households, how long (in years) since the electricity became available, distance to a hospital (in kilometers), and dummy variables for the availability of a market, a paved road, and for villages that have piped water as the main source of water supply, which are used to control for the socioeconomic and infrastructure conditions and health environment of the villages.

The effect of electricity consumption on the respiratory health outcome (γ) can be estimated by OLS if the amount of electricity consumption is exogenous to other factors affecting the respiratory health of household members. However, this is not the case. Besides the nonrandom placement of a community's electrification status, the pattern of electricity consumption among rural households in Cambodia is often based on both observed and unobserved factors, such as household income, the price of electricity, and a household's perception of the returns to investment on electricity. In this case, an endogeneity bias caused by an omitted variable is present if a household's perception on the potential advantages of electricity usage is correlated with the respiratory health outcome of the household members. Besides, the endogeneity issue caused by simultaneity bias may also exist in case that people need to use more electricity when they feel sick that was caused by being exposed to indoor air pollution. For instance, people might feel the urge to turn on a fan as they are having difficulty breathing.

In order to overcome these endogeneity challenges, this study employs the instrumental variable (IV) method. This study instruments for the amount of electricity consumption using electricity price (Z_k), taking advantage of the unique situation in rural Cambodia in which electricity price is determined exogenously. The electricity price in Cambodia is determined solely based on input factors on the supply side. Besides, the electricity generation and distribution in Cambodia are operated by various private enterprises. This results in exogenous price variation across the country. The first-stage estimate of the instrumental variable (IV) is obtained by estimating the following equation:

$$E_{jk} = \boldsymbol{X'}_{ijk}\ \boldsymbol{\beta_2} + \delta Z_k + \eta_p + \omega_{ijk} \qquad (4.2).$$

The electricity price (Z_k) is a valid instrument if it can influence the amount of household electricity consumption (instrument relevance), but does not directly affect the household members' respiratory health (instrument exogeneity). The household members' respiratory health outcomes are affected by the instrumental variable only indirectly through the amount of household electricity consumption.

As a result of the relatively high price of electricity in Cambodia, it is obvious that household electricity consumption is price elastic, especially for rural households whose incomes are relatively low and unstable. Fearing that they have to pay costly monthly electricity bills, a majority of households may choose to limit their daily electricity usage. The higher the price, the less electricity that those rural households can afford, as indicated in Figure 4.1 in Section 4.2.2 which shows a negative correlation between electricity price and household electricity consumption. While electricity price satisfies the instrument relevant condition, it is determined solely based on input factors on the supply side as discussed in Chapter 2. Therefore, our instrumental variable electricity price (Z_k) satisfies both conditions of a valid instrumental variable. It should be noted that the utility function is assumed to be a Cobb-Douglas aggregate of all goods consumed by a household. With the assumption of the Cobb-Douglas utility function, the electricity price has no effects on the demand for other goods particularly healthcare that may affect the individual's health outcomes. This assumption is very close to the reality of households because the demand healthcare is generally considered to be an emergency need which households would have to prioritize over the demand for electricity.

Some may concern that there might be a possibility the licensees connected to the "National Grid" and households subjected to a lower price are located in areas closer to better infrastructure such as a paved road and a hospital than their counterparts. Therefore, province fixed effects and village infrastructure controls such as, "distance to the nearest hospital", "years since electricity became available in the village", a dummy variable for "villages that have piped water as the main source of water supply", "a paved road", and "a market" are included in the model to address the above-mentioned concern. Moreover, I regress each village-level covariate on the electricity price to check its correlation. Column 1 of Table 4.3 shows the regression results of each village-level covariate on the electricity price without controls while Column 2 includes all other covariates and 22 province fixed effects as controls. There are no significant associations between electricity price and village characteristics such as the share of landless households in the village, distance to the nearest hospital, years since electricity first became available in the village, villages that have piped water as the main source of water supply, and the presence of a market and a paved road in the village. Therefore, it can be said that electricity price is exogenous in Equation (4.1) as it is not associated with the village characteristics that are important factors affecting the health outcomes of the people.

Besides the village-level infrastructure proxies, Table 4.3 also includes the correlation test between the electricity price and an individual-level health proxy (being sick with non-respiratory illness) as additional evidence to show that electricity price is not associated with non-respiratory health outcomes of the people.[20] Table 4.3 also shows the correlation test between the electricity price and a household-level annual medical expenditure to demonstrate that electricity price does not affect the household's spending related to healthcare.

[20] The variable being sick in general is not used in the correlation test because electricity price can affect respiratory health outcomes through its influence on the amount of electricity consumption.

Table 4.3 Village and individual characteristics by electricity price (correlation test)

Village and individual characteristics	By Electricity Price/100	
	No controls (1)	Controls (2)
Panel A: Village-level infrastructure proxies		
Years since electricity became available	0.069 (0.157)	0.068 (0.155)
Market	0.026 (0.021)	0.026 (0.034)
Paved road	0.020 (0.022)	0.003 (0.022)
Distance to hospital	0.236 (0.335)	0.136 (0.395)
Piped water is the main source of water supply	0.022 (0.023)	0.003 (0.021)
Share of landless households	0.340 (0.521)	-0.193 (0.517)
# of Observation (villages)	91	91
Panel B: Individual-level health proxy		
Non-respiratory illness	0.000 (0.002)	0.000 (0.002)
# of Observation (individuals)	3,088	3,088
Panel C: Household-level medical expenditure		
Ln annual medical expenditure	-0.054 (0.106)	-0.059 (0.111)
# of Observation (households)	642	642

Note: Columns 1 and 2 of *panel A* show coefficients from a regression of each village-level infrastructure proxy on electricity price. Columns 1 and 2 of *panel B* show coefficients from a regression of an individual-level health proxy on electricity price. Columns 1 and 2 of *panel C* show coefficients from a regression of a household-level medical expenditure on electricity price. Robust standard errors are presented in parentheses. Due to missing data on medical expenditure, the number of households in the sample is reduced to 642 from 734 in the analyses in *panel C*.
*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

In addition to the correlation test, this study also provides a balance test in Table 4.4 where village-level infrastructure proxies, individual-level health proxy, and household-level medical expenditure are compared between the higher and lower electricity price quantiles. To conduct the balance test, the study divides the sample into two quantiles based on the electricity price. The comparison of village-level infrastructure proxies, individual-level health proxy, and household-level medical expenditure between the higher and lower electricity price quantiles is done by performing statistical tests of the differences in means of village characteristics. Results in Table 4.4 show that there are no significant differences between the higher and lower electricity price quantiles in terms of "having a paved road in the village", "distance to the nearest hospital", "share of landless households in the village", "being sick with non-respiratory illness", and "annual medical expenditure". The balance test also shows that there are some significant differences in a few covariates between the two groups. The villages belonging in the higher price quantile show significantly higher mean for the variables "years since electricity became available", "a market in the village", and "piped water is the main source of water supply". These results negate the concern that villages connected to the "National Grid", which are subjected to a lower price, are located in areas closer to better infrastructure than their counterparts. In fact, some villages connected to the licensees importing electricity from the neighboring countries are also subjected to a reasonable price, some have a lower electricity price compared to villages connected to the National Grid.

It should be noted that although the balance test shows some significant differences between the higher and lower electricity price quantiles, all the village-level infrastructure proxies and province fixed effects are controlled for in the analysis as mentioned earlier.[21] Conditional on the village-level covariates, the electricity price is assumed to be independent of the factors affecting the health outcomes of the people. The study also provides estimation results where the village-level variables "years since electricity became available", "a market in the village", and "piped water is the main source of water supply" are excluded from the estimation model in Table A4.5 in the appendices. The conditional independence assumption is supported if the estimation results before and after this exclusion of the village-level variables do not change significantly.

[21] The district fixed effects cannot be used since there is not enough variation in electricity prices within a district.

Table 4.4 Village and individual characteristics by electricity price (balance test)

Village and individual characteristics	Mean		
	Higher quantile	Lower quantile	The difference (Δ)
Panel A: Village-level infrastructure proxies			
Years since electricity became available	6.510	5.024	1.486**
Market	0.204	0.095	0.109*
Paved road	0.245	0.143	0.102
Distance to hospital	13.224	14.629	-1.404
Piped water is the main source of water supply	0.265	0.119	0.146**
Share of landless households	8.816	6.238	2.578
# of Observation (villages)	49	42	
Panel B: Individual-level health proxy			
Non-respiratory illness	0.024	0.031	-0.007
# of Observation (individuals)	1,601	1,487	
Panel C: Household-level medical expenditure			
Ln annual medical expenditure	10.695	11.088	0.393
# of Observation (households)	311	331	

Note: The comparison of village-level infrastructure proxies, individual-level health proxy, and household-level medical expenditure between the higher and lower price quantiles is done by performing statistical tests of the differences in the means. Due to missing data on medical expenditure, the number of households in the sample is reduced to 642 from 734 in the analyses in *panel C*.

4.4 Empirical Results

4.4.1 First-stage estimation results

Table 4.5 presents the first stage estimates for the household electricity consumption of the baseline sample. The outcome variable is the monthly electricity usage (kWh) of each household. The coefficient of electricity price is negative and statistically significant. The baseline sample shows that an increase of 100 Riels in price leads to about 1.8 kWh decrease in the use of monthly electricity. In other words, for a one standard deviation increase in price (about 212 Riels), the electricity consumption falls by about 3.8 kWh per month which equals to 8.7% of the mean monthly electricity consumption.

Table 4.5 Electricity consumption: first stage OLS estimates of the baseline sample

	Electricity consumption (kWh)	
	Coefficient	**Standard error**
Electricity price/100	-1.789***	0.577
Age	-0.056	0.156
Age squared	0.0008	0.003
Education	0.253	0.266
Female	1.499*	0.825
Age of household head	0.260*	0.134
Education of household head	0.796*	0.436
Female-headed household	1.732	3.273
Household size	2.067***	0.798
Cook inside the house	-4.245	3.829
Ln adjusted income per capita	-0.009	0.986
Car	21.247***	6.935
Refrigerator	64.353***	9.799
TV	8.299***	3.029
Outage	-0.002	0.007
Share of landless households	0.119	0.197
Piped water is the main source of water supply	4.113	6.419
Market	0.521	5.154
Paved road	4.885	7.304
Years since electricity became available	0.109	0.569
Distance to hospital	-0.208	0.188
Province fixed effects	Y	
R^2	0.366	
Obs.	3,088	

Note: *** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

The five other important variables influencing the amount of electricity usage (education, household size, ownership of a car, and the use of a refrigerator and a TV) have significant coefficients of the expected sign as shown in Table 4.5. A one standard deviation increase in years of education of household heads (about 3.6 years) leads to a rise in monthly electricity usage by about 2.9 kWh. An increase of one household member results in an approximately 2.1 kWh increase in household monthly electricity consumption. Households owning a car, which represents wealthy households, consume approximately 21.2 kWh of monthly electricity more than its counterparts. Likewise, using a refrigerator and a TV leads to a hike in monthly electricity usage by about 64.4 kWh and 8.3 kWh, respectively.

4.4.2 Effect of electricity consumption on acute respiratory infection

4.4.2.1 Average effect of electricity consumption: baseline sample

Columns 1 and 2 in Table 4.6 present the coefficients from the OLS and IV regressions of acute respiratory infection of the baseline sample, respectively. Table 4.6 shows estimated coefficients and robust standard errors clustered at the village level for a subset of control variables. Both the coefficients on acute respiratory infection of OLS and IV regressions are negative and significantly different from zero at a 5% significant level. The IV estimate in Column 2 shows that a one kWh increase in monthly electricity consumption leads to a decrease in the probability of having acute respiratory infection by 0.2 percentage points. Relative to the mean of 0.033, this result suggests there is a 6% relative decrease in the incidence of acute respiratory infection among the baseline sample.

