ABSTRACT

WALSH, AMANDA CAROL Economic Considerations in Vector-Borne Disease Management. (Under the direction of Dr. Melinda Morrill and Dr. Walter Thurman).

Dengue fever is a growing global health concern. The common occurrence of large dengue epidemics is said to overburden health care systems in the developing world. However, the broader economic impact of epidemics is still largely unknown. While interest in dengue research within the scientific community and among health officials in developing countries is extensive, there is little research within economics on the subject. In Chapter 2, I explore important avenues for future research on the economic burden of dengue as well as emerging prevention technologies that have implications for other vector-borne diseases. I compare the transmission, treatment, and prevention of dengue to other insect-borne diseases. I review the existing economics literature on dengue and suggest avenues for future research based on existing applications in the infectious disease literature. I then discuss key economic considerations in the treatment and prevention of dengue and in the potential implementation of genetically modified mosquito technologies for mosquito-borne disease prevention.

Household surveys in developing countries increasingly collect information on physical housing attributes in lieu of monetary data to proxy for wellbeing. Best practices regarding the construction of indices from physical housing data have not been widely explored. In Chapter 3, I use data from the Peruvian National Household Survey to analyze the sorting of households into economic classes when varying the method used to generate an index via principal components analysis. I suggest best practices regarding the selection of econometric methods and the scale of index construction. I subdivide each geographic subsample into economic classes based on local sample distributions of the nationally formed index. The constructed index accurately differentiates housing attributes of varying quality and

corresponds strongly with income and consumption measures. The index is consistent with household demographic variables typically associated with wellbeing. The results are relevant to research in countries where reliable monetary proxies for wellbeing are costly to acquire.

Existing research on the economic impact of dengue among households focuses on individuals with clinically confirmed disease and their families. However, caregiving activities, avoidance behaviors, and changes in labor demand may cause the potential labor market impacts of an epidemic to extend beyond households that directly experience illness. In Chapter 4, I exploit exogenous fluctuations in the timing and scale of dengue epidemics in the Amazonian city of Iquitos, Peru from July 2005 to June 2010 to isolate changes in the work hours of all primary male and female residents in the region. I find that dengue epidemics are not associated with significant changes in the probability that males or females work, but are associated with large, statistically significant decreases in work hours for those who work positive hours. In aggregate, females reduce work hours more than males, both in levels of the point estimates and relative to mean hours.

Economic Consideration in Vector-Borne Disease Management

by
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BIOGRAPHY

Amanda graduated *summa cum laude* with a Bachelor's degree in Economics from Illinois Wesleyan University. Her dissertation in Economics was completed under the direction of Melinda Morrill and Walter Thurman at North Carolina State University. Her coursework focused on development economics and applied microeconomics and her research interests lie in analyzing issues of global health policy, household economics, and the regulation of genetically modified organisms.

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CHAPTER 1: INTRODUCTION

Dengue fever is a mosquito-borne virus that predominantly affects urban areas of tropical and sub-tropical regions throughout Southeast Asia, the Americas, and the Western Pacific (WHO 2015a). Estimates suggest that there were approximately 96 million symptomatic cases of the virus globally in 2010 (Bhatt et al. 2013). Symptoms include headache, fever, rash, and muscle aches. Severe cases, while only representing a small fraction of infections, can result in vomiting, internal hemorrhaging, and potentially death (WHO 2015a).[1] Frequently recurring epidemics are said to overburden health care systems in the developing world (Gubler 2012). However, the full economic impact of epidemics is yet to be determined.

In Chapter 2, I discuss economic considerations involved in mosquito-borne disease prevention, focusing specifically on dengue fever. I review the existing economics literature on dengue and suggest avenues for future research applying theories from related work in the infectious disease literature. I also discuss key economic considerations in the treatment and prevention of dengue and in the potential implementation of genetically modified mosquito technologies for mosquito-borne disease prevention. This chapter serves as a guide for future research on the economic burden of dengue and on emerging disease control technologies.

A reliable measure of economic wellbeing is necessary for analyzing important research topics in developing country contexts, including impact analyses and assessments of the link between health and household demographics. In lieu of monetary data, household surveys in developing countries are increasingly collecting information on housing construction

[1] The WHO estimates that there are approximately 500,000 dengue cases requiring hospitalization per year and that approximately 2.5% of these cases result in death.

materials, utilities, and durable goods ownership, which are then compiled into 'asset indices.' In Chapter 3, I determine the impact of varying the methods used to generate asset indices on the way in which households are sorted into economic classes. Using data from the Peruvian National Household Survey in 2006, I analyze one common method of asset index construction: principal components analysis (PCA) (INEI 2015). I assess the impact of varying the specific methods used to construct asset indices via PCA, including the number and type of variables that are used, the use of the correlation versus the covariance matrix, the number of principal components that are retained, and the population over which the index is formed. The findings in this chapter give guidance to researchers using data from developing countries that do not include monetary proxies for economic wellbeing.

Existing estimates of the economic impact of dengue at the household level focus on the families of individuals who test positive for dengue (see Beatty, Beutels, and Meltzer, 2011 and Shepard, Halasa, and Undurraga, 2014 for reviews). However, the impacts of an epidemic on household labor market outcomes may extend beyond those who experience illness. In Chapter 4, I use irregular fluctuations in dengue transmission that are arguably exogenous to the household to assess the impact of epidemics on household labor market outcomes in the Amazonian city of Iquitos, Peru. I rely on data from the Peruvian National Household Survey from July 2005 to June 2010 (INEI 2015). This research contributes to the literature on dengue epidemics as well as the infectious disease literature more broadly by assessing the impact of epidemics on the labor market outcomes of all households in an affected region. I conclude with a discussion of how the results inform intervention policies aimed at mitigating the negative impacts of dengue.

CHAPTER 2: ECONOMIC CONSIDERATIONS IN MOSQUITO-BORNE DISEASE PREVENTION

I. Introduction

Dengue has no cure and the only currently available prevention method is to control the *Aedes aegypti* mosquito that spreads the disease. Because current control methods have so far proven ineffective (primarily because of operational failures), entomologists in a number of countries are developing control technologies that involve the genetic modification of Aedes aegypti mosquitoes (*e.g.*, Carvalho et al. 2015). Genetically modified mosquito (GMM) trials throughout the Cayman Islands and Brazil have at times been controversial, due in part to negative public sentiments towards genetically modified organisms (GMOs) (Pollack, 2011).

At the same time, medical researchers have been working to develop a viable dengue vaccine (WHO, 2015b). However, a vaccine that successfully protects against all four strains of the virus has been difficult to develop. Vaccines and GMM methods have different potential benefits and costs to their implementation. The effect of incorporating either or both of these emerging technologies into existing control strategies is uncertain.

Within the scientific community and among health officials in developing countries, there is ample interest in assessing the economic burden of dengue and the potential efficacy of current and emerging intervention strategies. However, the economics literature on the subject is sparse and the need for future research is large. In this paper, I discuss economic considerations in mosquito-borne disease prevention, focusing specifically on dengue fever, in the hopes of guiding future economic research on the subject.

I begin by summarizing the disease burden of dengue throughout the globe and in the United States. I describe the most commonly used control methods and two emerging control technologies: vaccines and GMM. I compare the disease burden and control strategies of dengue to other insect-borne diseases including malaria. I review existing literature on the economic costs of dengue and point out areas in which cost estimates could be extended or improved. I explore avenues for future economic research on dengue based on applications from the infectious disease literature. I discuss key economic considerations in dengue treatment and prevention, namely: the analysis of dengue prevention as a public goods problem, the contribution of economic development to long run disease prevention, and the allocation of resources between treatment and prevention. I conclude with a discussion of the economic considerations involved in the potential implementation of GMM technologies for mosquito-borne disease prevention.

II. Dengue Fever

II.1. The Global Burden of Dengue

Recent estimates indicate that there are approximately 390 million cases of dengue per year globally, with about 96 million individuals presenting symptoms (Bhatt et al. 2013). The cost of dengue prevention and treatment for governments and health care systems is frequently estimated to be in the tens if not hundreds of millions of U.S. dollars per year in countries throughout Asia and South America (Beatty, Beutels, and Meltzer 2011; Shepard, Halasa, and Undurraga 2014). Together, the estimates suggest that billions of dollars are spent worldwide on dengue prevention and treatment every year. Still, dengue transmission has continued to spread over the past few decades. Instances of local transmission have now been recorded in Europe (France, Croatia, Portugal) and the United States (WHO 2015a).

II.2. Dengue in the United States

Dengue is becoming an increasing public health threat within the continental United States. A 2009 National Resources Defense Council (NRDC) report indicates that much of the southern half of the U.S., as well as large portions of the eastern and western coastlines, are at risk of dengue transmission due to the presence of *Aedes aegypti* or *Aedes albopictus*, a secondary dengue vector. Areas with high risk include states along the U.S.-Mexico border and along the Gulf or Atlantic coastlines (Knowlton, Rotkin-Ellman, and Soloman 2009). In 1980, Brownsville, Texas experienced its first outbreak of locally acquired dengue since 1945 with 63 reported cases (Añez and Rios 2013). Small outbreaks have occurred along the Texas-Mexico border every five to ten years since that time. Similarly, Key West, Florida experienced the first instances of locally acquired dengue since 1934 in 2009 and 2010 (22 and 66 cases each, respectively) and another outbreak occurred in Martin County in 2013 with 24 reported symptomatic cases (Florida Department of Health 2013).

Although over half of the continental United States is technically at a small risk of experiencing local dengue transmission due to the presence of the mosquitoes that transmit the disease, transmission depends on more than just vector prevalence. Some argue that the United States is less susceptible to dengue outbreaks because of the prevalence of air conditioning and screened windows. Both technologies prevent mosquitoes from entering homes during the day to bite people, leading to lower disease transmission after initial infections (Reiter et al. 2003; Brunkard and López 2007).

III. Current and Emerging Dengue Control Methods

III.1. Dengue Fever and the Aedes aegypti Mosquito

The *Aedes aegypti* mosquito is the main vector of the dengue virus.[2] *Aedes aegypti* primarily inhabit urban environments in tropical and subtropical regions (WHO 2015a). Female *Aedes aegypti* take blood meals almost every day, both for food and to stimulate reproduction, and they feed almost exclusively on human hosts. Unlike the *Anopheles* mosquitoes that transmit malaria, *Aedes aegypti* bite during the day, making bed nets an ineffective form of dengue control (Scott and Morrison 2003). The feeding patterns of *Aedes aegypti* females make them highly efficient vectors of the dengue virus. It is therefore believed that the mosquito density threshold above which a household is at risk for contracting dengue is very low (Scott and Morrison 2010).[3] Vector control programs then need to be highly effective at reducing mosquito populations to be successful.

The full transmission cycle of the dengue virus from *Aedes aegypti* mosquitoes to humans can be seen in **Figure 2.1**. After biting a human infected with dengue virus, there is an 'extrinsic' incubation period of about 7-14 days before a female *Aedes aegypti* is able to transmit the virus to other humans that it bites. A human that has been bitten by an infected female *Aedes aegypti* goes through an 'intrinsic' incubation period of about 4-7 days before they become viremic for about 5 days, during which time they may pass the virus on to other female *Aedes aegypti* (Scott and Morrison 2010).

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[2] *Aedes aegypti* is also the primary vector for Yellow Fever and the Chikungunya virus, which is rarer than dengue but more frequently has serious complications (CDC 2014a).

[3] Other factors that determine dengue transmission include human movement patterns, the number of asymptomatic individuals, and the number of dengue virus strains active in the population (Magori et al. 2009).

III.2. Current Aedes aegypti Control Methods

Because there is no cure for dengue and limited access to vaccines, the most readily available method for reducing the transmission of the disease is to directly control the dengue vector by suppressing or eradicating the *Aedes aegypti* mosquito that spreads the disease (WHO 2015a). Currently, the most commonly used technique for controlling adult *Aedes aegypti* populations is chemical adulticide (WHO 2015a). Adulticides come in the form of ultralow volume (ULV) space sprays applied inside (most effective) or outside houses, or in the form of indoor residual sprays (IRS) where a chemical is sprayed on house walls or surfaces that serve as resting sites for the adult mosquitoes. Space spray methods are more common than IRS because IRS is expensive to implement.[4] However, it has been argued that space sprays are not highly effective (Esu et al. 2010).

A seemingly simple way to decrease the population of *Aedes aegypti* is to clean, discard, or place larvicide in the containers in which female mosquitoes are likely to deposit their eggs (Morrison et al. 2008). Female *Aedes aegypti* lay eggs on the dry edge of small containers capable of holding standing water, including household items like buckets, trays, or old rubber tires (CDC 2014a; Tun-Lin et al. 2009). The eggs can survive as long as six to twelve months while dry and hatch into larvae after being inundated with water. It generally takes 5-8 days for larvae to turn into pupae and then adult mosquitoes, and neither larvae nor pupae can survive outside of water. If performed weekly, container control can break the entomological cycle through which adult mosquitoes breed, mature, and spread spatially.

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[4] Amy C. Morrison, personal correspondence

The WHO recommends emptying and cleaning open water containers every week or covering containers that cannot be emptied regularly. Containers can also be treated for several months with larvicide packets that kill or impede the growth of developing larvae and are often provided and applied by local health agencies free of charge (WHO 2015a). However, all households need to participate for container control to be successful, and full community participation has been difficult to achieve (Morrison et al. 2008). Other research also shows that the existing evidence for the efficacy of community participation based control programs is weak (Heintze, Garrido, and Kroeger 2007). For all of the above reasons, *Aedes aegypti* control has thus far proven difficult to achieve.[5]

III.3. Vaccines

There are currently five dengue vaccines in clinical trials and one, CYT-TDV, that was approved for use in Mexico in December of 2015 for individuals aged 9 to 45 (WHO 2015b). One major concern with the CYT vaccine is that it does not protect well against infections among individuals who have not been exposed to the virus before (Simmons 2015; Rodriguez-Barraquer et al. 2015). As more of a population is treated and transmission decreases, the vaccine will then become less effective. Decreased efficacy might also be an issue in areas where the disease is not already endemic and the population is unexposed.

Infection with one serotype of dengue provides lifetime immunity to that strain but only temporary immunity to the other three, and patients infected with a second serotype of dengue

[5] Prevention methods such as screened windows and commercially available repellants like DEET are often not cost effective solutions for the average household in an area affected by dengue. Additional control technologies such as adult mosquito traps and larval biological control methods (*e.g.*, placing fish, other insects, or copepods in water containers) are not yet widely in use and need to be further tested for efficacy in the field.

are at a higher risk of experiencing the severe manifestation of the disease (Guzman, Alvarez, and Halstead 2013). Therefore, a vaccine that does not fully protect against all serotypes of the virus could result in worse health outcomes for infected individuals (WHO 2015b). If the CYT vaccine replicates a first infection without providing full protection against all serotypes, it might cause increased risk of severe disease. Instances of dengue hospitalization were found to be higher among children under the age of 9 after taking the CYT vaccine, suggesting that the vaccine may increase the risk of serious dengue illness among previously unexposed populations (Simmons 2015). Even if a viable vaccine is brought to market, there is still a risk of complications in the future if more serotypes of dengue emerge that are not captured by the available vaccines.

Another key concern about the potential efficacy of dengue vaccines involves the rate at which populations would need to be vaccinated to prevent disease transmission. Low estimates of disease transmission using dynamic models suggest that 79% or more of the population would need to be vaccinated to successfully control dengue (Reiner et al. 2014). This is likely to be a difficult level of vaccination to achieve, and lower levels of compliance could negate control efforts for the reasons stated above.

III.4. Genetically Modified Mosquito Technologies

In response to the poor efficacy of available dengue control measures, entomologists throughout the world have been working to develop control technologies that involve the genetic modification of *Aedes aegypti* mosquitoes. Emerging GMM technologies can be broadly categorized into population suppression methods or population replacement methods. Population suppression techniques seek to reduce the number of *Aedes aegypti* mosquitoes in the wild. Suppression techniques typically involve the release of male mosquitoes that have been genetically modified so that their offspring will die. The death of the offspring of transgenic males can occur in the first or in later generations depending on the type of modification used (Legros et al. 2012). The complete elimination of the *Aedes aegypti* population via suppression methods is unlikely. Suppression programs therefore require the continued release of transgenic males into the wild population to be effective in the long run (Legros et al. 2012).