Table 4.6 Average effect of electricity consumption on respiratory health: baseline sample

	Acute respiratory infection		**Non-respiratory illness**	
	OLS (1)	IV (2)	OLS (3)	IV (4)
Electricity consumption (kWh)	-0.0002** (0.0001)	-0.002** (0.0008)	-0.0000 (0.0001)	0.0000 (0.0006)
Age	-0.0007 (0.0008)	-0.0008 (0.0009)	-0.0001 (0.0009)	-0.0001 (0.0009)
Education	-0.003*** (0.001)	-0.003** (0.001)	-0.0007 (0.0009)	-0.0007 (0.0009)
Female	0.010 (0.007)	0.013* (0.007)	0.006 (0.005)	0.006 (0.005)
Ln adjusted income per capita	0.003* (0.002)	0.003 (0.002)	0.003* (0.002)	0.003* (0.002)
Distance to hospital	-0.0004 (0.0004)	-0.0008 (0.0005)	0.0005 (0.0003)	0.0005 (0.0003)
Province fixed effects	Y	Y	Y	Y
Obs.	3,088	3,088	3,088	3,088

Note: Robust standard errors clustered at the village level are presented in parentheses. The electricity consumption is instrumented with the electricity price. See Table 4.5 for full list of control variables.
*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

Table 4.6 also shows the regression results of the non-respiratory illnesses to examine whether the results of respiratory illnesses described above are driven by a spurious correlation. For instance, higher earnings due to electricity usage may enable households to seek better healthcare services, resulting in better health outcomes in general. An individual is regarded as being sick with non-respiratory illnesses if he/she reported being sick in the past two weeks, but did not report respiratory symptoms such as cough or rapid breathing. Columns 3 and 4 in Table 4.6 show that non-respiratory illnesses are not associated with the use of electricity, confirming that the regression result of a causal relationship between the electricity usage and respiratory health is not driven by a spurious correlation.

The comparison between the OLS and IV estimates in Column 1 and 2 suggests that the price elastic households are more likely to adopt cleaner cooking fuels or are more aware of the smoke hazards than their counterparts. As postulated in Section 4.3, household income levels can be an important factor influencing their electricity consumption behavior given the electricity price. Therefore, it is important to look into the effect of electricity consumption within different income groups.

4.4.2.2 Heterogeneous effect of electricity consumption: income based sub-samples

The sample of households is divided into two quantiles based on the median of the adjusted income per capita. The median income per capita of the sample is about US $1,200.[22] Table 4.7 presents the coefficients from OLS and IV regressions of acute respiratory infection of two income-based quantiles. The table shows estimated coefficients and robust standard errors clustered at the village level for a subset of control variables. Columns 1 and 3 display OLS results while Columns 2 and 4 present IV results of the lower and upper-income sub-samples, respectively.

Similar to the baseline sample, the OLS estimates of the two sub-samples are smaller in magnitude than those of the IV. The IV estimate in Column 2 shows that a one kWh increase in the electricity usage decreases the probability of having acute respiratory infection among the individuals living in households in the upper-income quantile by 0.23 percentage points, which is a 7% relative decrease. On the contrary, the IV estimate of the lower-income sub-sample is not significantly different from zero. It should be noted that the first stage result of the lower-income sample is statistically significant at 10% significant level, indicating that lower-income households are less price elastic in terms of electricity consumption compared to the upper-income households.[23] This might be because the electricity usage among lower-income rural households is limited to lighting, and powering a TV or a fan (Bernard, 2010; Barnes, 2007; IEG, 2008), which leaves them less flexible in terms of electricity usage in

[22] The mean income per capita of the sample is approximately US $1,123.
[23] The first stage results of the sub-samples are shown in Table A4.2 and A4.3 in the appendices.

response to price, compared to the upper-income households. This, in turn, suggests the IV estimate of the baseline sample is mainly driven by the price elastic households in the upper-income sub-sample who are more likely to diversify their use of electricity. Table A4.4 in the appendices shows the regression results of the non-respiratory illnesses of the two income-based quantiles to show that the results of respiratory illnesses described above are not driven by a spurious correlation.

Table 4.7 Effect of electricity consumption on respiratory health: income-based sub-samples

	Acute respiratory infection			
	High-income quantile		Low-income quantile	
	OLS (1)	IV (2)	OLS (3)	IV (4)
Electricity consumption (kWh)	-0.0002* (0.0001)	-0.0023*** (0.0008)	-0.0002** (0.0001)	0.001 (0.001)
Age	0.0004 (0.001)	0.0005 (0.001)	-0.002 (0.001)	-0.002 (0.001)
Education	-0.003** (0.002)	-0.004** (0.002)	-0.003** (0.002)	-0.004** (0.002)
Female	0.006 (0.010)	0.006 (0.011)	0.014 (0.008)	0.010 (0.009)
Ln adjusted income per capita	-0.008 (0.007)	-0.020 (0.013)	0.002 (0.002)	0.003 (0.004)
Distance to hospital	-0.0000 (0.0006)	-0.0008 (0.0008)	-0.0009* (0.0005)	-0.0006 (0.0006)
Province fixed effects	Y	Y	Y	Y
Obs.	1,543	1,543	1,545	1,545

Note: Robust standard errors clustered at the village level are presented in parentheses. The electricity consumption is instrumented with the electricity price. See Table 4.5 for full list of control variables.
*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

4.4.2.3 Investigating the mechanism behind the effect of electricity consumption: those who do the cooking, children, and older adults sub-samples

As the incidence of acute respiratory infection is found in Section 4.2.3 to be more prevalent among three groups of individuals, this study looks further into these target sub-samples in order to investigate the mechanism behind the effect of electricity usage on respiratory health. The three sub-samples include those who are responsible for cooking for their family, children aged under six, and adults aged over 50. Tables 4.8 and 4.9 present the coefficients from OLS and IV regressions of acute respiratory infection of the three sub-samples within the baseline sample and the upper-income households, respectively. The three sub-samples under the upper-income sub-sample are analyzed because Section 4.4.2.2 indicates that the IV estimate of the baseline sample is mainly driven by the price elastic households in the upper-income sub-sample. The two tables show estimated coefficients for a subset of control variables and their robust standard errors clustered at the village level. Columns 1, 3, and 5 display OLS results while Columns 2, 4, and 6 presents IV results of the three sub-samples, respectively.

In Table 4.8, the OLS estimates of the three sub-samples are not significantly different from zero. Similarly, the coefficients found in the IV estimates of the three sub-samples are also not significantly different from zero, albeit larger in magnitude. However, statistically significant estimates are found in two sub-samples within the upper-income households in Table 4.9. The two sub-samples are those who do the cooking and adults aged over 50 among the upper-income households. Similar to Khandker et al. (2014) and Saing (2018), these results suggest that the benefits from electrification are heavily concentrated to richer households who are more likely to diversify their use of electricity to include clean cooking fuels.

Table 4.8 Heterogeneous effect of electricity consumption on respiratory health: people who cook, children aged under six, and adults aged over 50

	Acute respiratory infection					
	People who cook		Children aged under 6		Adults aged over 50	
	OLS (1)	IV (2)	OLS (3)	IV (4)	OLS (5)	IV (6)
Electricity consumption (kWh)	-0.0001 (0.0002)	-0.002 (0.002)	0.0001 (0.0003)	0.002 (0.007)	-0.0003 (0.0002)	-0.001 (0.001)
Age	0.0009 (0.005)	0.003 (0.005)	-0.028 (0.029)	-0.019 (0.038)	-0.002 (0.013)	0.0002 (0.012)
Education	-0.002 (0.003)	-0.001 (0.003)			-0.003 (0.003)	-0.003 (0.003)
Female	-0.034 (0.032)	-0.036 (0.031)	0.013 (0.024)	0.012 (0.024)	-0.004 (0.016)	-0.005 (0.016)
Ln adjusted income per capita	0.007 (0.005)	0.007 (0.005)	-0.0004 (0.007)	-0.002 (0.008)	0.001 (0.007)	0.001 (0.007)
Distance to hospital	0.001 (0.001)	0.0008 (0.001)	-0.003** (0.001)	-0.002 (0.003)	-0.0001 (0.001)	-0.0004 (0.001)
Province fixed effects	Y	Y	Y	Y	Y	Y
Obs.	686	686	374	374	620	620

Note: Robust standard errors clustered at the village level are presented in parentheses. The electricity consumption is instrumented with the electricity price. See Table 4.5 for full list of control variables. The covariate "education" is not included in analysis of the children aged under six sub-sample.
*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

Table 4.9 Heterogeneous effect of electricity consumption on respiratory health: people who cook, children aged under six, and adults aged over 50 among the upper-income quantile

	Acute respiratory infection					
	People who cook		Children aged under 6		Adults aged over 50	
	OLS (1)	IV (2)	OLS (3)	IV (4)	OLS (5)	IV (6)
Electricity consumption (kWh)	-0.0001 (0.0002)	-0.0047** (0.002)	-0.0002 (0.0006)	0.008 (0.010)	-0.0003 (0.0003)	-0.003*** (0.001)
Age	-0.003 (0.007)	0.005 (0.009)	-0.081* (0.046)	-0.080 (0.063)	0.0009 (0.019)	0.002 (0.018)
Education	-0.003 (0.003)	-0.001 (0.004)			-0.008* (0.005)	-0.012** (0.005)
Female	-0.044 (0.042)	-0.024 (0.048)	-0.010 (0.040)	-0.027 (0.053)	-0.012 (0.026)	-0.041 (0.032)
Ln adjusted income per capita	-0.010 (0.018)	-0.029 (0.024)	-0.033 (0.033)	0.088 (0.156)	0.026 (0.022)	0.019 (0.023)
Distance to hospital	0.0005 (0.002)	-0.0001 (0.002)	-0.002 (0.003)	-0.0005 (0.005)	0.001 (0.002)	-0.0008 (0.002)
Province fixed effects	Y	Y	Y	Y	Y	Y
Obs.	351	351	168	168	288	288

Note: Robust standard errors clustered at the village level are presented in parentheses. The electricity consumption is instrumented with the electricity price. See Table 4.5 for full list of control variables. The covariate "education" is not included in analysis of the children aged under six sub-sample.
*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

Column 2 of Table 4.9 shows that a one kWh increase in the electricity consumption lowers the probability of having acute respiratory infection among those who do the cooking by 0.47 percentage points, which is a 14.2% relative decrease. Likewise, Column 6 of Table 4.9 indicates that a one kWh increase in the electricity usage reduces the probability of having acute respiratory infection among the adults aged over 50 by 0.3 percentage points, which is a 9% relative decrease. It should be noted that the children samples do not satisfy the significant first stage result in order for this study to interpret the IV estimates.[24] Nevertheless, by comparing the OLS results between the children samples and the baseline sample, it can be inferred that the significant result found in the baseline sample is not driven by the children aged under six samples.

This finding differs from Barron and Torero (2017) who found a significant effect of electricity connection on acute respiratory infection among children aged under six. Children's respiratory health is affected by indoor air pollution in case households use kerosene for lighting and/or the mothers have to take care of the children while they are cooking. First of all, the difference in our findings is partly a result of the distinction in our independent variable. While Barron and Torero (2017) used the status of receiving discount vouchers for the adoption of electricity connection and compare electrified to non-electrified households, this study captures the effect of different amounts of electricity usage. As electricity is generally used for lighting as stated in Bernard (2010), Barnes (2007), and IEG (2008), the use of electric lighting may not differ substantially between households consuming different amounts of electricity. Furthermore, Cambodian grandmothers generally help in taking care of their newborn grandchildren or in cooking for the family.[25] Also, kids in rural areas usually play and run around outside the house due to their high energy. Thus, it is actually rare that the children are in the kitchen while their mother or grandmother is cooking.

The significant result found among those who do the cooking while the same results are not found in the children sample suggests that smoke from cooking is the main channel affecting the respiratory health found in the baseline sample. As previously explained in Section 4.1, electricity consumption can lead to the improvement in respiratory health through both direct and indirect channels. Besides the switch from traditional cookstoves to electric cookstoves (direct channel), electricity usage can improve respiratory health through an

[24] This is largely due to small sample size. The characteristics of the children aged under six sub-sample are similar to those of the baseline sample. Figure A4.1 in the appendices shows the relationship between electricity price and household electricity consumption of the children sub-sample.

[25] Approximately 61% of rural households consist of female household member(s) aged over 45 who can help in cooking or taking care of young children.

increase in income and access to information on TV (indirect channel). A rise in income, in turn, allows households to adopt cleaner cooking fuels such as electricity, liquefied petroleum gas (LPG)/cooking gas, or biogas which can reduce indoor air pollution. Access to information on TV can also raise awareness of the clean cooking products and smoke hazards which can influence households to adopt cleaner cooking fuels. Side evidence can be shown with the relationship between the amount of electricity consumption and the use of clean cooking fuels in Table 4.10 in which I regress the use of clean cooking fuels on electricity consumption alone (Column 1) and then include all other covariates and 22 province fixed effects as controls (Column 2).[26] The results show that the amount of electricity usage and the use of clean cooking fuels are positively correlated, suggesting the use of clean cooking fuels is the main mechanism behind the improvement of respiratory health among electrified rural households.

Table 4.10 Electricity consumption and the use of clean cooking fuels

	The use of clean cooking fuels	
	No controls (1)	Controls (2)
Electricity consumption (kWh)	0.004*** (0.0005)	0.002*** (0.0004)
Obs.	3,088	3,088

Note: Table 4.10 shows coefficients from a regression of the use of clean cooking fuels on electricity consumption without and with controls in Columns 1 and 2, respectively. The controls include all of the other covariates in Table 4.5 and 22 province fixed effects. Robust standard errors clustered at the village level are presented in parentheses.
*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

[26] Households are regarded as using clean cooking fuels if they use clean cooking fuels (electricity, LPG, or biogas) for at least one of their cookstoves. Approximately 50% of households in the baseline sample adopt clean cooking fuels.

4.5 Conclusion

This study uses the recent Multi-Tier Framework (MTF) survey for Cambodia conducted in 2017 to investigate the effect of electricity consumption on respiratory health among rural households in Cambodia using instrumental variable strategy to deal with the endogenous electricity consumption. Taking advantage of the unique situation in rural Cambodia in which electricity generation and distribution are operated by a large number of licensees, this study uses electricity tariffs as the instrument for the amount of electricity consumption.

With the limited empirical research on the effect of household electrification on respiratory health, this study provides empirical evidence on the effect of electricity consumption on respiratory health among rural households in Cambodia. A significant contribution of this study is the focus on how much electricity is consumed among rural households which varies considerably across different socioeconomic circumstances. In other words, this study explores the effect of different amounts of household electricity usage to contribute to the current literature of rural electrification which has mainly focused on comparing electrified to non-electrified households. Moreover, this study investigates the pathways between the use of electricity and respiratory health by analyzing target sub-samples found to have a higher prevalence of respiratory illness such as those who do the cooking, children aged under six, and adults aged over 50.

This study finds that electricity consumption reduces the prevalence of respiratory illnesses among rural households in Cambodia. Specifically, a one kWh increase in household electricity utilization lessens the probability of having acute respiratory infection by 0.2 percentage points. It is also found that the effect of household electricity consumption on respiratory health is heavily concentrated among higher-income households who are more likely to diversify their use of electricity to use clean cooking fuels. Among the upper-income quantile, a larger and significant coefficient is found for two sub-samples: those who do the cooking and adults aged over 50. A one kWh increase in electricity consumption among the higher-income households leads to a drop in the probability of having an acute respiratory infection of those who frequently cook and adults aged over 50 by 0.47 and 0.3 percentage points, respectively.

The evidence suggests that the main mechanism through which the use of electricity affects the respiratory health of rural households is through the switch from solid to clean cooking fuels and that this health benefit occurs mainly among higher-income households. The role of the reductions in kerosene use as suggested by Barron and Torero (2017) is not prominent in this study because the use of electric lighting may not vary significantly between households consuming different amounts of electricity.

An important policy implication derived from this study is the role of electricity tariff in determining how and how much rural households can utilize electricity. The relatively higher price of electricity in rural areas should be addressed in order to encourage a wider diversification of electricity usage, especially among low-income households. Besides the reduction in electricity price, low-income households should be informed of the health hazards from indoor air pollution and encouraged to adopt cleaner fuels. Moreover, although this study's focus is mainly on the different amounts of electricity consumption among electrified households, an emphasis should still be placed on the importance of the expansion of rural electrification as it is the first crucial step in improving people's welfare.

CHAPTER 5 – ELECTRICITY OUTAGES AND FIRM PERFORMANCE IN CAMBODIA

5.1 Introduction

Although there has been a growing literature on the impact of infrastructure on various aspects of economic growth and development, there has been relatively less research on how infrastructure, in particular electricity, affects firms' behavior. Nowadays, electricity has become a crucial input for most production processes as technological progressions in production have centered on electricity-powered technologies.

While electricity is known to boost economic growth and development, electricity provision and access remain poor in most developing countries. The United States Energy Information Administration (2013) estimated that in 2010 about 1.3 billion people worldwide still lacked access to electricity, approximately over 95 percent of whom live in developing countries. Besides the lack of access to electricity, developing countries also face the problem of unreliable electricity supply where unstable supply and outages are frequent. In fact, in Cambodia, electricity was the most commonly cited among the major constraints to firms' operation and growth according to the 2013 World Bank Enterprise Survey. As private sector development is essential for economic growth in developing countries and electricity has increasingly become an indispensable input for most firms, it is important to examine the effects of electricity outages and to understand how firms respond to such constraints.

While a growing strand of literature has found that electricity outages significantly reduced firm outputs (i.e. Abeberese, Ackah, & Asuming, 2021; Allcott, Collard-Wexler, & O'Connell, 2016; Cole, Elliott, Occhiali, & Strobl, 2018; Falentina & Resosudarmo, 2019; Fisher-Vanden, Mansur, & Wang, 2015; Hardy & McCasland, 2019), there has been little evidence on how firms respond to electricity shortages and those findings were contradictory and cannot be generalized. For instance, Abeberese et al. (2021) and Allcott et al. (2016) found that outages caused firms to reduced their input shares of materials due to the lower marginal productivity of materials, while Fisher-Vanden et al. (2015) found that firms increased their intermediate materials input to substitute for electricity shortages. Another conflicting finding is regarding the role of generators in mitigating the negative effects of power outages on firm performance due to generators' high fixed costs relative to the size of operation. This indicates that firm characteristics and their unique circumstances are important factors in identifying how firms respond to electricity outages. Specifically, factors such as costs of electricity and other inputs as well as their substitutability determine if firms can respond to electricity shortages by increasing or decreasing other inputs. The substitution among inputs may be possible if firms produce their own intermediate inputs that can be outsourced in times of electricity shortages. Moreover, the transaction costs and the extent of market transactions across firms are also important factors determining if firms can rely on input supplies from other firms in case of electricity shortages. Regarding the role of generators, firm size is an important factor determining if firms can use generators efficiently in times of outages. In addition, the costs of electricity from the grid as well as the frequency and length of outages can also affect the relative costs of a generator and its benefits. This study presents this unifying framework to understand contradictory evidence in previous studies by focusing on these factors.

This study aims to provide another evidence of the effects of electricity outages on firm productivity and how firms respond to electricity constraints in Cambodia where outages happen rather frequently and the use of generators is more common.[27] This study primarily uses the World Bank Enterprise Surveys (WBES) for Cambodia in 2013 which provide rich firm-level data that allow us to construct a measure of productivity as well as the firm-level monthly outage duration.

The main endogeneity concern in evaluating the effects of outages mentioned in the previous studies is that larger or more productive firms may be prioritized by the authority or electricity provider companies in times of electricity shortages. While this may be the case in some countries, this study provides evidence that such preferential treatment from the

[27] Data in Section 5.3 shows that approximately 47% of all firms in Cambodia own a generator.

authority or electricity provider companies may not happen in Cambodia where state-owned enterprises are rare.[28] In addition, a test for omitted variables developed by Oster (2019) will be conducted to determine whether the omitted variable bias is severe in our setting.

This study finds empirical evidence that outages have a significant negative impact on the productivity and revenues of firms in Cambodia. Specifically, an hour increase in monthly average outage duration causes a 0.8-0.9 percent decrease in productivity and a 1.3-1.4 percent decrease in revenues. These estimates indicate that lowering the monthly outage duration from the average of about 9 hours to zero, as is the usual case in most developed countries, could result in an approximately 7.2-12.6 percent increase in productivity and revenues. This study also finds that in response to outages, Cambodian firms reduce their materials input as a result of lower marginal productivity of materials. In addition, this study finds that the use of generators among Cambodian firms can significantly mitigate the negative impacts of outages despite their relatively high fixed costs.

The remainder of this chapter is structured as follows: Section 5.2 provides a literature review; Section 5.3 gives an explanation of the data; Section 5.4 presents the model to predict the effects of outages on revenues and productivity; Section 5.5 explains production function estimation; Section 5.6 outlines the empirical strategies; Section 5.7 discusses the empirical results; and Section 5.8 offers the conclusions.

5.2 Literature Review

This paper contributes to a growing strand of literature that investigates the effect of electricity shortages on firm performance (i.e. Abeberese et al., 2021; Allcott et al., 2016; Cole et al., 2018; Falentina & Resosudarmo, 2019; Fisher-Vanden et al., 2015; Hardy & McCasland, 2019). While most findings of previous studies have shown that electricity

[28] A detailed explanation is discussed in Section 5.4.3 where this study shows that electricity outages in Cambodia happen exogenously.

outages significantly reduced firm outputs, there has been little evidence on how firms respond to electricity constraints and those findings have been mixed.

Using state-level electricity shortages, Allcott et al. (2016) found that electricity shortages reduced Indian manufacturing firm's revenues and profits by 5 to 10 percent, but average productivity losses were significantly lower since most inputs could be reserved during electricity outages. Allcott et al. (2016) also showed both in their model and estimation results that electricity shortages caused firms to decrease their input shares of materials as a result of lower marginal revenue products of materials. The authors explained that the increase in electricity price from the use of generators causes firms to reduce electricity input which in turn reduces the marginal productivity of materials and labor (because of complementarity among these inputs). However, the authors found no significant effects of outages on labor input and concluded that labor is less flexible compared to materials input.

Also using regional-level electricity shortages, Fisher-Vanden et al. (2015) examined how Chinese firms responded to electricity shortages. They found that firms in regions with more shortages reduced factor shares of electricity, but increased those of materials. This finding contradicts that of Allcott et al. (2016) which showed a reduction in materials used in the production. Fisher-Vanden et al. (2015) explained that Chinese firms substituted for energy inputs with intermediate materials that had been outsourced due to electricity shortages. As a result, Fisher-Vanden et al. (2015) also found that the costs of production increased, mainly due to input factor substitutions.

Cole et al. (2018) examined the effects of power outages on revenues of firms in Sub-Saharan Africa. The authors found a significant negative relationship between outages and firm revenues among firms without generators but found no effect for firms with generators. They explained that perhaps the operation of generators is not sufficiently costly to have a negative effect on firm revenues.

With the focus on micro and small enterprises (MSEs) in Indonesia, Falentina and Resosudarmo (2019) found that electricity outages decreased firm labor productivity. The authors also found that the use of generators was positively correlated with firm labor productivity, suggesting that MSEs with generators had lower productivity losses compared to their counterparts when the electricity is in short supply.