Population replacement techniques seek instead to replace the disease-carrying wild population of *Aedes aegypti* with a transgenic strain of the mosquito that is incapable of transmitting the disease. Replacement techniques involve the release of female mosquitoes that have been genetically modified to not pass dengue on to human hosts. The desired trait of not transmitting disease is typically attached to a selfish genetic element to ensure that the trait will spread through the population (Sinkins and Gould 2006). Some have expressed concerns that replacement methods might cause the dengue virus to mutate and become more virulent, potentially causing worse health outcomes for infected humans (Medlock et al. 2009).

Regardless of the technique used to modify the mosquitoes, the potential release of GMMs has been controversial.[6] Particularly in the United States and Europe, where a heated debate continues surrounding genetically modified foods, public sentiment is already positioned against genetically modified organisms. Concerns have been expressed about potential

[6] A similar method to genetic modification that has been marketed as biological control and is therefore less controversial is to infect *Aedes aegypti* with a bacterium called *Wolbachia*. *Wolbachia* prevents the mosquitoes from being able to transmit dengue to human hosts and the bacterium itself cannot be transmitted to human hosts through mosquito bites (Antonelli 2015).

negative impacts on both humans and non-target organisms (Reeves et al. 2012). While many concerns have been disproved or dismissed within the scientific community, they persist in the eyes of much of the public (Pollack 2011; Wallace 2015). Importantly, because only female *Aedes aegypti* mosquitoes bite, only population replacement techniques result in humans being bitten by transgenic mosquitoes.[7] Still, the prospect of releasing transgenic insects of any sex into the wild has proven unsettling to some members of the public. Proposed field trials of one population suppression method in the Florida Keys elicited over 149,000 signatures in an online petition opposing GMM releases (Alvarez 2015).

IV. Dengue Compared to Other Diseases

In a comprehensive study of 291 diseases and injuries carried out by Murray et al. (2013) that was funded by the Bill and Melinda Gates Foundation, dengue was shown to rank very low in terms of disability adjusted life years (DALYs). This might seem to suggest that dengue is not worth much attention in terms of allocating resources towards treatment or control. However, DALY's do not reflect the overall economic burden of a disease. One of the most commonly stated concerns with dengue is the disease's tendency to occur at epidemic levels, overburdening health care infrastructures in countries that are already resource constrained in their ability to provide quality health care to their citizens (Gubler 2012). Then, even if the individual burden of dengue is low in terms of mortality or morbidity, the overall social cost of the disease may be quite high. Moreover, Clayton (2015a) shows that behavioral changes

[7] It should be noted that the available methods of separating male and female mosquitoes before implementing transgenisis are imperfect. Under most practical circumstances, some transgenic female mosquitoes will be released along with transgenic males, even within population suppression techniques. Concerns have been raised about potential allergic reactions to GMM bites (Reeves et al. 2012).

along with changes in labor demand during epidemics can lead to the restriction of labor market activities within households that are not directly affected by dengue illness. I review the rest of the existing literature on the economic burden of dengue below.

Even though the direct individual disease burden of dengue is not high, malaria, another mosquito-borne disease for which researchers are contemplating the use of GMMs, ranks 7th in DALYs out of the 291 diseases studied in the same analysis by Murray et al. (2013). Dengue is also one of 17 neglected tropical diseases (NTDs) prioritized by the WHO, and five other NTDs are also vector-borne[8] (WHO 2015c). In aggregate, vector-borne diseases account for approximately 16% of the global disease burden of all communicable diseases (WHO 2015d). It has been argued that dengue, which has four virus serotypes spread predominantly by one mosquito species, serves as a good model system to test vector control methods that may be relevant to the control of other vector-borne diseases (Legros et al. 2012). Then, even if the disease burden of dengue alone does not warrant the cost of developing new control methods, the extended implications of research on new control technologies for other insect-borne diseases certainly might.

IV.1. Dengue and Malaria[9]

Dengue is often compared to malaria, which receives substantially more attention in terms of research funding allocations and global health initiatives (Hotez and Molyneux 2007). The WHO provides fact sheets on both dengue and malaria that are straightforward and highly informative (WHO 2015e; WHO 2015a). Here I provide a brief comparison of the two diseases

[8] The other vector-borne NTDs are: Human African trypanosomiasis, Chagas disease, Leishmanasis, Lymphatic filariasis, and Onchocerciasis.
[9] This section draws from personal writing in the co-authored work (Antonelli et al. 2016).

focusing on their global prevalence, symptom severity, vector characteristics, and existing treatment and prevention options. **Table 2.1** displays a summary of the key facts for dengue and malaria side by side.

Both dengue and malaria affect populations in tropical and subtropical climates throughout the world. However, because of differences in the breeding habits of the mosquitoes responsible for spreading the two diseases, malaria generally affects rural areas near bodies of water, while dengue primarily affects urban populations (WHO 2015a). Recent WHO estimates indicate that there were about 214 million cases of malaria in 2015, about 428,000 of which resulted in death (WHO 2015e). Over 90% of deaths occurred in Africa, mostly among children. Although the death toll of malaria is still high globally, malaria death rates have decreased by over 60% since 2000. In contrast, dengue incidences have been continually increasing over the past few decades, leading to much concern among scientists and health officials (WHO 2015a).

There are important differences between the dengue and malaria vectors that determine the availability and efficacy of vector control programs. Malaria is spread by about 20 different species of *Anopheles* mosquitoes whereas dengue is only spread by *Aedes aegypti*, and to a lesser extent *Aedes albopictus* (WHO 2015e; WHO 2015a). Because malaria can be spread by so many species of mosquito, the direct suppression of the malaria vector is complicated. However, because all *Anopheles* species bite at night, one of the simplest and most affective forms of malaria prevention is long-lasting insecticide-treated bed nets (LLINs) that keep humans from being bitten while sleeping (WHO 2015e). Because *Aedes aegypti* bite during the day, bed nets are ineffective at controlling dengue (WHO 2015a).

Symptoms of malaria can be similar to those of dengue and include fever, headache, chills, and vomiting (CDC 2014b). Severe complications can involve anemia, respiratory distress, and cerebral malaria in children, and other forms of organ failure in adults. As with dengue, severe and fatal complications from malaria are generally avoidable via fast access to medical treatment (CDC 2014b). And unlike dengue, which is a virus that cannot be cured with antibiotics, malaria is a parasite that can be both treated and prevented with anti-malarial medications, although parasitic resistance to the available anti-malarial medications is an ongoing issue (WHO 2015e).

While the progress of dengue vaccine research has been encouraging in the past few years, the complexity of the malaria vector has made viable malaria vaccines more difficult to produce. One malaria vaccine (RTS,S) was cautiously released for pilot use in Africa by the WHO on October 23rd, 2015. However, the RTS,S vaccine requires four doses over 18 months, causing questions about the practical ability to fully administer the vaccine. Even then, the efficacy of the vaccine is only 36% among young children and only 26% among infants (Callaway and Maxmen 2015). There are over 20 other vaccines in clinical or advanced pre-clinical stages, but the efficacy of most is questionable at best (WHO 2015f).

V. Existing Literature on the Economic Costs of Dengue

V.1. Estimates of the Economic Disease Burden of Dengue

Research on the economic impact of dengue is limited. The existing literature is reviewed by Beatty, Beutels, and Meltzer (2011) and Shepard, Halasa, and Undurraga (2014). There are many estimates of the costs of dengue treatment for health care systems or households.

Available studies assessing household costs only measure the impacts of the disease in terms of direct health care costs or indirect costs from lost work hours for individuals who test positive for dengue and possibly their families. Estimates for the number of days lost from school or work are also highly variable between studies (*e.g.*, Suaya et al. 2009), due largely to inconsistent recording methods.

Only assessing immediate impacts among households that have been directly affected by dengue illness underestimates the economic costs of epidemics at the household (and healthcare) level. Behavioral changes and changes in labor demand during epidemics may cause labor market activities to be restricted within households that have not been directly affected by disease. Additionally, none of the available cost estimates account for the effects of dengue epidemics on the labor market activities of males compared to females. If there are differences in the allocation of caregiving tasks within the home based on gender, epidemics may impact the division of market labor within the household, potentially altering the power balance between men and women. In Chapter 4, I analyze the impacts of dengue epidemics on the labor market activities of both men and women in all households in an affected area. I confirm that labor market impacts extend beyond households experiencing illness and that females are disproportionately affected.

A key issue in the literature estimating the direct clinical costs of dengue is the use of inconsistent metrics for disease burden, which leads to equally inconsistent measures of the economic impact of the disease. The cost estimates reviewed in Beatty, Beutels, and Meltzer (2011) differ widely from study to study. Shepard and Halasa have since coauthored (with others) cost analyses for various countries and regions using more rigorous and consistent standards. Shepard et al. (2014) suggest methods for consistently recording dengue disease burden across countries so that more accurate estimates can be formed in the future.

Shepard et al. (2011) provide a meta-analysis of the economic cost of dengue in the Americas from 2000 to 2007. Accounting only for the cost of illness to health care providers and infected individuals from treatment expenses and lost wages, they found an average cost of 2.1 billion dollars per year. Similarly, Shepard, Undurraga, & Halasa (2013) found the cost of dengue illness in Southeast Asia from 2001 to 2010 to be around 950 million dollars per year on average. Combining these two regional studies alone puts the total cost of dengue illness, not counting the cost of prevention programs, in the billions of dollars per year globally. Using improved standards for measuring direct disease burdens does not capture the additional impacts on households that do not directly experience disease so that the existing estimates still likely underestimate the overall costs of epidemics. Having an accurate understanding of the economic costs of epidemics can better inform mitigation policies.

V.2. Dengue Prevention Cost Estimates

Accurate estimates of the costs and benefits of current and future control interventions are needed to analyze the efficiency of prevention programs. Existing cost-benefit analyses (CBAs) of current and emerging prevention technologies are reviewed in Beatty, Beutels, and Meltzer (2011) and Shepard, Halasa, and Undurraga (2014). Most of the CBAs assess current vector control initiatives. Vector control studies often measure benefits in terms of reductions in adult or immature mosquito indices, which do not address the impact of control measures on dengue transmission. There are several CBAs that assess the potential use of vaccines in developmental stages. There is currently one CBA assessing the potential use of GMM technologies for dengue prevention (Alphey, Alphey, and Bonsall 2011).

Most of the analyzed current or potential dengue interventions are found to be cost effective through existing CBAs. However, CBAs of individual control initiatives do not offer insight for policymakers when selecting among a myriad of current and emerging disease interventions. While several of the existing CBAs compare a small number of interventions, there are no comprehensive assessments of available interventions. Also, existing studies utilize inconsistent measurement standards, negating the ability to carry out cross-study comparisons. A set standard of program assessment would facilitate comparisons between the cost efficacy of current and emerging disease interventions to help policymakers generate informed decisions about the allocation of scarce resources.

VI. Avenues for Future Economic Research on Dengue

VI.1. Willingness to Pay for and Uptake of Prevention Technologies

Much of the most policy-relevant literature on infectious disease focuses on the willingness to pay for or the uptake of various treatment or prevention technologies. While there is a growing literature on the willingness to pay (WTP) for emerging dengue prevention technologies, much more work is needed. Existing studies primarily assess hypothetical WTP for dengue vaccines that are not yet available through surveys. Possibly due to the hypothetical nature of projective assessments, median vaccine WTP estimates vary drastically across studies and study areas (*e.g.*, Lee et al. 2015; Hadisoemarto and Castro 2013). WTP studies for currently available vector control technologies are limited and there are no studies on the WTP for emerging genetically modified mosquito (GMM) technologies.

Similarly, assessments on the uptake of new dengue prevention technologies, especially those utilizing experimental designs in their analysis, are limited. Most uptake studies for mosquito control technologies randomize the distribution of the technology itself but do not randomize the approach utilized to elicit program compliance (*e.g.*, Vanlerberghe et al. 2011). Compliance is simply measured via observations and determinants of compliance are based on household demographic traits and questionnaires about dengue knowledge and perceived risk. For example, Castro, *et al.*, (2013) find that households in Havana, Cuba with better dengue knowledge also had better control practices in terms of container behavior. Such studies are highly susceptible to omitted variables bias as both dengue knowledge and uptake of prevention technologies could be associated with unobserved individual traits.

Instead of relying on post-hoc surveys, Dupas (2009) relies on randomized control trials to determine the cause of prevention technology adoption decisions. In doing so, she is able to determine the impact of technology price, message framing, and the gender of the individual in the household who is approached about technology adoption. She finds that price matters while framing and gender do not. Other experimental willingness to pay and uptake studies are reviewed in Dupas (2011) and serve as an excellent model for future research on emerging dengue control technologies.

VI.2. Long Run Impact of Dengue Exposure at a Young Age

Although dengue is rarely lethal or permanently debilitating, economic research on the impact of exposure to infectious disease in utero, infancy, or early childhood suggests a potential venue through which dengue exposure early in life may contribute to educational and later life outcomes. The fetal origins hypothesis suggests that nutritional or other health deficiencies occurring in utero or before 24 months can determine health and other economic outcomes later in life (Barker 1992). The hypothesis, originally purported in the scientific community, has been increasingly explored in economic research. Almond and Currie (2011) provide a thorough review of this literature.

Economic literature exploring the fetal origins hypothesis utilizes "natural experiments" as sources of exogenous variation with which to assess the impacts of early health on later economic outcomes. One frequently cited example is that of Almond (2006) on the long run impacts of the 1918 Spanish flu pandemic in the U.S. on individuals whose mothers were exposed to the disease while pregnant. He finds that exposure to the flu in utero is associated with reductions in educational attainment and income as well as higher rates of physical disability. Bleakley (2007) looks at hookworm eradication in the US South and finds that eradication increases school attendance and enrollment rates for children and that positive impacts continue into adulthood where treated individuals experience increases in income and literacy. Miguel and Kremer (2004) study the impact of hookworm eradication in Africa on school attainment and find similar increases while also establishing a positive externality on non-treated individuals from decreased disease transmission. Existing fetal origins tests are readily extendable to the context of large dengue epidemics as they frequently occur due to forces that are arguably exogenous to household behavior.[10]

[10] See Chapter 4 for a more detailed explanation of the exogeneity of epidemics at the household level.

VI.3. Mosquito-Borne Disease and Household Income

While there have not been many studies assessing the impact of dengue on household income or production,[11] many such studies do exist in the context of malaria. Because malaria predominantly affects rural populations, much of the literature on malaria impacts is conducted in agricultural contexts. Asenso-Okyere, *et al.*, (2011) provide a review of the impact of malaria on agricultural development. They cite findings that malaria may have slowed economic growth in Africa by 1.3% per year. However, Datta and Reimer (2013) assess the cyclical link between GDP and malaria transmission at the macro-level across more than 100 malaria endemic countries over 17 years and find that the impact that GDP increases have had on reductions in malaria incidence is much larger than the reverse relationship. Kiiza and Pederson (2014) analyze the impact of repeat malaria cases on rural households and find that farm income declines by 50% due to repeat severe malaria episodes. Because dengue is an urban disease, malaria studies do not provide direct illumination on the household-level impact of dengue. However, malaria studies can serve as models for future research on the impact of dengue on income and production in urban households.

VII. Economic Considerations in Dengue Treatment and Prevention

VII.1. Dengue Prevention as a Public Goods Problem

Over the past twenty years, dengue control efforts have increasingly focused on eliciting community participation. Gubler and Clark (1996) suggest that it is necessary to incorporate communities directly into control programs in order to ensure that control efforts are

[11] See Chapter 4 for my analysis of the impact of dengue epidemics on household labor market outcomes.

sustainable over time; the implication is that community members continue to carry out control practices in the absence of external support from government or research organizations. Many subsequent studies have attempted to follow Gubler and Clark's advice by pursuing active community engagement in control programs (*e.g.*, Toledo et al. 2007). Despite strong efforts, community based strategies have often failed to elicit complete or lasting participation among community members (Tapia-Conyer, Méndez-Galván, and Burciaga-Zúñiga 2012). As a result, Heintze, Garrido, and Kroeger (2007) find that the evidence for the efficacy of community participation based control programs is weak at best.

Insufficient community participation in dengue control can be explained by theories analyzing disease prevention as a public goods issue. While there is no literature assessing dengue prevention as a public good, previous economic research has focused on other forms of disease prevention as a public good. Schelling (1978) theorizes that the private benefit to the individual from making a binary choice in the face of externalities depends on the number of other people making the same choice. Schelling includes self-imposed behavioral restrictions within the analyzed choice scenarios noting that "joining a self-restraining coalition, or staying out and doing what's done naturally, is a binary choice," (1978, p. 214). In many ways, participation in mosquito control programs can be seen as a self-imposed behavioral restriction. Positive or negative externalities can prevent individual adoption incentives from achieving socially optimal outcomes in such scenarios.[12]

[12] The works of Rohlfs (1974) on communication technology adoption and of Olson (1965) describe the same phenomena and have also inspired much of the existing work on disease prevention as a public good.