With the focus specifically on micro firms in Ghana in which the average firm size is 2 workers, Hardy and McCasland (2019) observed differential effects by firm size. In other words, firms without employees faced significant decreases in revenues and profits, while the same effects were not found among firms with employees. The authors also found that, during outages, firms with employees substitute for power shortages with the increase in labor inputs in order to avoid output losses.

Contradict to the findings of Cole et al. (2018) and Falentina and Resosudarmo (2019), the study of firms in Ghana by Abeberese et al. (2021) showed that the use of generators is unable to prevent firms from the negative effects of electricity outages on productivity and that may be a result of the inefficient use of generators by smaller firms, given generators' relatively high fixed costs. Similar to the finding of Allcott et al. (2016), Abeberese et al. (2021) found that firms reduced their materials input in response to electricity outages. The authors also found that electricity outages significantly decreased firm productivity and suggested that firms may shift their product mix toward less electricity-intensive products in order to alleviate the negative effects of power shortages on productivity.

Although most of the previous studies have shown that electricity outages have a significant negative impact on firm performance, there are two important issues that only some of the previous studies have covered and the findings have been mixed. The first issue is related to how firms manage their materials input in response to outages while the second one is about the role of generators in mitigating the negative effects of power outages on productivity. How firms respond to electricity outages and the benefits of operating generators may be different according to their unique characteristics and circumstances.

Factors such as costs of electricity and other inputs as well as their substitutability determine if firms can respond to electricity shortages by increasing or decreasing other inputs. The substitution among inputs may be possible in the case that firms produce their own intermediate inputs that can be outsourced in times of electricity shortages. In addition, the extent of market transactions across firms is important for efficient outsourcing. If transaction costs are low and there are many other firms in the domestic market, firms can rely on input supplies from other firms in case of electricity shortages. As shown in the study in China by Fisher-Vanden et al. (2015), Chinese firms substituted for electricity shortages by increasing the material inputs that was outsourced. However, these conditions are rare in most developing countries in which firms will resort to lower their inputs when facing energy shortages that can be seen in the study by Abeberese et al. (2021) and Allcott et al. (2016). In the Cambodian case, this study hypothesizes that outages will cause firms to lower their inputs because the in-house production of intermediate inputs is not common in Cambodia. In fact, the garment industry, which is the heart of the Cambodian manufacturing sector, is solely based on the low value-added CMT (Cut, Make and Trim) activity where the intermediate materials are supplied by the buyers, and the producing firms are paid a processing fee (Natsuda, Goto, & Thoburn, 2010). Thus, firms in Cambodia are more likely to reduce inputs in response to outages.

Regarding the role of generators, it can be helpful in mitigating the negative effects of outages in case that firms can use it efficiently which largely depends on the size of operation of a firm. Larger firms can bear the fixed costs of installing and operating a generator. In addition, the costs of electricity from the grid as well as the frequency and length of outages can also affect the relative costs of a generator and its benefits. In fact, since outages happen rather frequently and electricity price in Cambodia is relatively high, up to 47% of all firms own a generator.[29] [30] Therefore, this study hypothesizes that generators are useful in mitigating the negative impacts of outages on firm productivity in Cambodia.

[29] The data is based on the World Bank Enterprise Surveys (WBES) for Cambodia in 2013.

[30] The electricity price is relatively high in Cambodia. According to the IEA (2017), even the low-income households with a monthly electricity consumption of less than 10 kilowatt-hours (kWh), that are subjected to a subsidy from the government, still have to pay an electricity price that is higher than the average residential tariff in Indonesia, Malaysia, Thailand, and Vietnam.

5.3 Data

This study employs the World Bank Enterprise Surveys (WBES) for Cambodia in 2013.[31] The data was collected between February 2012 and February 2013. The survey used stratified random sampling to select the sample. Four levels of stratification were used in the survey: sector, establishment size, geographical location, and formal status.[32] The sector strata consist of five categories: (1) agro-processing, (2) manufacturing except for agro-processing, (3) trade, (4) tourism, and (5) other. The size stratification was stratified into three categories: small (less than 20 employees), medium (20 to 99 employees), and large (more than 99 employees). The geographic location stratification was defined in the five major urban economic centers: Phnom Penh, Siem Reap, Kampong Cham, Sihanouk Ville, and Battambang. The stratification by formal status is done by differentiating between firms that have the required registration with the Ministry of Commerce (formal firms) and those that do not (informal firms).[33]

The WBES for Cambodia in 2013 covers a wide range of establishment-level business environment topics including infrastructure level, access to finance, gender (of owner/manager), corruption, innovation, informality, and abundant performance measures. The sample consists of 775 firms, of which 472 are formal firms and 303 are informal firms. Due to missing data mainly of capital stocks and intermediate inputs, the final sample in the analysis is reduced to 450 firms (299 formal and 151 informal).

The variable of interest is the average monthly outage duration (measured in hours). Table 5.1 presents the average monthly outage duration of firms by size and formal status.

[31] There have been three datasets of the World Bank Enterprise Surveys (WBES) for Cambodia. The first one was conducted in 2007, the second one in 2013, and the latest one in 2016. The latest survey in 2016 cannot be used because the information on electricity price is not available.

[32] It should be noted that the primary sampling unit of this survey is an establishment. A firm may be composed of one or more establishments. However, since the survey also required that an establishment must make its own financial decisions and have its own management and control over its payroll, this study, for simplicity, generally uses the term 'firm' when referring to the survey sample.

[33] Business registration at the Ministry of Commerce is compulsory for all firms that have a name. Registered firms are protected with intellectual property rights and rights to their names, etc.

The average monthly outage duration among formal and informal firms is 13.8 hours and 12.0 hours, respectively. The reported average monthly outage duration of the small, medium, and large firms is approximately 10.6, 14.4, and 15.5 hours, respectively. This suggests that larger firms do not receive preferential treatment from the electricity provider companies.

Table 5.1 Average monthly outage duration by firm sizes and formal status

Average monthly outage duration (hours)						
	Formal		Informal		All firms	
	# of firms	Mean	# of firms	Mean	# of firms	Mean
Small	87	10.741	83	10.542	170	10.644
Medium	121	14.789	65	13.600	186	14.374
Large	91	15.440	3	16.667	94	15.479
Total	299	13.809	151	11.980	450	13.196

A set of variables representing firm characteristics are also generated using the survey data. Their summary statistics are shown in Table 5.2, which presents both the unweighted and weighted mean of each variable with weights given by sampling weights. The average firm age is approximately 12.8 years. The average number of employees is roughly 38 workers. Of all firms in Cambodia, approximately 47% own a generator, and about 10.3% are subsidiary firms. Moreover, foreign-owned firms consist of approximately 6.4% while exporting firms consist of roughly 3.8%, and firms that have a line of credit or a loan from a financial institution consist of 25.3% of all firms.

Table 5.2 Descriptive statistics of variables

Variables	Definition	Mean (unweighted)	S.D. (unweighted)	Mean (weighted)	S.D. (weighted)	Min.	Max.
Revenue	Firm's annual revenue (in thousands USD)	82,012	1,704,605	14,834	725,026	0.5	36,161,139
Value added	Firm's annual value added (in thousands USD)	36,640	751,897	6,605	319,812	-604	15,950,032
Outages	Firm's average monthly outage duration (hours)	13.196	22.991	9.162	16.480	0	175
Age	Firm's age	11.731	6.773	12.841	7.851	1	34
Formal	=1 if formal firm (has the required registration with the Ministry of Commerce)	0.664	0.473	0.412	0.493	0	0
Employee	Number of current employees	174.820	529.351	37.776	223.293	1	4381
Generator	=1 if firm owns or share a generator	0.598	0.491	0.470	0.499	0	1
Subsidiary	=1 if firm is part of a larger firm	0.231	0.422	0.103	0.305	0	1
Foreign	=1 if firm is owned 50% up by foreigners	0.198	0.399	0.064	0.245	0	1
Export	=1 if firm exports at least 1% of their annual production	0.120	0.325	0.038	0.192	0	1
Credit	=1 if firm has a line of credit or a loan from a financial institution	0.240	0.428	0.253	0.435	0	1
Small	=1 if firm has less than 20 employees	0.378	0.485	0.794	0.405	0	1
Medium	=1 if firm has 20 to 99 employees	0.413	0.493	0.171	0.377	0	1
Large	=1 if firm has more than 99 employees	0.209	0.407	0.035	0.185	0	1
Manufacturing	=1 if firm is in manufacturing sector	0.311	0.463	0.274	0.446	0	1
Agro-processing	=1 if firm is in agro-processing sector	0.122	0.328	0.197	0.398	0	1
Tourism	=1 if firm is in tourism sector	0.373	0.484	0.475	0.500	0	1
Trade	=1 if firm is in trade sector	0.011	0.105	0.020	0.140	0	1

Variables	Definition	Mean (unweighted)	S.D. (unweighted)	Mean (weighted)	S.D. (weighted)	Min.	Max.
Other	=1 if firm is in sector "other"	0.182	0.386	0.035	0.183	0	1
Phnom Penh	=1 if firm is located in Phnom Penh	0.602	0.490	0.497	0.501	0	1
Siem Reap	=1 if firm is located in Siem Reap	0.133	0.340	0.118	0.323	0	1
Kampong Cham	=1 if firm is located in Kampong Cham	0.098	0.297	0.212	0.409	0	1
Sihanouk Ville	=1 if firm is located in Sihanouk Ville	0.058	0.234	0.043	0.202	0	1
Battambang	=1 if firm is located in Battambang	0.109	0.312	0.131	0.337	0	1

5.4 Methodology

5.4.1 Modeling the Effects of Outages on Revenues and Productivity

The following model was used by Allcott et al. (2016) which this study follows and reproduces here. A firm uses capital *K*, labor *L*, electricity *E*, and materials *M* to produce output *Q*. The production function is assumed to be a Cobb-Douglas aggregate of capital, labor, electricity, and materials, with physical productivity (TFPQ) *A* [34]

$$Q_i = A_i \; K_i^{\alpha_K} \; L_i^{\alpha_L} \; M_i^{\alpha_M} \; E_i^{\alpha_E} \qquad (5.1).$$

Since the survey observes revenues rather than physical output quantities, the output *Q* in Equation (5.1) can be converted into revenues by multiplying both sides of Equation (5.1) with price *p*:

$$R_i = \Omega_i \; K_i^{\alpha_K} \; L_i^{\alpha_L} \; M_i^{\alpha_M} \; E_i^{\alpha_E} \qquad (5.2),$$

where revenue productivity (TFPR) Ω_i= A$_i p$.

The outage occurs with probability *δ*. Following Allcott et al. (2016), materials and electricity are considered to be fully flexible inputs that can be reduced in case of an outage. Labor is assumed to be yearly flexible, and capital is assumed to be fixed. Annual revenues can be shown as the expected value of revenues during grid power and outage periods:

$$\begin{aligned} R_i &= \Omega_i \; K_i^{\alpha_K} \; L_i^{\alpha_L}((1-\delta) \; M_{iG}^{\alpha_M} \; E_{iG}^{\alpha_E} + \delta \; M_{iO}^{\alpha_M} \; E_{iO}^{\alpha_E}) \qquad (5.3) \\ &= \Omega_i \; K_i^{\alpha_K} \; L_i^{\alpha_L} \; M_i^{\alpha_M} \; E_i^{\alpha_E} . \; V_i \end{aligned}$$

where

$$\begin{aligned} V_i &= \frac{(1-\delta) \; M_{iG}^{\alpha_M} \; E_{iG}^{\alpha_E} + \delta \; M_{iO}^{\alpha_M} \; E_{iO}^{\alpha_E}}{((1-\delta) \; M_{iG} + \delta \; M_{iO})^{\alpha_M} \; ((1-\delta) \; E_{iG} + \delta \; E_{iO})^{\alpha_E}} \qquad (5.4) \\ &= \frac{(1-\delta) \; M_{iG}^{\alpha_M} \; E_{iG}^{\alpha_E} + \delta \; M_{iO}^{\alpha_M} \; E_{iO}^{\alpha_E}}{M_i^{\alpha_M} \; E_i^{\alpha_E}}. \end{aligned}$$

The subscript G and O represent 'during grid power' and 'outage', respectively.

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[34] Physical productivity (*A*) or productivity in general is the efficiency in production. In other words, productivity refers to how much output is obtained from a given set of inputs. With the same set of inputs, more productive firms will produce higher amounts of output than less productive ones (Syverson, 2011).

Using lowercase variable to denote natural logs, revenues are:

$$r_i = \alpha_K k_i + \alpha_L l_i + \alpha_M m_i + \alpha_E e_i + \omega_i + v_i \qquad (5.5).$$

Define "measured TFPR" $\widehat{\omega}_i$ as the difference between logged revenues and input contributions,

$$\widehat{\omega}_i = r_i - \alpha_K k_i - \alpha_L l_i - \alpha_M m_i - \alpha_E e_i = \omega_i + v_i \qquad (5.6).$$

On a typical day that there is no outage, firms use electricity from the grid at price $p^{E,G}$. When there're outages, firms with generators can self-generate at price $p^{E,O} > p^{E,G}$. On the other hand, firms without generators have to pause their production activities, resulting in zero output during the outages. Equation (5.5) shows that electricity outages reduce revenues through two channels. First, electricity outages function exactly like input tax on electricity for firms with generators (Allcott et al., 2016). The increase in electricity price during outages ($p^{E,O} > p^{E,G}$) can cause firms to reduce electricity input e_i, which lowers the marginal revenue products of materials and labor. If the production function of most firms exhibit decreasing returns to scale—which is common in the production function literature, see, for instance, Collard-Wexler and De Loecker (2015)—the increase in electricity price will result in the reduction of other inputs. In fact, the estimation of production function in Section 5.4.2 shows that firms in Cambodia exhibit decreasing returns to scale. Thus, this study can hypothesize that the increase in electricity price caused by outages will result in the reduction of the demand for other production inputs among Cambodian firms. For firms without generators, the loss is larger since they have to stop the entire production activities.

Second, measured TFPR $\widehat{\omega}_i$ is affected by changes in v_i. For firm with generators, $V_i < 1$ because in a standard case $\alpha_M + \alpha_E < 1$, the production function is concave in M_i and E_i. In the case of small δ, V_i is decreasing in δ, meaning that more electricity outages cause more productivity loss. For firms without generators, v_i simplifies to $v_i = (1 - \alpha_M -$

$\alpha_E)\ln(1-\delta)$. Given that $\ln(1-\delta) \approx -\delta$, so $v_i \approx -\delta(1-\alpha_M-\alpha_E)$, which shows that the measured TFPR loss for firms without generators is larger than their counterparts. [35]

5.4.2 Production Function Estimation

Following Allcott et al. (2016), the first-order conditions are used to obtain production function coefficients α_L, α_M, and α_E with the assumption of profit maximization. Firms' profit function:

$$\Pi_i = \Omega_i K_i^{\alpha_K} L_i^{\alpha_L} M_i^{\alpha_M} E_i^{\alpha_E} - p^L L_i - p^M M_i - p^E E_i \qquad (5.7),$$

where p^L, p^M, and p^E are labor, materials, and electricity prices, respectively. Capital costs are excluded because they are regarded as a sunk cost before the firms make production decisions.

The first-order condition with respect to labor gives:

$$\alpha_L = \frac{p^L L_i}{R_i} \qquad (5.8).$$

The first-order condition with respect to materials gives:

$$\alpha_M = \frac{p^M M_i}{R_i} \qquad (5.9).$$

The first-order condition with respect to electricity gives:

$$\alpha_E = \frac{p^E E_i}{R_i} = \frac{(1-\delta)p^{E,G} E_{iG} + \delta\, p^{E,O} E_{iO}}{R_i} \qquad (5.10),$$

where the numerator is total expenditures on grid electricity plus fuel for self-generated electricity.[36]

[35] Even though the sample includes firms both in the manufacturing and service sectors, the implicit assumption of the model that electricity is a necessary input can be supported by the data. Except for one firm, all firms show positive electricity costs in our dataset. The only firm showing zero electricity usage is actually a big firm having 207 employees located in Phnom Penh in the sector specified as "other". As it is unlikely that 207 employees work in one place without electricity, I suspect misreporting of the electricity usage by this firm. Thus, it is excluded from the sample of empirical analysis below.

[36] Fuel costs for self-generated electricity are unobserved, so a proxy which is the total fuels cost among firms owning generators is used. Although firms without generators also report their fuel expenditures, the average cost is an insignificant amount of 6,881 Riels, compared to 32,933 Riels among firms with generators.

In order to obtain α_K, additional but not innocuous assumptions (Syverson, 2011) has to be made which are perfect competition and constant returns to scale in which $\alpha_K = 1 - \alpha_L - \alpha_M - \alpha_E$.

As a robustness check, this study employs another measure of productivity (denoted by TFPC) first developed by Hall (1989) which relaxes the assumption of perfect competition. In this method, the output elasticities $\alpha^L,\ \alpha^M$, α^E, and $\alpha^K$are calculated as the share of each input's cost relative to the total cost.

$$\alpha_L = \frac{p^L L_i}{p^L L_i + p^M M_i + p^E E_i + p^K K_i} \quad (5.11)$$

$$\alpha_M = \frac{p^M M_i}{p^L L_i + p^M M_i + p^E E_i + p^K K_i} \quad (5.12)$$

$$\alpha_E = \frac{p^E E_i}{p^L L_i + p^M M_i + p^E E_i + p^K K_i} \quad (5.13)$$

$$\alpha_K = \frac{p^K K_i}{p^L L_i + p^M M_i + p^E E_i + p^K K_i} \quad (5.14)$$

Similar to Allcott et al. (2016), this study obtains each α parameter for each sector classified by the World Bank Enterprise Survey using their medians because they are highly robust to outliers. After calculating each production function coefficient, measured TFPR and TFPC are computed as the difference between logged revenues and input contributions as in Equation (5.6).

In calculating the measured productivity, this study follows Foster, Haltiwanger, and Syverson (2008, 2016) and use log of the cost of materials as a proxy for m_i and log of the firm's book value for its capital stock as a proxy for k_i. This study simply uses log of the number of employees as l_i and log of total revenues as r_i. The electricity input e_i is the log of the sum of E_{iG} and E_{io} . E_{io} and $p^{E,O}$ are unobserved, so this study follows Allcott et al. (2016) and use the median price of electricity from the grid which is equal to 874 Riels/kWh as $p^{E,O}$. E_{io} is then obtained by dividing the proxy of fuel costs for self-generated electricity by the assumed $p^{E,O}$.

Table 5.3 shows the summary statistics of the estimated production function parameters among the five sectors.[37] The mean labor, materials, electricity, and capital coefficients of the measured TFPR are 0.157, 0.300, 0.046, and 0.373, respectively. The mean labor, materials, electricity, and capital coefficients of the measured TFPC are 0.103, 0.211, 0.028, and 0.531 respectively.

Table 5.3 Production function parameter estimates, TFPR, and TFPC

	Mean	
	TFPR (1)	TFPC (2)
Labor (α_L)	0.157	0.103
Materials (α_M)	0.300	0.211
Electricity (α_E)	0.046	0.028
Capital (α_K)	0.373	0.531
Measured TFPR	3.262	-
Measured TFPC	-	2.794

Note: Summary statistics for production function coefficients are based on the five sectors. Summary statistics for measured TFPR and TFPC are based on all the 450 firms in the dataset.

5.4.3 Empirical Strategy

From Equations (5.5) and (5.6) in Section 5.4.1, the estimation equation to estimate the effect of electricity outages on firm productivity or revenues as can be written as:

$$y_i = \beta_1 H_i + \boldsymbol{X'}_i \boldsymbol{\beta_2} + \lambda_z + \mu_s + \theta_p + \varepsilon_i \qquad (5.15)$$

where y_i is the firm's measured productivity or revenues*;* H_i represents a monthly average duration of electricity outages of firm i (measured in hours); $\boldsymbol{X}_i$ is a vector of observed firm

[37] The WBES classified firms into only five sectors which may be too broad to assume the same production function coefficients. Therefore, I manually divide the two largest sectors in the sample (manufacturing and tourism) into two subsectors using the information on the firm's main product line, and run a robustness check. The manufacturing sector is divided into garment and manufacturing except for garment. The tourism sector is divided into 'foods and beverages' and tourism except for 'foods and beverages'. The results are similar and shown in the appendix.

characteristics to control for variation in the productivity level across different firm attributes including number of employees, firm's age, formal status, generator ownership, subsidiary firm, foreign firm, exporting firm, and access to credit; λ_z is a size fixed effect (firm's size dummies determined by the World Bank Enterprise Surveys, i.e., small, medium, and large) to capture issues/shocks that commonly occur among small, medium, or large firms; μ_s is a sector fixed effect to capture differences in the productivity level across industries; θ_p is a location fixed effect based on the five major urban economic centers used in the geographic location stratification to control for differences in the availability of infrastructure such as roads and ports; and ε_i is an error term. Instead of using the model's outage probability δ, this study uses H_i which is a closely related proxy. Since H_i is a self-reported measure, there is a concern that firms operating longer hours also experience longer monthly outage duration. If firms operating longer hours tend to be more productive or have higher revenues, this will lead to an underestimation of the effects of outages. However, due to the data limitation, it is assumed that conditional on all firm characteristics including firm size dummies, the operating hours are comparable across firms. With this assumption, H_i can correctly represent the exogenous outage probability δ.[38]

A number of previous studies such as Allcott et al. (2016) and Fisher-Vanden et al. (2015) have employed instrumental variable method to estimate the effects of electricity shortages with the concern that larger or more productive firms may be prioritized by the authority or electricity provider companies in times of electricity shortages. This may be the case in their respective studies (India and China) where there is a considerable share of state-owned enterprises. In addition, officials in local governments in China are evaluated by regional economic performance. Thus, they may provide preferential treatment to larger firms with the aim to boost their local economies. However, such preferential treatment from the authority or electricity provider companies may not happen in Cambodia where state-owned

[38] Another similar concern is that firms tend to over-report the outage problem that can also lead to a possible underestimation of the effects of outages.

enterprises are rare.[39] Also, as shown in Table 5.1 in Section 5.3 where the average monthly outage duration by firm sizes is presented, this study can confirm that bigger firms in Cambodia do not receive such preferential treatment compared to their counterparts.

Table 5.4 Firm characteristics by outage duration (correlation test)

Firm characteristics	By monthly outage duration
Number of employees	1.080 (0.987)
Formal	0.001 (0.002)
Age	-0.029 (0.044)
Foreign	0.000 (0.001)
Export	0.000 (0.001)
Credit	-0.002 (0.001)
Subsidiary	-0.000 (0.001)
Obs.	450

Note: All regressions are weighted with sample weights. Robust standard errors clustered at the level of the combination of the four strata (sector, size, location, and formal status) are reported in parentheses.

Additionally, to show that electricity outages in Cambodia happen exogenously, this study follows Abeberese et al. (2021) and conduct correlation tests in which a number of firm characteristics are regressed on outage duration separately in Table 5.4. The results show that there are no significant associations between outage duration and firm characteristics in Cambodia. This study also provides a balance test in Table 5.5 where firm characteristics are compared between firms reporting the highest and lowest level of monthly outage duration. To conduct the balance test, the study divides the sample into three quantiles based on the monthly outage duration. The comparison of firm characteristics between the highest and lowest quantiles is done by performing statistical tests of the differences in the weighted

[39] The dataset contains only three state-owned enterprises which are excluded from the analysis.

means of firm characteristics. Results in Table 5.5 show that there are no statistically significant differences in firm characteristics between firms in the two quantiles.