Economic research on disease prevention has often utilized theories of dual equilibriums, one with low (socially suboptimal) and one with high (socially optimal) levels of adoption. Rolfs (1974) describes the transition point separating the two stable equilibriums as the critical mass of people needed to naturally incentivize other individuals towards adoption. Previous papers have also assessed private versus public payoffs from household participation in insecticide spraying programs for Malaria prevention (Brown 2011; Schelling 1978). Others estimate discrepancies between the private and public benefit of vaccination (*e.g.*, Brito, Sheshinski, and Intriligator 1991; Geoffard and Philipson 1997). The existing research consistently suggests that incentives are often needed to elicit socially optimal levels of participation in disease prevention.

Some papers have looked more broadly at disease prevention and treatment. Althouse, Bergstrom, and Bergstrom (2010) look at vaccination and treatment decisions for various illnesses while accounting for the potential positive and/or negative externalities accompanying different treatment and prevention decisions. Utilizing disease transmission models to determine efficient allocations of treatment and vaccination in the presence of such externalities, they find that regulatory incentives may be necessary to elicit optimal outcomes. Gersovitz and Hammer (2004) provide an extensive model to assess efficient allocations between the treatment and prevention of infectious disease. They offer differing specifications for fatal and non-fatal illnesses and account for externalities regarding both treatment and prevention. They model vector-borne disease but the focus is on pesticide use.

It is clear from previous research on disease prevention behaviors in the face of externalities that incentives are often needed to elicit optimal levels of prevention program participation.

However, some forms of dengue prevention, like container cleaning initiatives, differ from previously analyzed interventions in important ways. Previously assessed programs require temporary participation, while container cleaning requires weekly participation over an indefinite period. Program participation then depends not only on the externalities of control decisions but also on the ability of the household to maintain regular container cleaning which is likely to depend on household demographics. Assessments of participation in long-term dengue control programs would contribute substantially to the existing literature on disease prevention and would inform future control program policies.

VII.3. Economic Development and Long Run Dengue Prevention

The vast majority of countries at the highest risk of dengue transmission are low to middle income countries. While this is likely in part due to the fact that many low and middle income countries are located in tropical and subtropical climates, there are several infrastructural factors that are also likely to contribute to a nation's dengue transmission risk. Because *Aedes aegypti* breed in open water containers, one of the main infrastructural obstacles to preventing the spread of dengue lies in poor water and sewage availability (WHO 2009). Areas without reliable waste disposal tend to have recurring water drainage issues and those without piped water are forced to collect water in open containers for household use. The resulting higher number of containers with standing water act as egg-deposit sites for female *Aedes aegypti* (Morrison et al. 2008). Improving waste disposal and piped water availability would decrease the supply of open water containers for *Aedes aegypti* developmental sites and could therefore reduce the adult mosquito population.[13] Water and waste infrastructural improvements would also generate health benefits that extend beyond reduced dengue incidence, including a reduction in hookworm and gastrointestinal diseases that are prevalent in the areas most affected by dengue (Bleakley 2007).

Because *Aedes aegypti* bite during the day, improvements in household construction including screened windows and air conditioning are required to prevent *Aedes aegypti* from biting inhabitants (Reiter et al., 2003). Such household improvements are costly however and would require either higher household incomes or subsidization by outside sources to install. Improvements to health care infrastructures in dengue endemic countries would increase the ability to handle epidemics and minimize severe disease complications and deaths. Health infrastructure improvements would also increase the ability to treat a wide range of diseases requiring intravenous fluid replacement therapies or other simple medical interventions (WHO 1997). Improving transportation infrastructures would further increase the accessibility of health care facilities, thereby reaching a wider spectrum of individuals in need of treatment.

There is ample research linking health outcomes to educational and other economic outcomes (*e.g.*, Bleakley 2010; French 2012; Strauss and Thomas 1998). Limited health care access due to low income levels leads to worsened health outcomes, which can keep individuals from obtaining a formal education or working, leading to even lower incomes. A poverty trap is then formed wherein low incomes lead to poor health outcomes, which contribute to even lower incomes (French 2012). Infrastructural improvements and other

[13] The addition of concrete structures that can hold standing water could equally serve as egg-deposit sites for the mosquito. In this sense, paved roads or floors in conditions of poor drainage would lead to more mosquito development than dirt roads and floors.

development programs that increase health care access for low income individuals have the potential to stop or even reverse the cycle of poverty traps as healthier individuals are more likely to be able to obtain a formal education and/or participate in the labor market (Bleakley 2010; Strauss and Thomas 1998).

VII.4. Allocating Resources between Dengue Treatment and Prevention

Currently, there is no medical treatment that cures dengue. For the most common manifestation of the disease, health organizations suggest treating symptoms with over-the-counter pain relievers, rest, and fluids. Severe dengue can be fatal if untreated, but mortality is greatly reduced with properly administered fluid and electrolyte replacement therapy (NIH 2007; CDC 2014a). The WHO states that “for a disease that is complex in its manifestations, management is relatively simple, inexpensive and very effective in saving lives so long as correct and timely interventions are instituted,” (2009, p 25). Early detection and treatment can reduce dengue death rates from over 20% to below 1% (WHO 2015a).

As simple and effective as the treatment for dengue fever seems, health care infrastructures in low and middle income countries are often inadequate for treating the influx of cases that occurs during epidemics (Gubler 2012). The response among the scientific community to insufficient medical infrastructures for dengue treatment has often been to push for the prevention of the disease through vector control or vaccines rather than to try and tackle the infrastructural issues directly (*e.g.*, Tun-Lin et al. 2009). Although the control and prevention of dengue is vital to reducing the negative impacts of the virus in the long run, it is important that researchers and policymakers not overlook the immediate importance of ensuring individual access to effective and affordable treatment.

The WHO provides health professionals with detailed handbooks on the management of dengue including specific instructions about proper diagnosis and treatment. In them, the WHO addresses overcrowding in health care facilities during epidemics by recommending better triage practices to ensure that only instances of severe dengue are hospitalized (Handbook, 2012). However, better triage practices do not adequately address issues of insufficient resources to handle the increased number of cases that do require hospitalization. Hospitalized treatment typically consists of fluid replacement therapy and possibly blood transfusions in the rare case of severe shock (WHO 2015a). Although the availability of experienced health professionals to supervise patient recovery is essential for successful treatment, the necessary equipment is relatively basic in most instances.[14] The main issue then is the availability of health care professionals familiar with dengue management protocols, and low inventories of basic supplies like isolated hospital beds, IV fluid and equipment, laboratory equipment, and basic medications (WHO 2009; WHO 2015a).

The WHO claims that "emergency preparedness and response are often overlooked by program managers and policy-makers," and that "while plans have frequently been prepared in dengue-endemic countries, they are seldom validated," (2012: pp 123-124). It is possible though that the issue is one of a lack of resources at the national level rather than a lack of diligence. A potential solution for the mitigation of dengue would be to develop mobile response units capable of handling high volumes of dengue during epidemics. Because an area will typically only experience an epidemic every few years, response units could be formed at

[14] The necessity of trained health professionals who are familiar with dengue treatment protocols should not be overlooked. In 2013, both Pakistan and India experienced high death rates due to the over-application of IV fluids by health professionals (Staff Reporter 2013; Maya 2013).

the international level with neighboring countries pooling resources to form response teams. Long run dengue prevention will only be possible through vector control or an effective vaccine. However, dengue control is likely to take an extensive amount of time and resources. In the interim, steps could be taken to ensure that all areas are capable of treating cases of dengue and severe dengue in order to reduce critical health complications and fatalities to the lowest possible levels.

VIII. Using Genetically Modified Mosquitoes to Combat Insect-Borne Disease

There are many aspects outside of economics that need to be considered when deciding whether to implement technologies involving genetic modification. See, for example, Antonelli et al. (2016) or Macer (2005) for discussions on scientific, ethical, legal, social, and cultural considerations in the implementation of GMM technologies. Here, I discuss economic considerations in the potential implementation of GMM technologies to combat insect-borne diseases, focusing on the specific implications for dengue fever.

A key economic consideration in choosing to implement GMM technologies entails the efficacy and cost of GMM relative to other treatment or prevention measures, taking into account the increased regulatory costs of GMM implementation. As an emerging technology, the implementation of GMM technologies has been held to a higher regulatory standard than other vector control methods. Reducing regulations would decrease the costs of GMM implementation, but would not likely appeal to the many around the globe who are concerned about GMOs. Increased regulatory costs need to be accounted for in any comparative cost efficacy analysis between potential methods. It may then be the case that less controversial methods would be preferred from an economic standpoint as well as in the eyes of the public.

Another key economic concern in the implementation of GMM technologies involves their long run sustainability. If a transgenic mosquito release temporarily suppresses dengue transmission but fails to maintain suppression in the long run, the loss of herd immunity among affected human populations could result in larger epidemics and more people with severe disease. It may be difficult to convince governments or health organizations that continued interventions are needed when the apparent health burden of a disease is suppressed. The continued release of transgenic mosquitoes that is needed to maintain the efficacy of some population suppression methods is especially problematic. Regardless of the transgenic method used, potential issues of mutation may require additional releases of transgenic mosquitoes to maintain population replacement or suppression.

There are still many potential benefits to continuing research on GMM technologies for dengue control. Because the dengue virus and *Aedes aegypti* mosquito stand as a valuable model for disease vector research, developed technologies may have applications for the control of other insect-borne diseases including malaria, Chagas, and the West-Nile virus. Additionally, dengue transmission continues to spread throughout the globe, potentially leading to higher disease burdens in the future. Even if GMM technologies are not found to be a worthwhile investment for the control of dengue now, GMM research may still prove invaluable as the landscape for needed disease interventions continues to evolve in the future.

IX. Tables and Figures

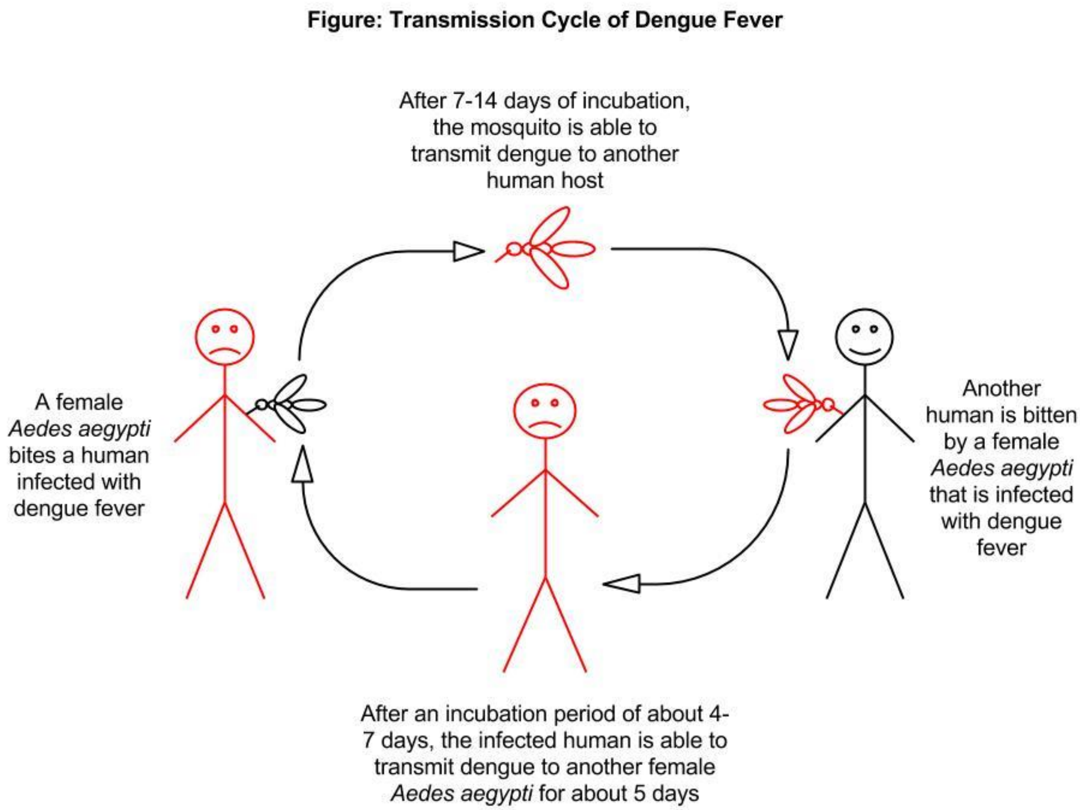


Figure 2.1: This figure shows the dengue transmission cycle between female *Aedes aegypti* mosquitoes and human hosts.

Table 2.1: Key Facts about Dengue and Malaria

	Dengue (WHO 2015a)	**Malaria** (CDC 2014b; WHO 2015e)
Vector	*Aedes aegypti, Aedes albopictus* (secondary)	about 20 species from the *Anopheles* genus
Strains	4 virus serotypes from the *Flavivirus* genus	4 parasite species from the *Plasmodium* genus
Severity	contracting a second serotype results in a higher likelihood of experiencing severe dengue	prevalence and severity varies with parasite (*Plasmodium falciparum* is the most common and deadly)
Immunity	contracting one serotype provides permanent immunity to that strain and temporary immunity to the others	partial immunity is accumulated over time and provides protection against severe disease
Diagnosis	ELISA tests for antigens (IgM & IgG), PCR	rapid diagnostic tests for antigens, microscopy, PCR
Symptoms	**classic:** fever, rash, headache, muscle aches, retro-orbital pain, vomiting **severe:** internal hemorrhaging, severe abdominal pain and vomiting, respiratory distress	**classic:** fever, headache, chills, vomiting **severe:** anemia, respiratory distress, cerebral malaria, organ failure
Mortality	about 12,500 deaths per year **without treatment**: about 20% mortality **with treatment**: less than 1% mortality	about 438,000 deaths in 2015 91% of deaths are from Sub-Saharan Africa, mostly among children
Global Burden	Bhatt et al. (2013): about 390 million cases per year including asymptomatic, about 96 million apparent cases WHO: about 500,000 severe cases requiring hospitalization per year	about 214 million cases in 2015 89% of cases are from Sub-Saharan Africa
Risk Groups	children, elderly, immunocompromised	children, elderly, immunocompromised; tourists & immigrants
Vaccines	Six vaccines in clinical trials. CYD vaccine in phase III trials in Latin America and Asia but has limited efficacy among those who have not been previously exposed to dengue virus (Simmons 2015)	RTS,S vaccine released for pilot use in Africa by WHO on October 23rd, 2015 but requires 4 doses over 18 months and has limited efficacy (Callaway and Maxmen 2015)
Treatment	**classic:** fluids, pain medication, rest **severe:** fluid replacement therapy, blood transfusion (rarely required)	antimalarial medications (parasite resistance is a continuing issue)
Vector Control	container control, indoor residual spraying (IRS) of insecticides, larvicide packets in collected water	long-lasting insecticide-treated nets (LLINs), indoor residual spraying (IRS) of insecticides

CHAPTER 3: MEASURING ECONOMIC WELLBEING USING EASILY OBSERVABLE HOUSING CHARACTERISTICS

I. Introduction

A reliable measure of economic wellbeing is necessary for analyses of numerous research topics in developing countries, including impact analyses and assessments of the link between health and household demographics. Within the economics literature, the traditional approach to measuring economic wellbeing has been to collect monetary measures of income or consumption, both of which can be difficult to objectively and consistently measure in developing country contexts. In lieu of monetary data, household surveys in developing countries increasingly collect information on housing construction materials, utilities, and durable goods ownership.[15] The combined data on physical housing attributes are typically called 'asset indices,' where assets refer to possessions that make up or are kept in the house. Benefits of using housing characteristic data include the ease of data collection and the reduced likelihood of recall bias or misreporting from survey participants (Sahn and Stifel 2003). However, the use of asset indices is new, and best practices regarding index construction have not been widely explored.

The goal of this research is to determine best practices for converting easily observable and objective measures of housing characteristics into a practical and reliable proxy for economic wellbeing. I first determine the impact of varying the methods used to generate asset indices on the way in which households are sorted into economic classes. Using data from the Peruvian National Household Survey, I analyze one common method of asset index construction:

[15] See the Progress out of Poverty Index (PPI) put forth by the Grameen Foundation (2015) or the Latin American Public Opinion Project assessed by Cordova (2009) for recent examples.

principal components analysis (PCA). I assess the impact of varying the specific methods used to construct asset indices via PCA, including the number and type of variables used, the use of the correlation versus the covariance matrix, the number of principal components retained, and the population over which the index is formed.