Table 5.5 Firm characteristics by outage duration (balance test)

Firm characteristics	Weighted Mean		
	Highest quantile	Lowest quantile	The difference (Δ)
Number of employees	48.005	29.533	18.472
Formal	0.412	0.407	0.005
Age	11.817	13.657	-1.840
Foreign	0.061	0.071	-0.010
Export	0.042	0.040	0.002
Credit	0.239	0.249	-0.010
Subsidiary	0.072	0.089	-0.017
Obs.	177	161	

Note: The comparison of firm characteristics between the highest and lowest quantiles is done by performing statistical tests of the differences in the weighted means of firm characteristics. There are no statistically significant differences in firm characteristics between firms in the two quantiles.

Moreover, a test for omitted variables developed by Oster (2019) will be performed below to address the concerns of a potentially unobservable selection bias. Oster's (2019) method can evaluate the effect of the potentially omitted variables on the coefficient of interest, based on assumptions about the relative importance of the potentially omitted variables compared to observed variables and the potential improvement in R^2.

5.5. Empirical Results

5.5.1 The effects of outages on productivity and revenues

Although the main focus of this study is the effects of outages on firm's productivity and revenues, this study also provides estimation results of the effects of outages on value-added as a robustness check and for comparison with the results of previous studies. Columns 1 and 2 of Table 5.6 present the OLS estimates of log TFPR and log TFPC, respectively, which also show that outages have a significant negative effect on productivity despite a concern of a possible underestimation of the effects of outages due to the self-reported measure of outage duration as discussed in Section 5.4.3. The magnitudes of the estimates in Table 5.6 also suggest economically meaningful impacts of outages. Specifically, an hour increase in monthly average outage duration causes a 0.8 percent and a 0.9 percent decrease in TFPR and TFPC, respectively. If the monthly outage duration is reduced from the average of 9 hours to zero, as in the typical case in most developed countries, the TFPR and TFPC rise by approximately 7.2 percent and 8.1 percent, respectively.

Columns 1 and 2 of Table 5.7 present the OLS estimates of log revenues and log value added, respectively, which show that outages have a significant negative effect on both revenues and value added despite a concern of a possible underestimation of the effects of outages due to the self-reported measure of outage duration as discussed in Section 5.4.3. The magnitudes of the estimates in Table 5.7 suggest economically meaningful impacts of outages. Specifically, an hour increase in monthly average outage duration causes a 1.4 percent and a 1.3 percent decrease in revenues and value added, respectively. In case the monthly outage duration is reduced from the average of 9 hours to zero, as in the typical case in most developed countries, the revenues and value added rise by about 12.6 percent and 11.7 percent, respectively.

Table 5.6 The effects of electricity outages on TFPR and TFPC

	ln(TFPR) **(1)**	**ln(TFPC)** **(2)**
Electricity outages (hours)	-0.008** (0.003)	-0.009** (0.004)
Age	0.019* (0.010)	0.021* (0.013)
Formal	0.229 (0.184)	0.142 (0.239)
Employee	0.000** (0.000)	0.000** (0.000)
Generator	-0.162 (0.170)	-0.248 (0.212)
Subsidiary	-0.342** (0.147)	-0.377** (0.180)
Foreign	0.690*** (0.254)	0.740** (0.303)
Export	0.201 (0.137)	0.250 (0.161)
Credit	0.0297 (0.154)	0.030 (0.208)
Medium	0.452*** (0.143)	0.578*** (0.175)
Large	0.291 (0.202)	0.359 (0.241)
Sector fixed effects	Yes	Yes
Location fixed effects	Yes	Yes
R^2	0.435	0.284
Obs.	450	450

Note: All regressions are weighted with sample weights. Robust standard errors clustered at the level of the combination of the four strata (sector, size, location, and formal status) are reported in parentheses.
*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

Table 5.7 The effects of electricity outages on revenues and value added

	ln(Revenues) **(1)**	**ln(Value added)** **(2)**
Electricity outages (hours)	-0.014*** (0.005)	-0.013*** (0.005)
Age	0.020 (0.023)	0.026* (0.017)
Formal	1.267*** (0.319)	1.313*** (0.295)
Employee	0.001*** (0.000)	0.001*** (0.000)
Generator	0.129 (0.279)	0.136 (0.316)
Subsidiary	-0.293 (0.302)	-0.231 (0.245)
Foreign	0.916*** (0.343)	0.894*** (0.271)
Export	-0.043 (0.602)	0.232 (0.575)
Credit	0.367 (0.384)	0.207 (0.265)
Medium	1.704*** (0.298)	1.757*** (0.269)
Large	2.659*** (0.311)	2.619*** (0.360)
Sector fixed effects	Yes	Yes
Location fixed effects	Yes	Yes
R^2	0.431	0.430
Obs.	450	450

Note: All regressions are weighted with sample weights. Robust standard errors clustered at the level of the combination of the four strata (sector, size, location, and formal status) are reported in parentheses.
*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

By comparing the magnitude of the effect of outages on log revenues and log TFPR, it can be seen that the regression results are in line with the prediction of the model in Section 5.4.1. The model predicts that the ln(revenues) loss is bigger than the ln(TFPR) loss because the loss in revenue equals the TFPR loss combined with losses from reductions in production inputs. The magnitude of the findings is also similar to those of Abeberese et al. (2021) who also found that reducing the average outage level to zero could result in about 10 percent increase in productivity of firms in Ghana.

It should be noted that the location of a firm is potentially an endogenous outcome of a firm's decision. Thus, there is a concern that high-performing firms may have establishments in areas with fewer power outages, while those with poor performance may stay in areas where power outages occur frequently. If this is the case, it may lead to an overestimation of the estimation results. However, the data show that the prevalence of power outages in an area changes over time. For instance, Sihanouk Ville experienced the worst average outages in 2013, but it was Battambang that experienced the worst average outages in 2007.[40] Table A5.3 in the appendices shows the average outages by geographical locations and years. Since the ranking of the severity of outages by locations fluctuates over time, firms able to choose location would consider other factors such as land price, roads, and ports, and choose to invest in a generator instead.

Table 5.8 presents the results of Oster's (2019) test for omitted variables which can assess the effect of the potentially omitted variables on the coefficient of interest. As proposed by Oster (2019), this study assumes that: (1) unobserved variables and the observed variables are of equal importance (δ=1); (2) the inclusion of omitted variables can lead to a maximum R^2 of 1.3 times the estimated R^2 in the full specification. With these assumptions, this study finds that potentially omitted variables could alter the coefficient on outage duration by about 0.001 for all our outcome variables which is about 0.1 percent difference. All the changes are well within the confidence intervals of the estimated coefficients, pointing that the estimated results are not significantly affected by the potentially omitted variables. In addition, in Column 3, this study also shows the value of δ, which is the relative degree of selection on observed and unobserved variables necessary to eliminate the estimated effects. Column 3 shows that the selection on unobservables would have to be 6-16 times stronger than the selection on observables to fully eliminate the estimated effects of outages.

[40] Author's calculation is based on the data from the WBES in 2013 and 2007.

Table 5.8 Bias-adjusted coefficients using Oster's (2019) test for omitted variable

Electricity outages (hours)	**Estimated coefficients (1)**	**Bias-adjusted coefficients (2)**	**Relative degree of selection to eliminate result (δ) (3)**
ln(TFPR)	-0.008	-0.007	6.573
ln(TFPC)	-0.009	-0.008	7.286
ln(Revenues)	-0.014	-0.015	-16.607
ln(Value added)	-0.013	-0.014	-14.125

Note: In the estimation of the bias-adjusted coefficients and δ, the assumed baseline controls include only firm size dummies, sector fixed effects, and location fixed effects. The set of full controls follows the specification explained in Section 5.4.3.

5.5.2 The effects of outages on production inputs

As discussed earlier, there has been little evidence on how firms respond to electricity shortages and those findings were mixed. For instance, Abeberese et al. (2021) and Allcott et al. (2016) found that outages caused firms to reduced their input shares of materials due to the lower marginal productivity of materials. However, Fisher-Vanden et al. (2015) found that firms increased their intermediate materials input to substitute for electricity shortages. This study, therefore, aims to provide more evidence on the effects of outages on production inputs. Columns 1 and 2 of Table 5.9 show the regression results of Equation (5.15) with the outcome variables replaced by log materials or log number of employees, respectively. Robust standard errors clustered at the level of the combination of the four strata (sector, size, location, and formal status) are reported in parentheses. The table also shows the bias-adjusted coefficients and the value of δ from Oster's (2019) test for omitted variables.

Column 1 of Table 5.9 shows that an hour increase in monthly average outage duration causes a 1.5 percent decrease in materials input. In other words, if the monthly outage duration is reduced from the average of 9 hours to zero, as in the typical case in most developed countries, firms will increase their materials input by about 13.5 percent. Column 2 of Table

5.9 shows that the effect of outages on labor input is smaller and is not statistically significant at conventional levels. These findings are in line with those of Allcott et al. (2016) who suggested that labor input is less flexible in response to outages compared to materials input which may be adjusted from day to day as outages occur.

Table 5.9 The effects of electricity outages on production inputs

	ln(Materials) **(1)**	**ln(Workers)** **(2)**
Electricity outages (hours)	-0.015** (0.006)	-0.002 (0.004)
Controls	Yes	Yes
R^2	0.2974	0.7282
Bias-adjusted coefficients	-0.015	-0.003
Relative degree of selection to eliminate result (δ)	9.452	-2.781
Obs.	450	450

Note: In the estimation of the bias-adjusted coefficients and δ, the assumed baseline controls include only firm size dummies, sector fixed effects, and location fixed effects. The set of full controls follows the specification explained in Section 5.4.3. Robust standard errors clustered at the level of the combination of the four strata (sector, size, location, and formal status) are reported in parentheses.
*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level

5.5.3 The effects of outages by generator ownership

To investigate the role of generators in mitigating the negative effects of electricity outages, this study divides the sample into two subsamples based on generator ownership. Table 5.10 presents the effects of electricity outages on revenues and productivity by generator ownership. Column 1 shows the estimation results for the subsample of firms with generators while Column 2 displays the results for the subsample of firms that do not use generators.

Robust standard errors clustered at the level of the combination of the four strata (sector, size, location, and formal status) are reported in parentheses.

Table 5.10 The effects of electricity outages by generator ownership

Electricity outages (hours)	**Generators (1)**	**No generator (2)**
ln(TFPR)	-0.002 (0.002)	-0.012* (0.007)
ln(TFPC)	-0.003 (0.003)	-0.013 (0.008)
ln(Revenues)	-0.003 (0.004)	-0.026** (0.011)
ln(Value added)	0.002 (0.005)	-0.029*** (0.010)
Obs.	269	181

Note: All regressions are weighted with sample weights. Robust standard errors clustered at the level of the combination of the four strata (sector, size, location, and formal status) are reported in parentheses.
*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

This study finds that the estimation coefficients among firms without generators are of greater magnitude than their counterparts and mostly statistically significant, while the coefficients among firms with generators are not. It should be noted that although the estimation coefficient for ln(TFPC) among firms without generators are not statistically significant at conventional levels, the *p*-value is only 0.139 which is just a little higher than the 10% significant level. This finding suggests that, for firms with generators, outages do not have significant effects on firm performance. This finding is in line with those of Cole et al. (2018) and Falentina and Resosudarmo (2019) who suggested that using generators can significantly alleviate the negative impacts of outages among firms despite their expensive costs.[41]

[41] It should be noted that since the sample is divided using the status of generator ownership, which is an endogenous outcome of firm decisions, there is a concern of sample selection issue. The estimation coefficients in this case, therefore, may only serve as a suggestive evidence regarding the benefits of generators.