I next construct an asset index over the national population as well as the urban and rural populations of Peru. Households in urban areas tend to be wealthier than those in rural areas. As a result, the distribution of the nationally-formed asset index among the urban population is predictably right-skewed, indicating a larger prevalence of high scores, while the distribution of the index among the rural population is predictably left-skewed. Therefore, nationally-formed economic classes will be clustered at high or low classes across local samples depending on the relative economic level of the assessed area.

I account for differences in the national score distribution among various local populations by splitting households into economic classes based on the distribution of the national index among each subpopulation. In doing so, I generate nationally-weighted economic classes for each subpopulation that are nearly identical to those derived from the subpopulation alone. Using the national index to generate local scores has the additional benefit of providing a means with which to compare the economic level of various subpopulations since the localized asset indices cannot be readily compared.

Lastly, I carry out a case study of the city of Iquitos, which is located in the Peruvian Amazon and situated within the mostly rural province of Maynas. The results of the case study confirm the results for urban and rural populations at the national level. I compare the national asset index to measures of income and consumption for the city of Iquitos and find relatively similar levels of correspondence among the three measures. The findings in this paper give guidance to researchers using data from developing countries that do not include reliable monetary proxies for economic wellbeing.

II. Measuring Wellbeing

Researchers interested in economic development have long debated the proper measurement of wellbeing (*e.g.*, Sen 1993 and Deaton 1997). Several nebulous terms for wellbeing including 'wealth' and 'socioeconomic status' (SES) suffer from vague measurement standards and are difficult to define or apply broadly in development contexts. Here, I briefly review three methods of measuring wellbeing: Amartya Sen's capability approach, sociological indices of SES, and measures of household income or consumption.

Sen introduced a capability approach to the assessment of wellbeing that focuses on "the alternative combinations of things a person is able to do or be – the various 'functionings' he or she can achieve," (Sen 1993, 270–271). The approach examines individual freedom of choice regarding access to food, health, shelter, education, work, and political and social engagement. The capability approach was adapted (though narrowed in scope) by Mahbub Ul Haq to form the Human Development Index (HDI) implemented by the United Nations Development Programme in 1990 (UNDP 2015). While the capability approach has theoretical appeal, it involves measuring subjective or intangible aspects of human wellbeing and requires extensive questions about aspects of individual livelihood.

Within the sociology, psychology, education, and health literature, the focus of wellbeing measurement has largely revolved around measures of socioeconomic status (SES) (Oakes and

Rossi, 2003). It is difficult to find a consistent and comprehensive definition or standard of measurement of SES. In a report for the National Center for Education Statistics, a panel of experts concluded that "SES can be defined broadly as one's access to financial, social, cultural, and human capital resources" (Cowan et al. 2012, 4). A variety of SES indices have been used in the past, but most rely on the measurement of income, education, and some measure of occupational prestige (Cowan et al. 2012).

The traditional approach to wellbeing measurement within the economics literature has been to focus on monetary measures of material resources like income or consumption as proxies for household wealth. Wealth here refers to the value of all assets of a household net of the value of all liabilities or debts. Wealth can be seen as an indicator of a household's ability to acquire desirable things like food, shelter, and health care, or to carry out desirable activities like leisure. The target, then, in measuring household wealth is the same as with measures derived from the capability approach or with measures of socioeconomic status.

In focusing on material resources, one assumes there is a strong correlation between monetary measures and other key aspects of wellbeing. Economists often incorporate household demographic characteristics in analyses, including the age, education, occupation, gender, and number of household residents. But while indices of SES compile material resources and demographic measures into a single index, monetary and demographic measures are often analyzed separately in economic research. Household wealth is utilized as an indicator of wellbeing that is separate from, but related to, demographic traits and other key aspects of wellbeing like health and nutrition.

Deaton (1997) recommends using consumption data rather than self-reported income information as a proxy for wellbeing in developing country contexts. He argues that consumption data are easier to measure reliably given the prevalence of informal labor markets and lack of formal financial markets in many developing countries. However, reliable consumption data have often proven difficult to collect in developing countries since it depends on accurate recall among survey participants often over long periods of time and without formal records of purchases (Sahn and Stifel 2003). Filmer and Pritchett (2001) instead recommend collecting data on housing construction and asset ownership.

III. Constructing Asset Indices via Principal Components Analysis (PCA)

The most commonly used method for forming an asset index is principal components analysis (PCA), which differentiates households based on the variation in their housing construction materials, utilities, and durable goods ownership. The first principal component is the normalized linear transformation of the original variable that has maximum variance across observations.[16] The second principal component is the normalized linear transformation that has the highest variance of all of the linear transformations that are uncorrelated with the first principal component, and so on. In this way, the first few principal components capture most of the variation of the original set of variables (Jolliffe 2002). The combined linear coefficients are restricted to have unit length, making each principal component a weighted average of the original variables.[17]

[16] Joliffe (2002) provides a detailed description of principal components analysis (PCA). Much of this description is drawn from that work.
[17] Variables such as income are often normalized to z-scores before principal components are calculated.

PCA can be carried out using the covariance or correlation matrix of the original data. Utilizing the covariance matrix requires that the original data be measured in consistent units. When variables are measured in drastically different units, their variances will also be drastically different, even if the difference is not meaningful in economic terms. The PCA will then be driven by potentially uninformative differences in variation. If the included variables are instead standardized to all have unit variance, the covariance matrix of the standardized variables is equal to the correlation matrix of the original variables. Differences in the cross-correlations of the variables then reflect economically meaningful differences in the co-variation of the included variables. Using the correlation matrix also has the benefit of increasing the comparability of principal components formed over different sets of variables.

In the current context, measures of physical housing traits have naturally different units of measurement. The units of measurement for categorical indicators of housing construction materials or utilities depend on the number of potential responses for each attribute. On the other hand, indicators of the possession of various durable goods are binary. Other measures, like the number of rooms in a house, have integer units that reflect a physical reality. To use the covariance matrix for PCA, one must first convert all variables to consistent units. One way to standardize the units of measurement is to convert the variables into binary indicators by making an indicator for each potential survey response for each attribute. For categorical variables, this may be good practice anyway as the numerical units assigned to each categorical entry are arbitrary. For physical measures like the number of rooms, the breakdown of responses into binary indicators allows for nonlinearities in the contribution of the attribute to the PCA. The other alternative is to standardize the variables and assess the correlation matrix of the original variables in the PCA. I compare the outcomes of PCA using the covariance matrix and the correlation matrix with the appropriate variable format for each method below. I utilize the correlation matrix of the original variables throughout the majority of this work.

The number of principal components that should be retained for asset index construction from PCA is unclear. One of the main functions of PCA is to reduce the dimensionality of the included variables while maintaining the descriptive power of the initial set (StataCorp 2013). The Sociology literature that has used PCA to date has typically reduced the economic indicators down to the first principal component, assuming that the generated index reflects household economic wellbeing (Filmer and Pritchett 2001). I discuss the information provided by additional principal components below, but I focus on the first principal component throughout the majority of the analysis.

Utilizing standardized variables, the first principal component for each household *i* is given by:

$$y_i = \sum_{k=1}^{K} a_k x_{ki}^* \,, \; i = 1, \dots, N \;, \tag{1}$$

with

$$x_{ki}^* = \left(\frac{x_{ki} - \overline{x_k}}{s_k}\right), i = 1, \dots, N \,, \tag{2}$$

where y_i is the first principal component for household i, assumed here to represent household economic wellbeing, and $x_{ki},\; k = 1, \dots, K$ is the value of economic indicator *k* for household *i*. The variable $\overline{x_k}$ is the sample mean of economic indicator *k*, s_k is the standard deviation around the mean, and a_k is the weight given to economic indicator *k* through the process of maximizing the variance of y_i. The first principal component y_i is the largest eigenvector of the correlation matrix of the variables x_{ki}. It can be shown that the first principal component is the linear combination of the weighted standardized economic indicator variables for that household that has maximum squared multiple correlation with the original variables.

The extent to which each physical housing attribute influences a household's asset index depends on the variation of that particular attribute among the sample population. In other words, the weights, a_k, are determined by which variables exhibit the widest variation among the sample and thereby most significantly differentiate each household from the rest of the sample. Because PCA will only differentiate household attributes relative to the included sample, the population scale at which asset index weights are generated is likely to impact the sorting of households into economic classes. Some studies suggest that separate indices should be constructed for rural and urban populations because differences in infrastructural availability can lead to all households in a rural area lacking attributes possessed by urban households (Córdova 2009).

Creating separate asset indices for subpopulations based on urbanization may not be appropriate. First, it may be the case that all individuals in rural areas with limited infrastructure have a lower level of economic wellbeing than their urban counterparts. Also, asset indices formed across different samples cannot be easily compared. In any case, the appropriate scale at which asset weights should be generated has not been sufficiently assessed. In this paper, I argue that constructing asset indices at a national scale provides a more standard measure of economic wellbeing that allows for comparisons across subpopulations. I retain the benefits associated with local asset indices by forming economic classes based on the distribution of the national index among each subpopulation of interest. I discuss best practices for constructing an asset index at the national level that still allows for detailed economic analysis at the local level in greater detail below.

IV. Asset Indices versus Measures of Household Consumption or Income

Previous papers comparing asset indices and consumption measures have found general agreement between the two measures regarding the ordinal sorting of households into economic classes, although the strength of the agreement between the measures is subjective (Sahn and Stifel 2003; Filmer and Pritchett 2001). Previous asset indices have also been shown to correspond with outcomes such as education and health as well as, or more closely than, consumption (Córdova 2009; Sahn and Stifel 2003; Filmer and Pritchett 2001). However, Filmer and Pritchett (2001) point out that the existing results do not fully indicate whether asset indices or consumption data provide a better measure of economic wellbeing. They suggest that because asset indices are typically constructed from data on durable goods ownership, they provide a better measure of long run economic wellbeing while consumption better measures fluctuations in short run economic wellbeing.

It is worth noting that there are limitations to using physical housing attributes as a measure of economic wellbeing. Some limitations are shared by measures of household income or consumption, while others are unique to asset indices. One issue is that data collected on housing construction materials and durable goods ownership do not typically account for differences in the quality of goods of the same type. For example, a survey might ask if the household owns a television without specifying its value. A 20-year-old television would then receive the same valuation as one that is brand new. Asset indices therefore do not capture the full heterogeneity of household assets. Measures of household consumption address this issue by asking for the monetary value of goods consumed. Questionnaires on household assets could reflect the same standards of measurement, but this would negate two of the main stated benefits of the asset index: that it does not rely on the accurate recall of monetary values, and that it does not require sensitive questions about household finances.

Another limitation of asset indices is that the definition of assets used is restricted to only the physical possessions that make up or are kept within the home. Indices do not capture other forms of assets, including financial assets like savings or investments, which likely contribute to the long run economic wellbeing of a household. Financial assets are also generally excluded from consumption measures and can only be captured by asking direct questions. Financial assets are also more likely to be prevalent in countries with well-established financial systems, which are not generally the countries in which an asset index would be most useful. Datasets that include both physical housing attribute data and data on household financial assets could be used to assess the correspondence of asset indices with other measures of household assets.

V. Research Location

This research relies on survey data collected in Peru in the Amazonian city of Iquitos. Peru is a middle income country with a population of a little over 30 million people. GDP growth in Peru has been strong over the past decade, averaging about 5% per year (The World Bank 2015). The national poverty rate has dropped drastically from 58.7% in 2004 to 23.9% in 2013 (INEI 2015). While both rural and urban poverty rates have decreased, the poverty gap between rural and urban areas has remained large. In 2004, the percentage of people living below in the poverty line in rural areas was 83.4% compared to 48.2% in urban areas. As of 2013, the urban poverty rate had dropped to only 16.1% while the rural poverty rate remained at 48% (INEI 2015). Access to high quality sanitation, water, education, and transportation infrastructure present large challenges for increased economic growth in rural areas (IFAD 2015).

In the heart of the Amazon rainforest, the city of Iquitos lies within the Maynas province that is encompassed in the Loreto region. Outside of the city of Iquitos, the Maynas province and greater Loreto region are comprised of mostly rural areas with low levels of income and infrastructural development. Within the rainforest (Selva) region, of which Loreto is a part, the urban poverty rate was 59.4% in 2004 and 22.9% in 2013, while the rural poverty rate was 81.5% in 2004 and 42.6% in 2013 (INEI 2015).

Figure 3.1 shows maps of the Loreto region and of the city of Iquitos within the Maynas province. With an estimated population of over 400,000 people, Iquitos is the largest city in the world that cannot be traveled to by road. It is bordered by the Amazon, Itaya, and Nanay Rivers and the Amazon rainforest, making it an ecological island. Within the confines of the city, there is a large amount of infrastructural variation and economic diversity without high levels of economic segregation. There are four districts in the city (Iquitos, Punchana, Belen, and San Juan Bautista) with slightly differing levels of average income and infrastructural development. Within each district, however, it is not uncommon for neighboring households to vary extensively in physical housing attributes (Getis et al. 2003).

VI. Data Description

The data for this analysis come from the Peruvian National Household Survey (ENAHO) carried out by the Peruvian National Institute of Information and Statistics (INEI) beginning in 2004 (INEI 2015). Each year, the INEI surveys a random selection of households within pre-defined survey areas to ensure that all geographic areas throughout the country are included. Households are randomly selected each year, and the location of each surveyed household is provided via its Peruvian district code, which is similar to a U.S. zip code. Districts are further identified by their estimated population level. I analyze asset indices formed at the national level, across urban and rural populations, and among the Loreto region, Maynas province, and districts of the city of Iquitos in order to compare indices constructed across various samples.

The ENAHO data include information on the main construction material of the walls, floor, and roof of the house. The survey also includes indicators for whether or not a household possesses electricity, piped sewage, potable water, internet, cable TV, a landline or cellular phone, and a gas or electric stove. The physical housing attribute data are accompanied by data on the age, education, work hours, and sex of all household members. The survey measures household consumption and income, which can be compared to asset indices generated from the physical housing attribute data. Up to 2006, the survey also collected subjective information on the general condition of the property measured with a 5 point Likert scale ranging from 'very bad' to 'very good.' I focus my analysis on 2006 in order to include the property condition measure. **Table 3.1** defines the variables collected in the ENAHO survey in 2006. I generate separate binary indicators for each potential entry of each aspect of housing construction, utilities, and durable goods.

Table 3.2 provides the mean and standard deviation of key household descriptive variables as well as the percentage of the sample with each household attribute for the entire population of Peru and for urban and rural populations. The number of household observations in each sample is provided at the bottom of the table. There are over 19,000 households surveyed for all of Peru, a little over half of which comprise rural populations. **Table 3.2** indicates that the sample characteristics vary based on geographic scale. For example, the average education level of household heads in urban areas is higher than in rural areas and higher than the average for the national sample. Average household income and consumption are also higher among the urban population compared to the rural population or the national sample. The various indicators of housing quality display the same pattern indicating that average housing quality in rural areas is lower than the national average while average housing quality in urban areas is higher than the national average. **Table 3.3** shows the same summary information as **Table 3.2** for the city of Iquitos as well as the surrounding Maynas province and Loreto region. The same differences between rural and urban areas can be seen between the largely rural Loreto region and the city of Iquitos.

Characteristics that are either highly prevalent or highly absent throughout the population do not contribute substantially to PCA. The cross-correlations of the included variables for all of Peru in 2006 are provided in **Table 3.4**. I reduce all categorical variables down to a single binary indicator for ‘high quality’ to better compare correlations across categories. Unsurprisingly, the number of rooms and bedrooms are highly correlated (r = 79.3%). The correlation between having piped sewage and having water supplied through a faucet is also high (r = 63.24%). All physical housing attributes other than the quality of the roof material display strong correlations with each other (r > 30%). The reported cross-correlations form the basis of the PCA, the results of which I discuss in detail in the next section.

VII. Results

VII.1. Varying the Econometric Methods of PCA

I first describe the impact of varying the econometric methods used to generate asset indices via PCA. I focus on the number of principal components used, the format of the variables used, and the use of either the covariance or correlation matrix of the original variables. I find that the first principal component is the most appropriate for capturing the value of physical housing attributes. I also find that altering the format of the input variables or the use of the correlation or covariance matrix of the original variables does not substantially alter the resulting first principal component (FPC) scores.

Table 3.5 shows the scoring coefficients for all 11 principal components derived from the limited set of 11 housing indicators. The included variables are a collapsed set of the full categorical variables defined in **Table 3.1** so that all indicators measure the possession of desirable housing attributes. As can be seen in **Table 3.5**, the scoring coefficients for the first principal component are all positive, indicating that first principal component differentiates between housing materials of varying quality. The magnitude of each coefficient indicates the weighting of that attribute in the principal component score. The attributes are listed in order of their scoring coefficients for the first principal component. Piped sewage, high quality flooring material, and a gas or electric stove have the largest weights. High quality roofing materials matter the least, followed by internet access. The first principal component accounts for 42% of the total variance.

The variables with the largest coefficients are shaded for the rest of the principal components. The second principal component seems to differentiate between housing size and housing quality. The scoring coefficients for the number of rooms and bedrooms are far larger than the coefficients for any other attribute and the coefficients for most of the other attributes of housing quality are negative. Households with a high second principal component score will therefore be those with large homes and not necessarily those with homes that are built out of high quality materials or that possess desirable utilities or durable goods. The second principal component accounts for 11.3% of the total variance of the included variables. Each of the additional principal component scores differentiate one single attribute and do not appear to have meaningful interpretations. As expected, the percentage of the variance captured by each respective principal component declines. The first six principal components capture 83.33% of the total variance.

Table 3.6 shows the correlation of the FPC scores generated using either:

1) the correlation or covariance matrix of the original variables, and

2) the full variable set listed in **Table 3.1** or the collapsed variables used in **Table 3.5**.

The correlation between each of the resulting FPC scores is over 97%. The correlation between the FPC scores generated using the correlation or covariance matrix of the same variable sets are 98.7% and 99.4%. The correlations of additional principal components using differing variable groups and econometric methods are not shown here but are not very high.

Based on the results presented in **Table 3.5** and **Table 3.6**, the first principal component score seems to be an accurate indicator of overall housing quality. When using PCA to construct the FPC score of housing traits, the details of the econometric methods used, in terms of formatting the input variables or using the covariance versus the correlation matrix, do not appear to have practical significance. The theoretical equivalence of using the correlation versus the covariance matrix, as long as appropriate variable units are used, supports the practical results found here.

VII.2. First Principal Component (FPC) Score

Table 3.7 shows the first principal component (FPC) score coefficients for each binary household attribute used in the PCA for all of Peru and for the rural and urban sample populations. **Table 3.8** offers the same information for the sample of the Loreto region, Maynas province, and city of Iquitos. The score coefficients serve as weights to generate an FPC score for each household in the sample. The FPC score of each household is the value of the asset index for that household and measures overall housing quality.[18] An attribute with a positive coefficient factors positively into the asset index, indicating that it is of high quality.

The results are consistent with what one would expect regarding attribute quality. A household's asset index is increased if their house has more rooms or bedrooms, or if it is made of higher quality construction materials like brick or cement walls, cement, wood, or tile floors, or a metal or cement tile roof. In contrast, houses made of low quality housing construction materials, such as mud, dirt, palm, or wood walls, dirt floors, or a mud or wood roof, have a

[18] The calculated asset index can then serve as a proxy for a household's economic wellbeing.

lower asset index. Similarly, having piped sewage or potable water increases a household's asset index, while relying on latrine or canal sewage or collecting water from a well, river, or other shared source decreases their asset index. Having no public services also factors negatively into the index, while possessing electricity, a cellular or landline phone, internet or cable TV, and a gas or electric stove factors positively into the index.

FPC score coefficients that are larger in magnitude in either direction have a larger impact on a household's asset index. Because the magnitude of the coefficient depends on the variance of that attribute within the included sample population, the score coefficients differ based on the analyzed sample population. For example, the number of rooms or bedrooms in the home has a larger positive impact on the asset index formed over the urban sample rather than the rural sample, while having a house with wood, mud, or palm walls has a larger negative impact. Having a house with a cement floor has a larger positive impact among rural households, while having a house with a wood or tile floor has a larger positive impact among urban households. The scoring coefficient differences likely reflect disparities in the infrastructure of the respective areas, though they may also reflect differences in tastes and preferences. The scoring coefficients for the national sample almost always lie between those of the urban and rural samples, indicating a more median standard of differentiation between the attributes.

VII.3. FPC Score Results across Various Sample Populations

Dividing a sample into economic classes based on the distribution of the asset index will yield varying results based on the sample score distribution over which the index is divided. **Table 3.9** shows the correspondence between the FPC score ranks of households in rural and urban areas. **Table 3.10** shows the same information for the sample populations of the Loreto region and the city of Iquitos. ***Panels 1 and 3*** in **Table 3.9** and **Table 3.10** show the correspondence between FPC score ranks that are:

1) calculated with index weights derived from the national sample (**Table 3.7**, Column 1), and divided into classes based on the score distribution among the national sample,

and

2) calculated with index weights derived from each local sample (**Table 3.7**, Columns 2-3 and **Table 3.8**), and divided into classes based on the score distribution among the respective local sample.

Panel 1 indicates that households in rural areas are more likely to lie in lower nationally-formed FPC score ranks, even if they are categorized into higher FPC score ranks that are formed among the rural sample. In contrast, ***Panel 3*** shows that urban households are more likely to be sorted into higher nationally-formed FPC score ranks, even if they are sorted into lower FPC score ranks that are formed among the urban sample. The score ranks among the Loreto sample display similar results to those of the rural sample, and the score ranks among the Iquitos sample display similar results to those of the urban sample, though the results are less extreme in both cases than for the full rural and urban samples.

The results clearly show that nationally-formed FPC score ranks correspond with differing local score distributions for each local sample. The benefit of using a national asset index is that it allows for a comparison of economic wellbeing levels across sub-populations. The downside to using a national asset index is that you lose descriptive power at local levels of analysis since households are clustered into high or low economic classes depending on the comparative economic level of the sub-population.

I propose a solution that allows for cross-group comparisons while differentiating the levels of economic wellbeing within a specific sample in greater detail. I calculate FPC scores with weights derived at the national level (**Table 3.7**, Column 1) but then divide households into classes based on the score distribution among each local sample. Weights generated across the national sample provide a common standard for comparing physical housing attributes, just as a national currency provides a common standard for comparing household income or consumption. Subdividing each local sample into classes based on the distribution of the nationally-formed scores at the local level then consistently splits each local sample into economic quantiles of interest.

Panels 2 and 4 within **Table 3.9** and **Table 3.10** show the correspondence between FPC score ranks that are calculated using index weights derived from the national sample population (**Table 3.7**, Column 1) and are divided into classes based on:

- the score distribution among the national sample population,

and

- the score distribution among the local sample population.

The ranks formed from the national index weights split over each local score distribution correspond with the fully localized measures more strongly than the ranks calculated with the national weights split over the national score distribution (***Panels 1 and 3***).

The same results can be seen in **Figure 3.2** and **Figure 3.3**, which show the distribution of the raw FPC scores at the national, rural, and urban levels. The distribution of the Peru FPC scores is bi-modal and skewed to the left. The distribution of the rural FPC scores are heavily skewed to the left, indicating a higher prevalence of low scores, while the distribution of the urban FPC scores are skewed to the right, indicating a higher prevalence of high scores. The distributions of the national and rural FPC scores are similar when looking only at the rural sample population, as are the distributions of the national and urban FPC scores when looking only at the urban sample population. The figures indicate that evenly distributed economic classes can be formed using either local or national FPC scores as long as the classes are formed over the local sample of interest and not at the national level.

VII.4. Results for the City of Iquitos

For the rest of the analysis, I focus on the population of Iquitos, Peru. I utilize the FPC score rank constructed with nationally-formed scoring coefficients split across the resulting FPC score distribution among the sample population of Iquitos. I call this measure the 'Peru-Iquitos FPC score rank'. **Figure 3.4** shows the distribution of the Peru-Iquitos FPC score rank among the districts of Iquitos to compare the relative economic levels of each district. The figure indicates that the FPC score distributions among the districts of Punchana and Belen are skewed towards lower economic classes, while the score distribution among the district of Iquitos is skewed towards higher classes. The FPC score classes are fairly evenly distributed among the district of San Juan Bautista. The results point out differences in each district's economic level that are important to consider for research conducted in the city.

VII.5. Comparing the FPC Score Rank to Other Measures of Wellbeing

To assess how well the asset index corresponds to other measures of household economic wellbeing, **Table 3.11** shows the correspondence between the Peru-Iquitos FPC score rank and income and consumption ranks for the Iquitos sample. ***Panels 1 and 2*** show that the correspondence between the Peru-Iquitos FPC score rank and each of the income and consumption ranks is consistent but weak. In both instances, the correspondence between economic classes is stronger at the high and low ends of the distribution than it is among the middle classes, an issue referred to as ‘clumping’ or ‘truncation’. Clumping may be reduced by incorporating additional physical housing attributes into the asset index (McKenzie, 2005). ***Panel 3*** shows that the correspondence between the income rank and consumption rank is itself consistent but fairly weak. The correlation between the income and consumption measures is about 75%, while the correlation between each of the income and consumption measures and the Peru-Iquitos FPC score rank is about 55% (results available upon request).

In order to further assess the ability of the asset index to sort households into consistent economic classes, **Table 3.12** shows the correspondence between key household descriptive variables and the Peru-Iquitos FPC score rank. The FPC score class corresponds strongly with the education level of the household head and with reported household income and consumption. However, there is not a monotonic relationship between the FPC score rank and the age, gender, or paid work hours of the household head.

The FPC score rank corresponds more strongly with a property being in below or above average condition than with a property being in average condition. Not surprisingly, the FPC score rank corresponds strongly to the various physical housing attributes used to generate the index. For example, none of the households in the lowest FPC score class have piped sewage, a gas or electric stove, a landline phone, or electricity, while nearly all households in the highest FPC score class possess these things. There are also strong monotonic relationships between the FPC score classes and the number of rooms and bedrooms in the home as well as the materials of the floors, walls, and roofs.

VIII. Conclusion

Asset indices calculated via PCA consistently differentiate between high and low quality housing attributes among both national and local sample populations. However, there is a difference between the economic classes that are formed when FPC scores are calculated and divided by their distribution at the national or local level. A national asset index provides a means with which to compare the economic levels of various subpopulations. However, national index ranks are likely to be clustered within local populations depending on the average economic level of that area. Local asset indices differentiate the relative economic levels of a local population in greater detail but suffer from a lack of generalizability as the economic classes of one population cannot be compared to those of another. In this paper, I propose a solution that offers the generalizability of a national index and the differentiability of a local index. I calculate FPC score ranks using weights derived at the national level that are split based on the resulting FPC score distribution among each local population of interest. In this manner, I form economic classes that are highly similar to those formed using local asset indices but that are based on a common national standard of asset measurement.

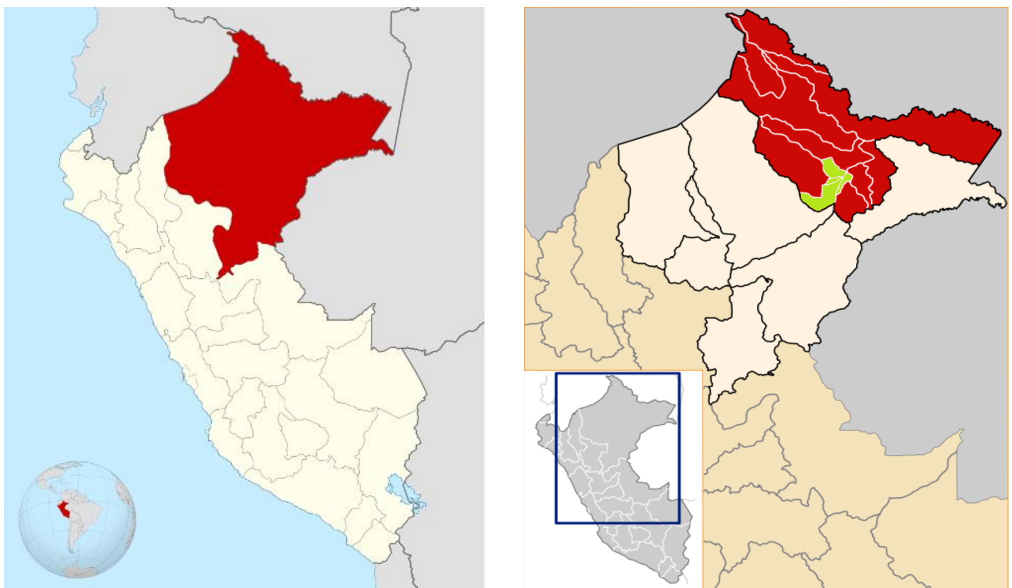
In analyzing the impact of varying the econometric methods with which PCA is carried out, I find that the use of the correlation or the covariance matrix does not significantly alter results so long as the utilized variables are converted to the proper units for each method. I find that the first principal component best approximates household economic wellbeing and that retaining only the first principal component when constructing asset indices is sensible. The current data do not allow for an analysis of varying the number of type of physical housing attributes that are included in the PCA. Future research in this area would further contribute to the forming of best-practices for asset index construction.

Focusing on the city of Iquitos, the correspondence between the asset index and reported household income and consumption is consistent but fairly weak at 55%, although the correspondence between the income and consumption measures themselves is only 75%. It is still not clear which of the asset index, income, or consumption measures provides a more accurate representation of economic wellbeing. As suggested in previous literature, it may be the case that an asset index measures economic wellbeing in the long run, while consumption and income provide reliable short run measures. Tests of the short run versus long run hypothesis can be carried out by tracking the growth of each of these measures over time and would contribute to the existing literature.

Reliable proxies for economic wellbeing are vital to a large amount of development research, including impact analyses and studies of the link between household health and economic wellbeing. An asset index can be generated from physical housing attributes that are easy to measure, can be directly observed, and do not require sensitive questions about the financial situation of households. The asset index can then serve as a proxy for economic wellbeing in a wide array of development research.

This paper contributes to the existing literature by analyzing the impact of varying several of the methods of asset index construction. I find that the first principal component offers a useful approximation of housing quality, while additional principal components provide little additional information. The use of the covariance versus the correlation matrix when carrying out PCA does not substantially alter results, at least for the first principal component, as long as the appropriate variable format for each method is used. Lastly, I find that asset indices formed at the national level can be used to split households into economic classes that closely resemble those generated by local indices by considering the distribution of the nationally-formed index among the local sample. The findings help form best practices for future index construction.

IX. Tables and Figures



The Loreto Region of Peru	The Maynas Province in the Loreto Region of Peru (City of Iquitos highlighted in green)

Figure 3.1: Maps of the Loreto Region, Maynas Province, and City of Iquitos in Peru.
Iquitos lies within the Maynas Province which lies within the Loreto Region.
Image Source: Wikipedia

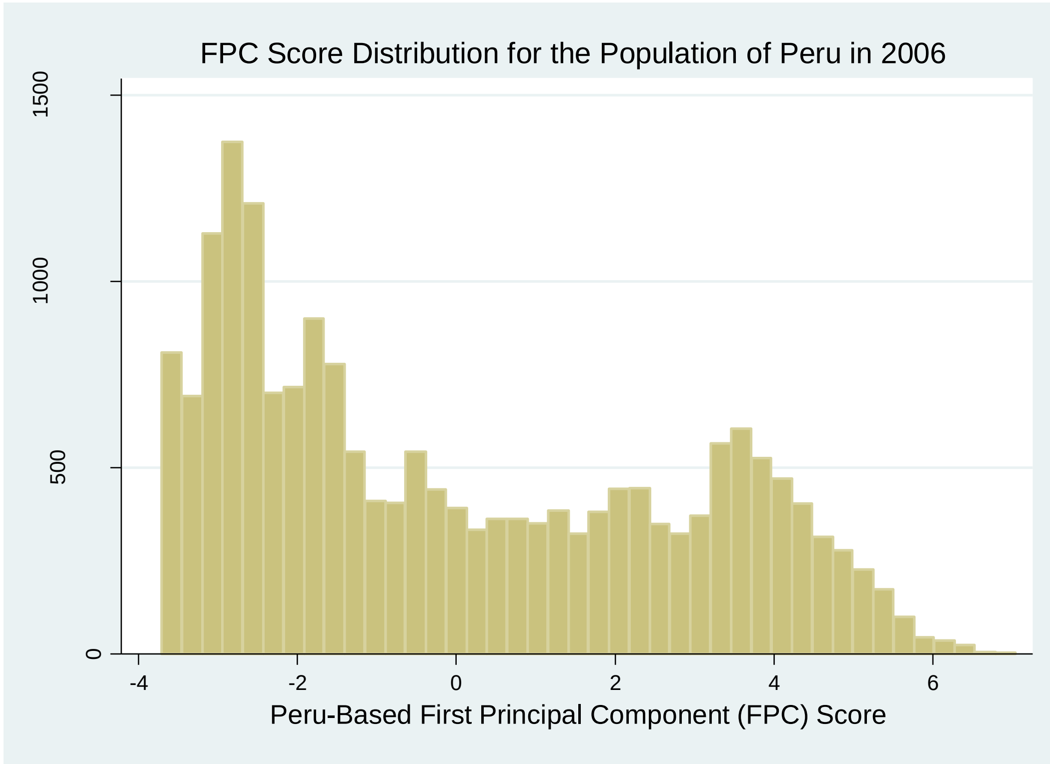


Figure 3.2: This figure shows the frequency distribution of the Peru FPC scores for the population of Peru in 2006. Households are assigned FPC scores using the national scoring coefficients reported in **Table 3.7**. Data are from the INEI ENAHO survey (INEI, 2015).