5.6 Conclusion

Despite a growing literature on the impact of infrastructure on various topics of economic growth and development, there have been relatively few studies on the implications of electricity outages for firms in developing countries. This study provides a unifying framework to understand conflicting evidence of the previous studies and adds another evidence of the effects of electricity outages on firm productivity and how firms respond to electricity constraints in Cambodia where outages happen rather frequently.

This study finds that outages significantly lower the productivity and revenues of firms in Cambodia. Specifically, an hour increase in monthly average outage duration causes a 0.8-0.9 percent decrease in productivity and a 1.3-1.4 percent decrease in revenues. These findings suggest that reducing the monthly outage duration from the average of approximately 9 hours to zero, as is the common scenario in most developed countries, has the potential to increase productivity and revenues by about 7.2-12.6 percent. This study also finds two important findings regarding how Cambodian firms respond to outages. First, firms reduce their materials input in response to outages due to lower marginal productivity of materials. Second, most Cambodian firms use a generator, and that it can significantly mitigate the negative effects of outages despite its relatively high fixed costs.

These findings have clear policy implications for both the government and for firms. Since the reliability of the available electricity service is crucial in facilitating growth and attract new investments, the magnitude of the negative effects of outages found in this study may be useful for the government and/or the responsible agencies in prioritizing between multiple important issues that require development at the same time. Furthermore, the findings suggest that the use of a generator is useful for Cambodian firms in reducing the negative impacts of outages on their productivity.

CHAPTER 6 - SUMMARY AND POLICY IMPLICATIONS

This dissertation assesses the household and firm-level impacts of electricity development in Cambodia by conducting empirical studies that focus on the three important aspects of electricity development in Cambodia, i.e. access, affordability, and reliability. Each of the empirical studies makes significant contributions to the current literature on the impacts of infrastructure on various aspects of economic growth and development.

Before presenting the three main empirical studies, this dissertation provides an overview of the electricity development in Cambodia in Chapter 2, while Chapter 1 gives an introduction which focuses on the objectives and significance of the dissertation. The first empirical analysis in Chapter 3 focuses on the impacts of access to electricity on the changes in employment structure, which is the main channel through which electrification affects people's welfare. It fills the gap in the literature by examining into employment categories, the topic that has resulted in mixed findings in previous studies. As well as categorizing employment structure into agricultural and nonagricultural sectors, the study explores the movement out of agriculture by further looking into three types of nonagricultural employment: self-employment, wage employment, and unpaid work. Understanding structural changes in the labor market is important because nonfarm employment plays a vital role in lifting people out of poverty (Hoang et al., 2014; Lanjouw & Shariff, 2004; Seng, 2015). Moreover, the study provides evidence on the important contributions of the informal sector such as self-employment and unpaid employment in the rural economy during the early transition to non-agricultural activities.

Since the current literature on rural electrification has mainly focused on comparing electrified to non-electrified households, the second empirical study in Chapter 4 contributes to the current literature by analyzing the effects of different amounts of electricity usage on respiratory health among rural households in Cambodia. A significant contribution of this study is the focus on how much electricity is consumed among rural households which is related to the issue of affordability of electricity and that it varies considerably across different household socioeconomic circumstances. The price of electricity—which is relatively high compared to its neighboring countries—is another important factor affecting the electricity consumption behavior among rural households. Since the electricity price in Cambodia is determined exogenously by each supplier based on the full-cost recovery principle, this study employs electricity price as an instrumental variable to address the endogeneity of electricity consumption in order to evaluate its effect on respiratory health outcomes.

The third empirical study in Chapter 5 centers on the issue of the reliability of electricity in Cambodia. Since there has been relatively little research on the effects of electricity shortages on firm behaviors, this study examines the effects of electricity outages on firm performance in Cambodia where outages happen rather frequently. Additionally, this study also provides another evidence on how firms respond to electricity constraints as previous studies have shown mixed findings that cannot be generalized.

By analyzing various micro-level datasets in Cambodia, this dissertation finds evidence that rural electrification shifts labor out of agricultural activities toward nonagricultural employment and that this movement is dominated by an increase in nonfarm self-employment activities. The study also finds evidence of small external effects of rural electrification on the movements out of agriculture into nonagricultural self-employment. In addition, this dissertation finds that electricity consumption reduces the prevalence of respiratory illnesses among rural households in Cambodia. It is also found that the effect of household electricity consumption on respiratory health is heavily concentrated among higher-income households who are more likely to diversify their usage of electricity to use clean cooking fuels. The evidence suggests that the main mechanism through which the use of electricity affects the respiratory health of rural households is through the switch from solid to clean cooking fuels and that this health benefit occurs mainly among higher-income households. Last but not least, this dissertation finds evidence that electricity outages significantly lower the productivity and revenues of firms in Cambodia. In response to outages, Cambodian firms reduce their materials input due to lower marginal productivity of materials. Besides, most Cambodian firms use a generator in response to outages, and that it can significantly mitigate the negative effects of outages despite its relatively high fixed costs.

Based on the evidence presented above, there are three main direct policy implications that can be drawn. Firstly, it is crucial to achieving 100% electricity access in Cambodia. In recent years, the government of Cambodia has done a good job in increasing electricity access from an electrification rate of 26.4% in 2008 to 91.8% in 2018. The remaining households without access to electricity are likely to be located in remote areas where: (1) it is time-consuming and costly for the investment in the expansion of the existing grid system, (2) electricity businesses may not yield the same profits as other regions. While more efforts should be placed on the expansion of the existing grid system to provide electricity access to poor households in the remote areas, another possible policy recommendation is that the government may provide more incentives to attract more private investors to act as electricity providers in remote areas. Although the policies to attract more private investors may be less time-consuming and more cost-effective (in the short run) in bringing electricity access to isolated households than expanding the National Grid to reach all remote areas, it should be noted that the electricity prices from the private providers are generally higher than those from the government. Therefore, the government of Cambodia needs to consider the balance between efficiency, equity, and sustainability for the future planning of the electricity sector. Another possible way to achieve 100% electricity access without subjecting poor households to a high electricity price is that the government may consider giving subsidies for remote households to invest in the Solar Home System. Using the Solar Home System, households do not have to pay for monthly electricity bills but have to pay a relatively high initial cost. With subsidies from the government, poor households are likely to adopt the Solar Home System, but the questions regarding its capacity, durability, and weather dependency remain. More research on the costs and benefits analysis of the Solar Home System in the context of rural Cambodia is necessary.

Secondly, as electricity price is shown to determine how and how much rural households can utilize electricity, the government of Cambodia needs to tackle the issue of relatively high price of electricity in order to encourage a wider diversification of electricity usage, especially among low-income households. Specifically, rural households connected to the isolated system that generates electricity using diesel fuel are subjected to a high price but are not subjected to the subsidy program from the government, unlike those connected to the National Grid. Therefore, a similar subsidy program for low-income households connected to the isolated system should be considered. Alternatively, the government may put more effort into the expansion of the existing grid system to include those areas as mentioned above. Besides the reduction in electricity prices, low-income households should be informed of the health hazards of indoor air pollution and encouraged to adopt cleaner fuels.

Last but not least, the evidence in Chapter 5 shows that the government in Cambodia also needs to improve the reliability of electricity as it is crucial in facilitating growth and attract new investments. Furthermore, the analysis in Chapter 5 finds that the use of a generator is useful for Cambodian firms in reducing the negative impacts of outages on their productivity. The popular use of generators as a response to outages shows that there are also environmental costs from the unreliable electricity supply. In addition, not all firms can afford to invest in a generator; small businesses without generators are still badly affected by outages. Therefore, the government should put more effort into increasing the supply capacity in order to improve electricity reliability. The Electricité du Cambodge may consider investing in more electricity generation plants to increase the supply capacity. Alternately, the government may boost the investment in electricity generation plants from the private sector in the form of tax incentives, abolishing license fees, or even subsidies.

In assessing the impacts of electricity development in Cambodia, this dissertation analyzes all three pressing issues of electricity development (access, affordability, and reliability). Since this dissertation shows empirical evidence on the importance of rural electrification in Cambodia and that the remaining households without access to electricity are likely to be located in remote areas as mentioned above, the next interesting question to answer is whether the benefits of the use of the Solar Home System for isolated households without electricity access outweigh the costs/disadvantages (its capacity, durability, and weather dependency). Due to the limitation of data, the empirical analysis in Chapter 3 cannot differentiate different sources of electricity. Similarly, with the use of electricity price data in Chapters 4 and 5, the analyses mainly focus on the observations connected to the grid line. Since the Solar Home System can be a potential solution to achieving 100% electricity access in the near future without subjecting poor households to a high electricity price, future research may evaluate the costs and benefits of the Solar Home System for households without access to the electricity grid.

APPENDICES

Appendices of Chapter 3

Table A3.1 Summary statistics of variables used in individual-level analysis

Variables	Obs.	Mean	S.D.	Min.	Max.
Outcome Variables					
Agricultural total employment	804,736	0.849	0.358	0	1
Nonagricultural total employment	804,736	0.128	0.334	0	1
Nonagricultural self-employment	804,699	0.050	0.218	0	1
Nonagricultural wage employment	804,699	0.064	0.244	0	1
Nonagricultural unpaid employment	804,699	0.014	0.117	0	1
Variable of Interest					
Electrified households	804,736	0.106	0.307	0	1
Household Characteristics					
Toilet	804,736	0.172	0.377	0	1
Piped water	804,736	0.035	0.185	0	1
House with 3 or more rooms	804,736	0.041	0.198	0	1
Own the house	804,736	0.970	0.170	0	1
Household size	804,736	5.369	2.217	1	27
Number of children aged less than 5	804,736	0.422	0.672	0	8
Individual Characteristics					
Years of schooling	804,736	3.720	3.334	0	13
Age	804,736	36.204	14.559	15	98
Female	804,736	0.531	0.499	0	1
Married	804,736	0.717	0.451	0	1
Divorced	804,736	0.025	0.157	0	1
Widowed	804,736	0.049	0.215	0	1
Buddhist	804,736	0.969	0.173	0	1
Muslim	804,736	0.017	0.130	0	1
Christian	804,736	0.003	0.056	0	1

Table A3.2 Summary statistics of variables used in district-level analysis

Variables	Obs.	Mean	S.D.	Min.	Max.	Mean (1998)	Mean (2008)	Δ
Outcome Variables (%)								
Agri. total emp.	222	84.391	9.989	39.210	95.354	83.686	85.096	1.410
Nonagri. total emp.	222	13.426	9.107	2.830	59.344	12.584	14.268	1.684*
Nonagri. self-emp.	222	4.928	3.619	0.157	19.556	4.555	5.301	0.746*
Nonagri. wage emp.	222	7.093	6.350	2.034	43.794	6.876	7.310	0.434
Nonagri. unpaid emp.	222	1.255	1.067	0	6.916	0.889	1.621	0.732***
Variable of Interest (%)								
Electrified households	222	8.668	9.579	0	69.722	5.035	12.300	7.265***
District Characteristics (%)								
Toilet	222	13.773	12.473	0	62.671	5.680	21.867	16.187***
Piped water	222	3.114	4.401	0	27.718	1.587	4.641	3.053***
Households with 3 or more rooms	222	3.661	3.113	0	16.135	2.965	4.358	1.392***
Own the house	222	95.238	3.213	79.255	99.488	95.097	95.379	0.282
Household size	222	5.347	0.432	3.938	6.874	5.521	5.173	-0.347***
Individual with children aged less than 5	222	33.656	6.150	21.191	52.995	38.048	29.265	-8.782***
People aged > 59	222	7.654	2.248	0.808	15.067	6.965	8.343	1.378***
Average years of schooling	222	3.445	1.029	0.523	6.578	2.960	3.930	0.969***
Average age	222	35.794	1.788	31.876	41.962	35.024	36.563	1.538***
Gender ratio (female/male)*100	222	110.35	15.122	51.077	143.559	111.649	109.051	-2.598
Married	222	71.544	3.776	62.028	79.763	71.075	72.014	0.939**
Divorced	222	2.498	0.705	0.808	4.717	2.815	2.181	-0.633***
Widowed	222	4.847	1.301	1.426	8.108	5.364	4.330	-1.033***
Buddhist	222	95.503	13.180	6.732	100	95.126	95.880	0.754
Muslim	222	1.617	4.251	0	31.651	1.501	1.733	0.232
Christian	222	0.374	1.026	0	11.507	0.409	0.338	-0.070
Ln of district population	222	8.076	0.573	6.385	9.267	7.919	8.234	0.314***
Ln of distance to nearest provincial town (base year)	111	3.492	0.874	0.405	4.867	-	-	-
Located along the national border (base year)	111	0.216	0.413	0	1	-	-	-
Located in mountainous or plateau areas (base year)	111	0.180	0.386	0	1	-	-	-

Note: The total number of observations in each time period is 111. "-" represents information not applicable.
***Significant at the 1 percent level.
**Significant at the 5 percent level.
*Significant at the 10 percent level.