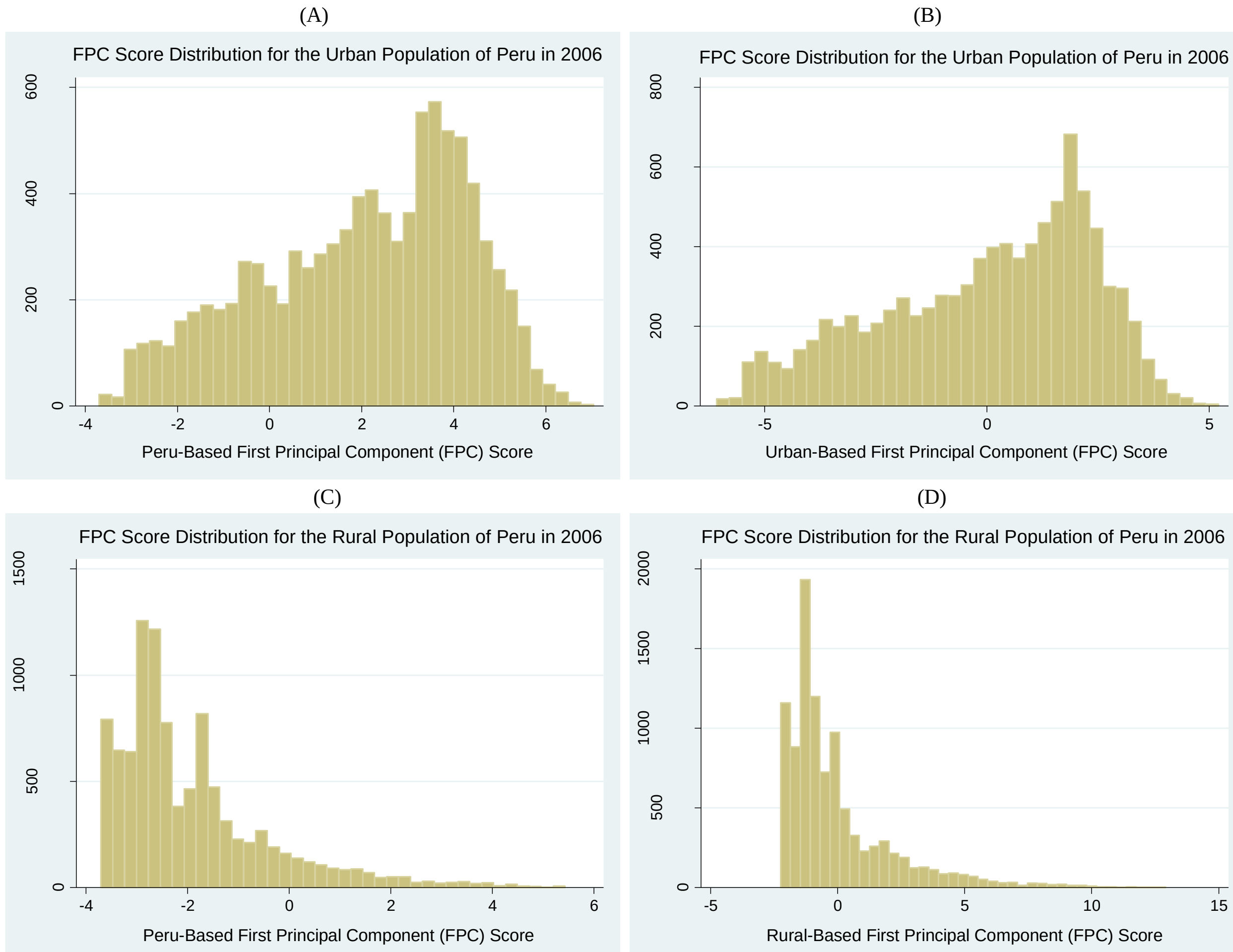
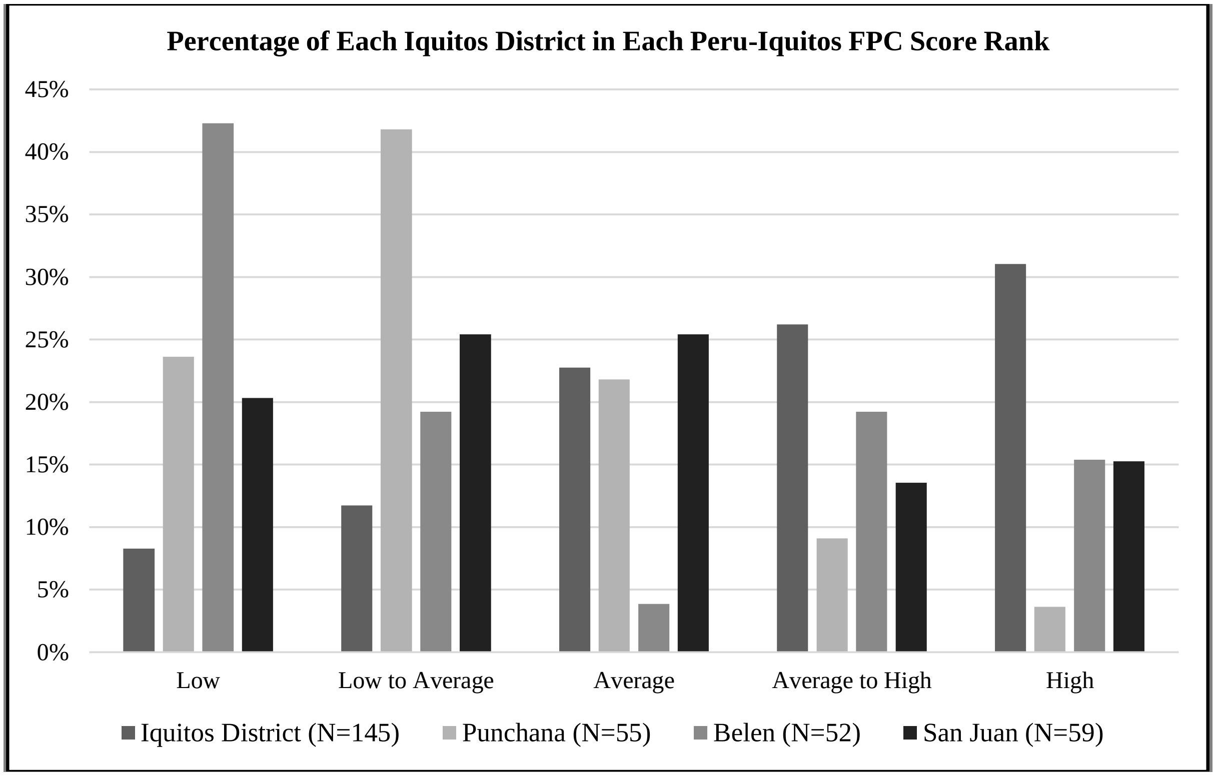


Figure 3.3: This figure shows the frequency distribution of the Peru FPC scores for the urban and rural populations of Peru in 2006. In panels (A) and (C), households are assigned FPC scores using the national scoring coefficients reported in **Table 3.7**. In panels (B) and (D), households are assigned FPC scores using locally derived scoring coefficients. Data are from the INEI ENAHO survey (INEI, 2015).



District	Peru-Iquitos FPC Score Rank Low	Low to Average	Average	Average to High	High	Total
Iquitos District	8.28%	11.72%	22.76%	26.21%	31.03%	145
Punchana	23.64%	41.82%	21.82%	9.09%	3.64%	55
Belen	42.31%	19.23%	3.85%	19.23%	15.38%	52
San Juan	20.34%	25.42%	25.42%	13.56%	15.25%	59
Total	59	65	62	61	64	311

0%-5%	5%-10%	10%-15%	15%-20%	20%-25%	25%-30%	30%-35%	35%-40%	40%-45%

Figure 3.4: This figure shows the percentage of each of the four districts of the city of Iquitos that lie within each Peru-Iquitos FPC Score Rank. Households are assigned FPC scores using the national scoring coefficients reported in **Table 3.7** and divided into classes based on the FPC score distribution among the Iquitos sample. Data are from the INEI ENAHO survey (INEI 2015).

Table 3.1: Key Variable Definitions for INEI-ENAHO Survey Economic Indicators

Category	Categorization of Possible Responses
Household Head Information	
Age	age of household head
Sex	sex of household head (1=female)
Education	years of education of household head
Paid Weekly Work Hours	number of hours worked last week for pay
Household Economic Information	
Total Expenditure	total gross household expenditure
Total Income	total gross household income
General Condition of the Home	very bad/bad, average, good/very good
Household Size	
Rooms (1-16)	number of rooms
Bedrooms (0-13)	number of rooms used for sleeping
Housing construction Materials	
Wall Material	brick/concrete/stone/ashlar, wood, adobe/cane/mat/mud/other
Roof Material	concrete/tile/corrugated sheets/fibre cement, wood/cane/mat/mud/leaves/straw/other
Floor Material	wood/tile/vinyl, cement, dirt/other
Household Utilities	
Water Source	faucet (potable), rain/well/river/shared/other
Sewage Type	piped, tank/latrine/canal/shared/none
Other Public Services	electricity, landline phone, cellular phone, internet, cable TV
Gas/Electric Stove	own a gas or electric stove (1=yes) (compared to wood/coal/kerosene/none)

Data are from the INEI ENAHO survey (INEI 2015).

Table 3.2: Mean of household characteristics and percentage of sample with each attribute for all of Peru and for the urban and rural populations in 2006

	Peru	Urban Population	Rural Population
Household Head Information			
gender (1 = female)	21.34%	25.98%	16.99%
age (years)	49.653	49.937	49.387
	(15.259)	(14.624)	(15.829)
	[14-98]	[14-98]	[14-96]
education (years)	7.286	9.359	5.338
	(4.928)	(4.761)	(4.240)
	[0-18]	[0-18]	[0-18]
total paid hours worked last week	38.177	37.137	39.154
	(25.307)	(29.502)	(20.551)
	[0-112]	[0-112]	[0-112]
Household Economic Information			
total gross expenditure	10,524.51	15,940.20	5,433.69
	(10,582.53)	(12,118.57)	(5,072.58)
	[0-424,817.8]	[0-424,817.8]	[0-51,311.68]
total gross income	13,423.54	20,543.75	6,730.43
	(18,922.74)	(22,440.73)	(11,351.47)
	[0-636,476.7]	[0-429,530.6]	[0-636,476.7]
Property Condition (1 = yes)			
below average	17.80%	11.21%	24.00%
average	63.32%	58.08%	68.24%
above average	18.88%	30.72%	7.75%

Table continued on next page…

Table 3.2 Cont.: Mean of household characteristics and percentage of sample with each attribute for all of Peru and for the urban and rural populations in 2006

	Peru	Urban Population	Rural Population
PCA Input Variables			
Number of Rooms & Bedrooms			
number of rooms	3.303	3.780	2.855
	(1.842)	(1.910)	(1.654)
	[1-16]	[1-16]	[1-16]
number of bedrooms	1.847	2.263	1.456
	(1.292)	(1.350)	(1.100)
	[0-13]	[0-13]	[0-11]
Wall Material (1 = yes)			
mud/palm/other	51.73%	27.48%	74.53%
wood	11.02%	5.45%	16.26%
brick/cement	37.24%	67.07%	9.21%
Floor Material (1 = yes)			
dirt/other	54.17%	24.23%	82.31%
cement	37.22%	58.83%	16.92%
wood/tile	8.61%	16.95%	0.78%
Roof Material (1 = yes)			
leaf/wood/other	19.70%	12.88%	26.10%
tile/cement	80.30%	87.12%	73.90%
Water Source (1 = yes)			
rain/well/shared	44.28%	19.92%	67.17%
faucet (potable)	55.72%	80.08%	32.83%
Sewage Type (1 = yes)			
latrine/canal/shared sewage	58.60%	25.76%	89.47%
piped sewage	41.40%	74.24%	10.53%
Other Services & Utilities (1 = yes)			
no public services	65.30%	36.74%	92.14%
landline phone	21.08%	41.29%	2.08%
cell phone	23.08%	41.85%	5.44%
internet/cable TV	11.24%	21.61%	1.48%
gas/electric stove	43.06%	76.09%	12.01%
Observations	19,243	9,324	9,919

Standard deviations provided in parentheses. Ranges provided in brackets. Data are from the INEI ENAHO survey (INEI, 2015).

Table 3.3: Mean of household characteristics and percentage of sample with each attribute for the Loreto Region, Maynas Province, and City of Iquitos in 2006

	Loreto Region	Maynas Province	Iquitos City
Household Head Information			
gender (1 = female)	15.47%	21.15%	24.12%
age (years)	46.405	47.382	48.248
	(13.860)	(13.851)	(13.864)
	[18-93]	[18-93]	[18-93]
education (years)	7.431	8.171	9.203
	(4.480)	(4.642)	(4.562)
	[0-17]	[0-17]	[0-17]
total paid hours worked last week	36.626	38.288	39.688
	(22.347)	(24.895)	(27.000)
	[0-110]	[0-110]	[0-110]
Household Economic Information			
total gross expenditure	9,505.64	12,841.08	15,606.21
	(9,780.18)	(11,690.13)	(12,114.22)
	[157-72,443.6]	[157-72,443.6]	[157-72,443.6]
total gross income	12,072.04	16,712.02	20,539.59
	(16,970.14)	(20,190.20)	(21,781.19)
	[0-151,178.3]	[96.49-151,178.3]	[96.49-151,178.3]
Property Condition (1 = yes)			
below average	17.36%	18.51%	17.04%
average	68.43%	62.02%	59.81%
above average	14.21%	19.47%	23.15%

Table continued on next page…

Table 3.3 Cont.: Mean of household characteristics and percentage of sample with each attribute for the Loreto Region, Maynas Province, and City of Iquitos in 2006

	Loreto Region	Maynas Province	Iquitos City
PCA Input Variables			
Number of Rooms & Bedrooms			
number of rooms	2.962	3.264	3.672
	(1.627)	(1.762)	(1.710)
	[1-11]	[1-11]	[1-11]
number of bedrooms	1.867	2.087	2.421
	(1.433)	(1.551)	(1.530)
	[0-10]	[0-10]	[0-10]
Wall Material (1 = yes)			
mud/palm/other	28.68%	21.39%	12.86%
wood	44.53%	33.65%	27.33%
brick/cement	26.79%	44.95%	59.81%
Floor Material (1 = yes)			
dirt/other	71.19%	55.77%	41.16%
cement	25.28%	37.74%	50.16%
wood/tile	3.52%	6.49%	8.68%
Roof Material (1 = yes)			
leaf/wood/other	55.22%	36.06%	16.08%
tile/cement	44.78%	63.94%	83.92%
Water Source (1 = yes)			
rain/well/shared	70.69%	52.40%	40.19%
faucet (potable)	29.31%	47.60%	59.81%
Sewage Type (1 = yes)			
latrine/canal/shared sewage	71.32%	53.61%	39.23%
piped sewage	28.68%	46.39%	60.77%
Other Services & Utilities (1 = yes)			
no public services	77.48%	62.02%	49.20%
landline phone	17.23%	29.09%	38.91%
cell phone	11.19%	21.15%	28.30%
internet/cable TV	9.56%	16.35%	21.86%
gas/electric stove	23.40%	38.22%	50.48%
Observations	795	416	311

Standard deviations provided in parentheses. Ranges provided in brackets. Data are from the INEI ENAHO survey (INEI, 2015).

Table 3.4: Cross-correlations between household attributes for all of Peru in 2006 (N=19,243)

	Rooms	Bedrooms	Wall Material	Floor Material	Roof Material	Potable Water	Piped Sewage	Landline Phone	Cell Phone	Internet
Bedrooms	79.30%									
Wall Material	20.94%	27.79%								
Floor Material	32.94%	34.89%	52.78%							
Roof Material	17.73%	15.43%	21.01%	19.17%						
Potable Water	32.21%	33.05%	26.66%	44.03%	19.26%					
Piped Sewage	36.27%	38.14%	43.24%	58.33%	17.75%	63.24%				
Landline Phone	38.83%	40.78%	36.90%	45.57%	13.58%	37.55%	51.22%			
Cell phone	28.61%	32.17%	30.68%	40.89%	9.14%	30.46%	39.64%	33.19%		
Internet/Cable	27.88%	27.40%	25.41%	28.44%	11.16%	23.98%	31.49%	43.96%	33.32%	
Gas/Electric Stove	28.68%	31.69%	45.53%	62.37%	15.33%	42.70%	57.91%	49.52%	47.50%	31.95%

Data are from the INEI ENAHO survey (INEI 2015).

Table 3.5: Scoring coefficients for each household attribute for each of the principal components for all of Peru in 2006 (N=19,243)

	Principal Component										
Variable	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Piped Sewage	0.3667	-0.168	0.0334	-0.3034	0.2292	-0.0669	0.0857	0.0814	0.0596	-0.8181	-0.0202
Floor Material	0.3534	-0.2467	0.0536	-0.1091	-0.2491	-0.0795	-0.0825	-0.5066	-0.6771	0.0813	-0.0504
Gas/Electric Stove	0.3503	-0.2797	-0.0852	-0.0558	-0.1286	0.0838	-0.4033	-0.3662	0.6657	0.1583	0.0131
Landline Phone	0.3308	0.0122	-0.1755	0.1764	0.1903	-0.3952	-0.5713	0.5049	-0.1908	0.1349	0.015
Potable Water	0.3042	-0.0856	0.1398	-0.4604	0.5243	0.0729	0.3292	0.1101	0.0121	0.5172	0.0155
Number of Bedrooms	0.3031	0.5883	0.0026	-0.0942	-0.2032	-0.0191	0.06	-0.0024	0.0864	0.0246	-0.707
Number of Rooms	0.2898	0.6266	0.0294	-0.0865	-0.1251	-0.0066	0.0102	-0.1178	0.018	-0.0265	0.6959
Wall Material	0.2845	-0.2753	0.1523	0.1756	-0.5297	-0.3372	0.4886	0.3331	0.163	0.0982	0.0951
Cell Phone	0.2819	-0.0924	-0.2746	0.1387	-0.1666	0.8093	0.0164	0.3323	-0.1509	-0.0072	0.032
Internet/Cable	0.2462	0.0412	-0.3233	0.6575	0.4127	-0.088	0.3463	-0.3165	0.0344	-0.0243	-0.0314
Roof Material	0.1384	0.0222	0.857	0.3888	0.1486	0.2094	-0.1605	0.0095	0	-0.0423	-0.0344
*Rho**	42.02%	11.30%	8.91%	7.81%	7.01%	6.28%	4.72%	4.04%	3.20%	2.87%	1.83%

This table displays the scoring coefficient of each household attribute and for each principal component resulting from a PCA on the full sample of Peru in 2006. Each categorical response for housing construction materials has been limited to a binary indicator of high or low quality to facilitate a comparison between rather than within household attributes. Shaded entries indicate the variables with the largest coefficients for each principal component. Data are from the INEI ENAHO survey (INEI 2015).

**Rho* indicates the percentage of the variance captured by each principal component.

Table 3.6: Pearson correlations between first principal component scores for Peru in 2006 (N=19,243) calculated via various methods

	Correlation Matrix, All Variables	Correlation Matrix, Limited Variable Set	Covariance Matrix, All Variables
Correlation Matrix, Limited Variable Set	98.54%		
Covariance Matrix, All Variables	99.36%	97.37%	
Covariance Matrix, Limited Variable Set	98.14%	98.73%	98.55%

This table shows the Pearson correlations between the FPC scores generated across the population of Peru using PCA over 1) the correlation matrix of the original variables, or 2) the covariance matrix of the original variables. The original variables are either broken down into binary indicators for each potential categorical response (All Variables- see **Table 3.2**) or are limited to include only a single binary indicator for each attribute category, signifying that the attribute is of "high quality" (Limited Variable Set- see **Table 3.5**). Data are from the INEI ENAHO survey (INEI 2015).

Table 3.7: First Principal Component (FPC) score coefficients for each indicator variable for all of Peru and for the urban and rural populations in 2006

Variable	Peru	Urban Population	Rural Population
Number of Rooms (1-16)	0.1967	0.247	0.2045
Number of Bedrooms (0-13)	0.2065	0.2372	0.1992
Wall Material (1 = yes)			
mud/palm/other	-0.2213	-0.2386	-0.1231
wood	-0.0852	-0.1035	-0.0598
brick/cement	0.2839	0.2766	0.2618
Floor Material (1 = yes)			
dirt/other	-0.2843	-0.253	-0.3183
cement	0.1925	0.069	0.2917
wood/tile	0.1733	0.1984	0.1381
Roof Material (1 = yes)			
leaf/wood/other	-0.1178	-0.1132	-0.1467
tile/cement	0.1178	0.1132	0.1467
Water Source (1 = yes)			
rain/well/shared	-0.2548	-0.2799	-0.2451
faucet (potable)	0.2548	0.2799	0.2451
Sewage Type (1 = yes)			
latrine/canal/shared sewage	-0.3011	-0.3162	-0.2998
piped sewage	0.3011	0.3162	0.2998
Other Services & Utilities (1 = yes)			
no public services	-0.2862	-0.2712	-0.2973
landline phone	0.2498	0.2536	0.2221
cell phone	0.2167	0.1792	0.2228
internet/cable TV	0.175	0.1919	0.1579
gas/electric stove	0.2706	0.2033	0.2658
Observations	19,243	9,324	9,919
Variables	19	19	19
*Rho**	39.99%	29.56%	25.75%

FPC score coefficients are derived for each household attribute via principal component analysis (PCA). Scores are derived over each sample population. Data are from the INEI ENAHO survey (INEI, 2015).
**Rho* indicates the percentage of the variance captured by the first principal component.

Table 3.8: First Principal Component (FPC) score coefficients for each indicator variable for the Loreto Region, Maynas Province, and City of Iquitos in 2006

Variable	Loreto Region	Maynas Province	Iquitos City
Number of Rooms (1-16)	0.2122	0.2279	0.2262
Number of Bedrooms (0-13)	0.1993	0.2144	0.211
Wall Material (1 = yes)			
mud/palm/other	-0.1383	-0.1559	-0.1469
wood	-0.1211	-0.1525	-0.1975
brick/cement	0.2772	0.2733	0.2798
Floor Material (1 = yes)			
dirt/other	-0.2622	-0.2657	-0.2638
cement	0.2217	0.2134	0.1927
wood/tile	0.1215	0.1158	0.1187
Roof Material (1 = yes)			
leaf/wood/other	-0.2493	-0.2563	-0.236
tile/cement	0.2493	0.2563	0.236
Water Source (1 = yes)			
rain/well/shared	-0.2539	-0.2388	-0.2362
faucet (potable)	0.2539	0.2388	0.2362
Sewage Type (1 = yes)			
latrine/canal/shared sewage	-0.2802	-0.2796	-0.2898
piped sewage	0.2802	0.2796	0.2898
Other Services & Utilities (1 = yes)			
no public services	-0.27	-0.265	-0.271
landline phone	0.2379	0.2293	0.231
cell phone	0.1874	0.1844	0.1785
internet/cable TV	0.1743	0.1621	0.1644
gas/electric stove	0.2583	0.2557	0.2607
Observations	795	416	311
Variables	19	19	19
*Rho**	51.85%	50.84%	43.40%

FPC score coefficients are derived for each household attribute via principal component analysis (PCA). Scores are derived over each sample population. Data are from the INEI ENAHO survey (INEI, 2015).
**Rho* indicates the percentage of the variance captured by the first principal component.

Table 3.9: Distribution between various FPC score ranks for rural and urban sample populations in 2006

Urban Population (N = 9,324)

		Peru FPC Score Rank				
	(1)	**Low**	**Low to Average**	**Average**	**Average to High**	**High**
Urban FPC Score Rank	**Low**	2.20%	6.02%	11.48%	0.30%	0
	Low to Average	0	0	6.49%	13.47%	0
	Average	0	0	0	17.69%	2.32%
	Average to High	0	0	0	2.53%	17.48%
	High	0	0	0	0	20.03%

		Peru-Urban FPC Score Rank				
	(2)	**Low**	**Low to Average**	**Average**	**Average to High**	**High**
Urban FPC Score Rank	**Low**	18.32%	1.67%	0	0	0
	Low to Average	1.67%	15.82%	2.47%	0	0
	Average	0	2.51%	15.02%	2.48%	0
	Average to High	0	0	2.46%	15.36%	2.20%
	High	0	0	0	2.19%	17.85%

Rural Population (N = 9,919)

		Peru FPC Score Rank				
	(3)	**Low**	**Low to Average**	**Average**	**Average to High**	**High**
Rural FPC Score Rank	**Low**	14.26%	0	0	0	0
	Low to Average	21.57%	3.04%	0	0	0
	Average	0.86%	20.26%	0	0	0
	Average to High	0	9.85%	9.92%	0	0
	High	0	0.03%	11.92%	6.91%	1.38%

		Peru-Rural FPC Score Rank				
	(4)	**Low**	**Low to Average**	**Average**	**Average to High**	**High**
Rural FPC Score Rank	**Low**	14.26%	0	0	0	0
	Low to Average	0.31%	23.36%	0.95%	0	0
	Average	0	1.58%	17.26%	2.28%	0
	Average to High	0	0	2.21%	16.03%	1.53%
	High	0	0	0	1.69%	18.54%

Households are assigned FPC scores using either the national or respective local scoring coefficients reported in **Table 3.7** and are divided into economic classes based on the FPC score distribution among the national sample or among the respective local sample. Data are from the INEI ENAHO survey (INEI 2015). Panels show the percentage of each sample population falling into each pair of score ranks. Cells are color coded according to the key below.

0%	0% - 0.99%	1% - 3.99%	4% - 7.99%	8% - 11.99%	12% - 14.99%	15% +
⬜	░	▒	▓	▨	▩	⬛

Table 3.10: Distribution between various FPC score ranks for the Loreto region and city of Iquitos in 2006

Loreto Region (*N* = 795)

Peru FPC Score Rank

(1) Loreto FPC Score Rank	Low	Low to Average	Average	Average to High	High
Low	14.59%	0	0	0	0
Low to Average	23.65%	0	0	0	0
Average	11.45%	10.31%	0	0	0
Average to High	0	3.77%	9.56%	6.67%	0
High	0	0	0	5.66%	14.34%

Peru-Loreto FPC Score Rank

(2) Loreto FPC Score Rank	Low	Low to Average	Average	Average to High	High
Low	13.08%	1.51%	0	0	0
Low to Average	0	23.65%	0	0	0
Average	0	0.25%	19.87%	1.64%	0
Average to High	0	0	1.01%	18.87%	0.13%
High	0	0	0	0.13%	19.87%

Iquitos City (*N* = 311)

Peru FPC Score Rank

(3) Iquitos FPC Score Rank	Low	Low to Average	Average	Average to High	High
Low	15.11%	4.82%	0	0	0
Low to Average	0.64%	4.18%	14.79%	0.32%	0
Average	0	0	0.32%	19.61%	0
Average to High	0	0	0	7.40%	12.54%
High	0	0	0	0	20.26%

Peru-Iquitos FPC Score Rank

(4) Iquitos FPC Score Rank	Low	Low to Average	Average	Average to High	High
Low	18.33%	1.61%	0	0	0
Low to Average	0.64%	18.97%	0.32%	0	0
Average	0	0.32%	19.61%	0	0
Average to High	0	0	0	19.61%	0.32%
High	0	0	0	0	20.26%

Households are assigned FPC scores using either the national or respective local scoring coefficients reported in **Table 3.7** and **Table 3.8** and are divided into economic classes based on the FPC score distribution among the national sample or among the respective local sample. Data are from the INEI ENAHO survey (INEI, 2015). Panels show the percentage of each sample population falling into each pair of score ranks. Cells are color coded according to the key below.

0%	0% - 0.99%	1% - 3.99%	4% - 7.99%	8% - 11.99%	12% - 14.99%	15% +

Table 3.11: Distribution between various economic class ranks for the city of Iquitos in 2006 (N = 311)

Panel (1): Rows = Peru-Iquitos FPC Score Rank; Columns = Iquitos Income Rank

(1)	Low	Low to Average	Average	Average to High	High
Low	12.22%	5.14%	1.61%	0.96%	0
Low to Average	4.18%	7.72%	5.47%	2.25%	0.32%
Average	1.29%	3.86%	5.79%	5.79%	3.22%
Average to High	0	1.61%	6.43%	7.40%	4.50%
High	0	0	1.61%	5.47%	13.18%

Panel (2): Rows = Peru-Iquitos FPC Score Rank; Columns = Iquitos Expenditure Rank

(2)	Low	Low to Average	Average	Average to High	High
Low	12.54%	4.50%	2.25%	0.64%	0
Low to Average	3.86%	7.72%	5.79%	1.61%	0.96%
Average	1.93%	3.54%	4.82%	5.47%	4.18%
Average to High	0.32%	2.25%	5.79%	7.40%	4.18%
High	0	0.96%	0.32%	5.79%	13.18%

Panel (3): Rows = Iquitos Income Rank; Columns = Iquitos Expenditure Rank

(3)	Low	Low to Average	Average	Average to High	High
Low	16.86%	3.14%	0	0	0
Low to Average	2.29%	11.71%	5.43%	0.57%	0
Average	0.86%	4.29%	8.00%	6.57%	0.29%
Average to High	0	0.57%	5.71%	9.43%	4.29%
High	0	0.29%	0.86%	3.43%	15.43%

Households are assigned FPC scores using the national scoring coefficients reported in **Table 3.7** and divided into classes based on the FPC score distribution among the Iquitos sample. Data are from the INEI ENAHO survey (INEI 2015). Panels show the percentage of Iquitos sample falling into each pair of score ranks. Cells are color coded according to the key below. The sample includes 311 observations.

0%	0% - 0.99%	1% - 3.99%	4% - 7.99%	8% - 11.99%	12% - 14.99%	15% +

Table 3.12: Mean of household characteristics and percentage of sample with each attribute by Peru-Iquitos FPC Score rank for Iquitos in 2006

Peru-Iquitos FPC Score Rank (1-5):	Low	Low to Average	Average	Average to High	High
Household Head Information					
gender (1 = female)	16.13%	25.81%	29.03%	24.19%	25.40%
age (years)	46.758	47.500	45.468	50.403	51.063
	(16.715)	(11.830)	(12.242)	(14.859)	(12.669)
education (years)	5.774	7.065	9.177	11.403	12.540
	(3.128)	(3.763)	(4.051)	(4.163)	(3.847)
total paid hours worked last week	37.258	40.855	38.177	36.371	45.683
	(17.397)	(29.877)	(32.183)	(27.273)	(25.709)
Household Economic Information					
total gross expenditure	8,288.2	13,675.7	19,051.3	21,920.3	36,215.6
	(4,629.7)	(7,486.1)	(8,462.3)	(9,092.4)	(17,140.8)
total gross income	8,052.2	14,080.3	23,354.9	29,076.6	51,961.2
	(5,715.0)	(7,727.6)	(14,767.2)	(17,764.7)	(31,658.6)
Property Condition					
below average	35.48%	38.71%	8.07%	3.23%	0%
average	58.06%	56.45%	85.48%	66.13%	33.33%
above average	6.45%	4.84%	6.45%	30.65%	66.67%

Table continued on next page…

Table 3.12 Cont.: Mean of household characteristics and percentage of sample with each attribute by Peru-Iquitos FPC Score rank for Iquitos in 2006

Peru-Iquitos FPC Score Rank (1-5):	Low	Low to Average	Average	Average to High	High
PCA Input Variables					
Number of Rooms & Bedrooms					
number of rooms (1-16)	2.032	3.097	3.645	4.274	5.286
	(0.829)	(1.155)	(1.680)	(1.439)	(1.337)
number of bedrooms (0-13)	1.048	1.903	2.500	2.936	3.698
	(0.798)	(1.097)	(1.586)	(1.366)	(1.227)
Wall Material					
mud/palm/other	33.87%	22.58%	8.07%	0%	0%
wood	66.13%	46.77%	20.97%	1.61%	1.59%
brick/cement	0%	30.65%	70.97%	98.39%	98.41%
Floor Material					
dirt/other	96.77%	74.19%	27.42%	8.07%	0%
cement	3.23%	25.81%	70.97%	87.10%	63.49%
wood/tile	0%	0%	1.61%	4.84%	36.51%
Roof Material					
leaf/wood/other	70.97%	8.07%	1.61%	0%	0%
tile/cement	29.03%	91.94%	98.39%	100%	100%
Water Source					
rain/well/shared	96.77%	53.23%	33.87%	11.29%	6.35%
faucet	3.23%	46.77%	66.13%	88.71%	93.65%
Sewage Type					
latrine/canal/shared sewage	100%	74.19%	19.35%	3.23%	0%
piped sewage	0%	25.81%	80.65%	96.77%	100%
Other Services & Utilities					
no public services	100%	87.10%	45.16%	14.52%	0%
landline phone	0%	8.07%	35.48%	56.45%	93.65%
cell phone	0%	8.07%	27.42%	35.48%	69.84%
internet/cable TV	0%	0%	6.45%	29.03%	73.02%
gas/electric stove	0%	12.90%	59.68%	79.03%	100%
Observations	62	62	62	62	63

Standard deviations provided in parentheses. Households are assigned FPC scores using the national scoring coefficients reported in **Table 3.7** and are divided into 5 classes based on the national score distribution among the Iquitos sample. Data are from the INEI ENAHO survey (INEI 2015).