Appendices of Chapter 4

Table A4.1 Definition of variables

Variables	Definition
Outcome Variable	
Acute respiratory infection	Equals 1 if the individual reports to be sick with coughing and rapid breathing in the past 14 days
Variable of Interest	
Electricity consumption (kWh)	Last month's electricity consumption of each household
Instrumental Variable	
Electricity price	Electricity price of each village, measured in Riels
Individual Characteristics	
Age	Age of each individual, measured in years
Education	Years of completed education of each individual
Female	Equal 1 if the individual is female
Household Characteristics	
Age of household head	Age of each household head, measured in years
Education of household head	Years of completed education of each household head
Female-headed household	Equal 1 if the household head is female
Cook inside the house	Equal 1 if the household normally cook inside the dwelling
Ln adjusted income per capita	Natural logarithmic of household income per capita, adjusted using the OECD-modified equivalent scale
Car	Equal 1 if the household owns a car
Refrigerator	Equal 1 if the household owns a refrigerator
TV	Equal 1 if the household owns a TV
Outage	The duration of weekly outage, measured in minutes
Village Characteristics	
Piped water is the main source of water supply	Equal 1 if piped water is the main source of water supply in the village
Share of landless households	Share of landless households in the village
Market	Equal 1 if there is a market inside the village
Paved road	Equal 1 if the village is accessible by car or truck by paved road all year long

Variables	Definition
Years since electricity became available	How long since electricity first became available in the village, measured in years
Distance to hospital	Distance from the village to the nearest hospital, measured in kilometers

Table A4.2 Electricity consumption: first stage OLS estimates of the target sub-samples

	Electricity consumption (kWh)				
	High-income quantile (1)	Low-income quantile (2)	People who cook (3)	Children aged under 6 (4)	Adults aged over 50 (5)
Electricity price/100	-2.085*** (0.643)	-1.204* (0.701)	-1.619** (0.642)	-0.821 (0.704)	-2.059*** (0.793)
R^2	0.4757	0.2250	0.3413	0.4759	0.3309
F-statistics	11577.51	107558.26	290.35	9873.03	605.96
Pr > F	0.000	0.000	0.000	0.000	0.000
Obs.	1,543	1,545	686	374	620

Note: Robust standard errors clustered at the village level are presented in parentheses.
*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

Table A4.3 Electricity consumption: first stage OLS estimates of the target sub-samples among the upper-income households

	Electricity consumption (kWh)		
	People who cook (1)	Children aged under 6 (2)	Adults aged over 50 (3)
Electricity price/100	-1.950** (0.860)	-1.136 (1.281)	-3.314** (1.319)
R^2	0.4424	0.7077	0.4598
F-statistics	81.07	128.01	994.03
Pr > F	0.000	0.000	0.000
Obs.	351	168	288

Note: Robust standard errors clustered at the village level are presented in parentheses.
*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

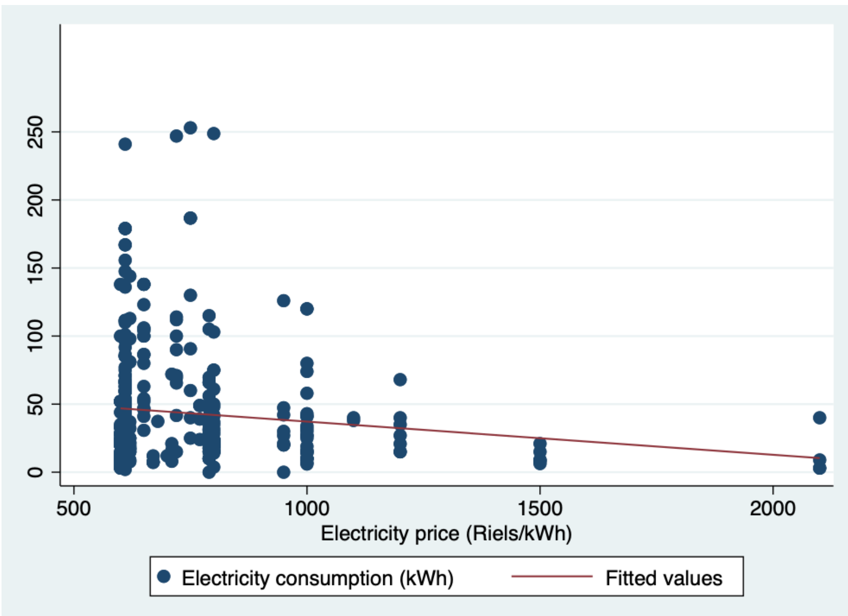

Figure A4.1 *The Relationship between Electricity Price and Household Electricity Consumption of the children aged under six sub-sample*

Source: The MTF Survey in Cambodia (2018)

Table A4.4 Falsification test: effect of electricity consumption on non-respiratory illnesses in the income-based sub-samples

	Non-respiratory illnesses			
	High-income quantile		Low-income quantile	
	OLS (1)	IV (2)	OLS (3)	IV (4)
Electricity consumption (kWh)	-0.0001 (0.0001)	0.001* (0.0006)	0.0001 (0.0001)	-0.005 (0.004)
Age	-0.001 (0.002)	-0.001 (0.002)	0.0006 (0.001)	0.0003 (0.001)
Education	-0.0000 (0.001)	0.0002 (0.001)	-0.0008 (0.001)	0.002 (0.003)
Female	0.003 (0.006)	0.003 (0.006)	0.010 (0.008)	0.025* (0.014)
Ln adjusted income per capita	0.022*** (0.008)	0.028*** (0.011)	0.002* (0.001)	-0.002 (0.007)
Distance to hospital	0.0002 (0.0005)	0.0006 (0.0007)	0.001** (0.0005)	0.0001 (0.001)
Province fixed effects	Y	Y	Y	Y
Obs.	1,543	1,543	1,545	1,545

Note: Robust standard errors clustered at the village level are presented in parentheses. The electricity consumption is instrumented with the electricity price. See Table 5 for full list of control variables.
*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

As another falsification test, Table A4.4 shows the regression results of the non-respiratory illnesses of the two income-based quantiles to examine whether the results of respiratory illnesses described in the main text are driven by a spurious correlation. For instance, higher earnings due to electricity usage may enable households to seek better healthcare services, resulting in better health outcomes in general. An individual is regarded as being sick with non-respiratory illnesses if he/she reported being sick in the past two weeks, but did not report respiratory symptoms such as cough or rapid breathing. Opposite to the result on respiratory health in the main text, Column 2 in Table A4.4 shows that the use of electricity is positively associated with the incidence of non-respiratory illnesses. This result validates two important notions. First, it confirms that the regression result of a causal relationship between electricity usage and respiratory health in the main text is not driven by a spurious correlation. Second, the use of electricity also has negative consequences. A study by Pellegrini and Tasciotti (2016) and Tasciotti (2017) found that household members living in electrified households are more likely to experience malaria. The authors explained that electric lights attract malaria vectors. Besides, outdoor lighting available after the sunset may change people's habits and increases their exposure to malaria vectors. Although it is not known for sure the prevalence of malaria among the reported non-respiratory illnesses due to the data limitation, Cambodia is known to have the highest malaria burden compared to its neighboring countries (Laos, Thailand, and Vietnam) and the WHO Western Pacific Region overall (World Health Organization, 2018). Further research may focus on the link between electricity usage and malaria occurrence in Cambodia with the use of a more specific indicator for malaria.

Table A4.5 Robustness check: average effect of electricity consumption on respiratory health

	Acute respiratory infection	
	OLS (1)	IV (2)
Electricity consumption (kWh)	-0.0002** (0.0001)	-0.002* (0.001)
Age	-0.0007 (0.0008)	-0.0008 (0.0009)
Education	-0.003*** (0.001)	-0.003** (0.001)
Female	0.011 (0.007)	0.013* (0.007)
Ln adjusted income per capita	0.003* (0.002)	0.003 (0.002)
Distance to hospital	-0.0006 (0.0004)	-0.001* (0.0005)
Province fixed effects	Y	Y
Obs.	3,088	3,088

Note: Robust standard errors clustered at the village level are presented in parentheses. The electricity consumption is instrumented with the electricity price. Different from the model used in the main text, the control variables used in this robustness check exclude the village-level variables "years since electricity became available", "a market in the village", and "piped water is the main source of water supply".
*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

As mentioned in Section 4.3, Table A4.5 provides estimation results where the village-level variables "years since electricity became available", "a market in the village", and "piped water is the main source of water supply" are excluded from the estimation model to check whether the conditional independence assumption is supported. Table A4.5 shows that the estimation results before and after the exclusion of the village-level variables do not change significantly. Therefore, it can be inferred that, conditional on the village-level covariates, the electricity price is independent of the factors affecting the health outcomes of the people.

Appendices of Chapter 5

As a robustness check, I manually divide the two largest sectors in the sample (manufacturing and tourism) into two subsectors using the information on the firm's main product line. The manufacturing sector is divided into garment and manufacturing except for garment. The tourism sector is divided into 'foods and beverages' and tourism except for 'foods & beverages'. In this section, I show the estimation results using these more narrowly defined sectors. As shown in Table A5.1 and A5.2, all the results are very similar to the baseline results in the main text.

Table A5.1 Production function parameter estimates, TFPR, and TFPC

	Mean	
	TFPR (1)	TFPC (2)
Labor (α_L)	0.154	0.104
Materials (α_M)	0.285	0.204
Electricity (α_E)	0.049	0.027
Capital (α_K)	0.373	0.531
Measured TFPR	3.383	-
Measured TFPC	-	2.828

Note: Summary statistics for production function coefficients are based on the more narrowly defined sectors described above. Summary statistics for measured TFPR and TFPC are based on all the 450 firms in the dataset.

Table A5.2 The effects of outages on revenues, value-added, TFPR, TFPC, and production inputs

Electricity outages (hours)	**Estimated coefficients**
ln(TFPR)	-0.007** (0.003)
ln(TFPC)	-0.008** (0.003)
ln(Revenues)	-0.013** (0.005)
ln(Value added)	-0.012** (0.005)
ln(Materials)	-0.011* (0.006)
ln(Workers)	-0.003 (0.004)

Note: All regressions are weighted with sample weights. Robust standard errors clustered at the level of the combination of the four strata (sector, size, location, and formal status) are reported in parentheses.
*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level

Table A5.3 Average monthly outage duration (hours) by geographical locations and years

	2007	2013
Phnom Penh	3.552	14.386
Siem Reap	4.590	11.008
Sihanouk Ville	-	15.673
Battambang	10.516	8.949
Kampong Cham	1.669	12.114
Other locations	6.068	-
Total	3.909	13.196

Note: Data on Sihanouk Ville in 2007 is not available. Instead, firms located outside the four major urban economic centers in 2007 were grouped as "others". The data in 2007 contains a significant number of missing values (105 out of total of 498 firms).

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