CHAPTER 4: IMPACTS OF DENGUE EPIDEMICS ON HOUSEHOLD LABOR MARKET OUTCOMES

I. Introduction

Existing cost estimates of the impact of dengue at the household level focus on the families of individuals who test positive for dengue (see Beatty, Beutels, and Meltzer, 2011 and Shepard, Halasa, and Undurraga, 2014 for reviews). However, the impacts of an epidemic on household labor market outcomes may extend beyond households who experience illness. Individuals may increase their labor supply in anticipation of or in response to increased healthcare costs for their family. Alternatively, individuals may stay home to prevent themselves from getting sick, to care for other family members who stay home, or to take protective measures to control the mosquitoes that spread the disease. Changes in labor demand during epidemics due to decreased tourism rates may also affect work hours regardless of family health. This research contributes to the literature on dengue epidemics as well as the infectious disease literature more broadly by assessing the impact of epidemics on the labor market outcomes of all households in an affected region.

I use irregular fluctuations in dengue transmission that are plausibly exogenous to the household to assess the impact of epidemics on household labor market outcomes in the Amazonian city of Iquitos, Peru. I rely on data from the Peruvian National Household Survey (ENAHO) carried out by the Peruvian National Institute of Information and Statistics (INEI) from July 2005 to June 2010 (INEI 2015). The repeated cross-sectional data allows for the inclusion of controls for season, district, and year to isolate the impacts of unseasonably large dengue epidemics on labor market outcomes. I also estimate a difference-in-differences model utilizing the fact that epidemics occurred at the same time of year in 2005-2006 and 2007-2008, but not in 2006-2007. I estimate labor market outcomes for all primary males and females (household heads or spouses of heads) in the region.

One identifying assumption of the analysis is that, absent the occurrence of dengue epidemics, the outcomes of males and females surveyed during epidemics would have followed the same trend as the outcomes of males and females surveyed outside of the epidemics. I provide evidence that no change in survey implementation that might impact the results occurred during epidemics. The other identifying assumptions are that no other shock occurred during the dengue epidemics and that the intensity of each epidemic was not the result of a shift in the labor market. I provide evidence supporting these assumptions below.

I find that primary female residents decrease work hours by more than primary males during dengue epidemics, both in terms of point estimates and in percent changes relative to mean work hours. The weekly work hours of males who work more than 7 hours per week significantly decrease by around 3.3 hours, or 6.8% relative to the mean of approximately 48 hours per week, while the work hours of females who work more than 7 hours per week significantly decrease by about 6.9 hours, or 15.1% relative to the mean of approximately 46 hours per week. I find no evidence for a change in the probability that males or females work more than 7 hours per week during epidemics. I consider differences in the response of male and female work hours to epidemics based on household structure, illness reports, and economic status in order to isolate various labor supply and labor demand impacts through which epidemics may affect work hours.

The results show that labor market activities are restricted during epidemics, even among households that do not experience illness directly, indicating other mechanisms through which epidemics impact labor market activities such as avoidance behaviors or labor demand impacts. The results also indicate which members of society may be most susceptible to labor market restrictions during epidemics. I find that in most types of households, women are more affected than men. I also find that individuals in households with lower economic status are more affected during epidemics, regardless of gender. I conclude with a discussion of how the results inform intervention policies aimed at mitigating the negative impacts of dengue. I also discuss the implications of this work on future studies of the impacts of infectious disease epidemics at the household level.

II. Previous Literature on Infectious Disease and Labor Market Outcomes

Much of the recent literature on infectious disease within households pertains to the willingness to pay for, or the uptake of, various treatment or prevention technologies. The uptake and willingness to pay literature is reviewed by Dupas (2011) and is discussed in detail in Clayton (2015b). There is also an extensive literature on the impact of exposure to infectious disease in utero, infancy, or early childhood on educational and later life outcomes. The fetal origins literature is extensively reviewed by Bleakley (2010). However, neither the willingness to pay literature nor the fetal origins literature offer insight into the broader household-level impacts of infectious disease.

Many recent studies have attempted to assess the relationship between disease and income or household productivity. Studies assessing the cyclical link between income and health are typically conducted at the macro-level and display mixed results about the magnitude of the causal effect of health on income or vice versa (for example, French 2012; Datta and Reimer 2013). There are a few studies that look at the impact of malaria on agricultural productivity and rural income (for example, Asenso-Okyere et al. 2011; Kiiza and Pederson 2014). However, these studies are not directly applicable to understanding the household-level impact of dengue since dengue is an urban, rather than a rural disease.

There are many existing studies that attempt to measure the economic burden of various infectious diseases, including dengue, at both the national and household level.[19] A key issue with the existing literature is that the inclusion criteria for economic costs of disease vary widely from study to study and typically only focus on households who directly experience the illness in question. For dengue, many studies include medical expenses and lost hours of work or schooling among infected individuals and sometimes caregivers in their direct or indirect costs (Halasa, Shepard, and Zeng 2012). The same is true for literature on Malaria (i.e., Kiiza and Pederson 2014). Bleakley (2010) defines the indirect costs of infectious disease as reduced productivity or human capital development in terms of the intensity of labor or ability to achieve cognitive gains from education among infected individuals. All of these definitions of direct and indirect disease costs only assess the economic impacts of disease for infected individuals and possibly their families.

Some studies discuss the importance of additional indirect costs of dengue in terms of the overburdening of healthcare systems or the negative effects of disease transmission on tourism

[19] Beatty, Beutels, and Meltzer (2011) and Shepard, Halasa, and Undurraga (2014) offer detailed reviews of the literature estimating the economic burden of dengue.

(for example, Shepard, Halasa, and Undurraga 2014; Shepard et al. 2011). However, to my knowledge, no studies have attempted to incorporate broader community-wide impacts into household-level assessments of the economic burden of dengue. The same is true for the economic literature assessing the costs of other infectious diseases like malaria, hookworm, and the flu (for example, Asenso-Okyere et al. 2011; Bleakley 2007; Almond 2006). Studies that do assess the costs of disease for broader communities include government costs along with costs for infected individuals and their families, but still do not look at the effects experienced by households in the area who do not experience illness (for example, Halasa, Shepard, and Zeng 2012). By focusing on accurately identifying disease burden from a clinical standpoint rather than an economic standpoint, previous studies have thus failed to capture additional behavioral changes among individuals in an area affected by infectious disease outbreaks that may contribute to the economic burden of disease for households.

III. Research Location and Context: Dengue Transmission in Iquitos, Peru

This research relies on data collected in the city of Iquitos in northeastern Peru. With an estimated population of over 400,000 people, Iquitos is the largest city in the world that cannot be reached by road. It is bordered by the Amazon Rainforest and the Amazon, Itaya, and Nanay Rivers, making it an ecological island. The city of Iquitos comprises four districts (Iquitos, Punchana, Belen, San Juan Bautista) and lies within the Loreto region. **Figure 4.1** shows a map of the Loreto region and of the location of the city of Iquitos.

The labor market in Iquitos includes both formal and informal sectors. The city has fairly large commercial retail and financial sectors with banks and shopping malls in the city center.

International and domestic tourism comprises a large portion of the economic activity in Iquitos, and there are many hotels, restaurants, nightclubs, casinos and travel companies that employ local citizens. At the same time, there is an active informal labor market. It is common in Iquitos for people to provide taxi services with personal vehicles or to sell food or handicrafts at market stalls and within homes. I include both formal and informal labor in my analysis.

Iquitos has a tropical climate with year-round rainfall and warm temperatures, causing dengue to be continually transmitted at low levels. Still, the summer months (November to March) coincide with a significant increase in transmission. Warmer temperatures shorten the extrinsic incubation period that female *Aedes aegypti* mosquitoes undergo before being able to transmit the virus to humans (Scott and Morrison 2010). Dengue is then transmitted from mosquito to human more rapidly, increasing disease density. Stoddard et al. (2014) describe dengue transmission in Iquitos from July of 2000 to June of 2010. They define the peak transmission season as September to April with most activity occurring around December.

Although temperatures likely play a role in dengue transmission, Stoddard et al. (2014) find that dengue incidence varies both seasonally and across years for a variety of complex reasons. They describe that one likely cause of dengue epidemics is the introduction of a new serotype of the virus into the affected population. Dengue has four separate serotypes, and while contracting one provides lifelong immunity to that serotype, it provides only temporary immunity to the others. The introduction of a new serotype into a population in which very few people are already immune to it can then lead to a larger-than-average dengue outbreak. The introduction of a new serotype can occur when even a small number of infected humans travel into the area and are bitten by local mosquitoes, which then transmit the disease to local human populations.[20] Although not all causes of dengue transmission at epidemic levels are known, it seems likely that the occurrence of a dengue epidemic constitutes an arguably exogenous shock to households.

The scope of the direct human health impacts of dengue in Iquitos in terms of symptomatic dengue cases is often small. **Figure 4.2** shows the moving 4-week average of the number of reported dengue cases in Iquitos from 2005 to 2010 as reported in Stoddard *et al*. (2014).[21] The sample probably only captures about 40% of the Iquitos population since only individuals who come to one of six reporting clinics in the area for treatment are observed.[22] Stoddard *et al*. further note that participation was not complete among the sample population. Still, the largest number of annually reported cases during the research period is 825 from mid-2008 to mid-2009, representing approximately 0.55% of the estimated sample population.[23]

Despite the relatively small (in scale) human health impact of dengue in Iquitos throughout the study period, epidemics elicit a large response within the community. The Loreto Regional Health Department (LRHD) often responds to dengue epidemics with widespread intra-household adulticide spraying campaigns to control mosquito populations. Throughout the

[20] Amy C Morrison, personal correspondence

[21] I smooth the data on dengue transmission over 4 week increments to account for sharp weekly fluctuations that do not reflect overall transmission patterns. I use the period of 4 weeks to match household survey data on individual illness reports (INEI 2015).

[22] Clinical data only capture symptomatic cases and Bhatt *et al*. (2013) estimate that symptomatic dengue cases represent approximately 40% of all dengue infections due to the prevalence of asymptomatic cases.

[23] The largest epidemic in Iquitos occurred from October 2010 to February 2011 and is not captured in the data. Over 23,000 cases were reported, representing approximately 14% of the population (assuming about 40% of the population was sampled). Over 3,000 of the cases were symptomatic (about 2% of the population), 104 of which were severe (about 0.03% of the population), and 22 of which resulted in death (Amy C. Morrison, personal correspondence). In comparison, during the epidemic of H1N1 flu in the United States in 2009, there were 60.8 million cases, representing approximately 19.82% of the population, 274,304 hospitalizations, or 0.09% of the population, and 12,469 deaths (Shrestha et al. 2011).

study period, each campaign reached about 30,000 to 50,000 homes out of the approximately 80,000 homes in the city (Stoddard et al. 2014). The campaigns are highly visible due to their scale and because they entail the LRHD entering each home three times over the course of about three weeks. All households in the area are therefore likely to be aware that a dengue epidemic is occurring regardless of whether or not their members contract the disease.

IV. Potential Response of Labor Market Outcomes to Dengue Epidemics

In this research, I focus on the impacts of dengue epidemics on the labor market outcomes of primary male and female household residents. Dengue epidemics could cause changes in labor demand and labor supply and may differentially affect men and women. For example, gender roles may dictate who is responsible for caring for sick family members (more likely among females) or for providing family members with transportation to a health clinic (more likely among males). Gender roles might also determine an individual's employment opportunities and different occupations may be differentially affected during epidemics in terms of labor demand.

Dengue epidemics are likely to decrease tourism rates (Shepard, Halasa, and Undurraga 2014). Labor demand may then decrease during epidemics for those whose occupation is heavily reliant on tourism, including many of those in the services sector like market vendors, restaurant workers, hotel employees, and tour guides. National statistics indicate that females are far more likely to work in the services sector compared to males. The percentage of working females in Peru who reported being employed in the services sector was around 61.3% in 2005 and 66.6% in 2010. In contrast, the percentage of working males who reported working in the services sector was only about 45.8% in 2005 and 48.7% in 2010 (International Labour Organization 2015). It may therefore be the case that work hours among females who work positive hours are more negatively affected during dengue epidemics compared to males, regardless of potential responses in labor supply.

Regarding the impact of dengue on labor supply, household labor and/or health behaviors may be affected during a dengue epidemic regardless of whether or not their members contract dengue. For example, people may increase their labor supply in anticipation of a health shock to their family. Alternatively, people may stay home as an act of caution to prevent themselves from contracting dengue[24] or to take actions to protect their household from the mosquito that spreads the disease. People may also be more likely to consider the illness of a household member serious enough to require that family members stay home to care for them or to take them to a health care facility during a dengue epidemic. Later in the paper, I analyze heterogeneous responses among primary male and female work hours to epidemics based on household structure, illness reports, and economic status in order to isolate the various mechanisms discussed here.

V. Data Description

Using data reported in Stoddard et al. (2014), I focus on dengue transmission between July 2005 and June 2010 in the city of Iquitos, Peru. I merge the weekly transmission data with

[24] Research has suggested that the entomological risk of contracting dengue is at the household level (Scott and Morrison 2003). However, human transportation is also said to play a key role in dengue transmission (Magori et al. 2009). It is therefore unclear whether staying home would prevent one from contracting dengue or not.

household level data from the ENAHO survey carried out by the INEI (INEI 2015).[25] The INEI attempts to maintain a representative sample of the national population each year. They survey a random selection of households within pre-defined survey areas to ensure that all geographic areas throughout the country are covered.[26] They randomly select households each year, making the sample a repeated cross-section, rather than a panel.[27]

Table 4.1 shows the number of household-level observations in the sample, broken down by household type. The full pooled sample includes 1,844 household-level observations. Each observation includes data on all household residents, including the primary male and female resident (when one is present), where the term 'primary resident' refers to either the household head or the spouse of the head. I separately analyze all primary male and female residents in the sample as well as single male and female household heads, and primary male and female residents in dual-headed households. The majority of households in the sample are dual-headed households, comprising about 1,288 observations. Single female household heads are almost twice as prevalent as single male heads, with 360 versus 196 observations.

Dengue transmission patterns in Iquitos from July 2005 to June 2010 are shown in **Figure 4.2** while **Table 4.2** provides the mean and standard deviation of key independent and control variables for the analysis. The average number of dengue cases reported in the past 4 weeks is

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[25] The ENAHO data are available from 2004 to 2013 but the dengue transmission data are only available until June 2010 and there are issues of missing ENAHO data in 2004. There were also issues with the inflation of reported transmission data during 2004 because of a clinic remaining open for extended hours to accommodate a larger number of incoming dengue cases during the 2004 epidemic (Stoddard et al. 2014). I therefore focus my research on data from July 2005 to June 2010.

[26] **Table A.1** in the appendix shows the distribution of household observations across trimesters, fiscal years, and districts. The sample is fairly evenly distributed across trimesters and years. The proportion of the sample from each district is not evenly distributed but generally reflects differences in population level.

[27] There is a limited panel component to the sample, with 112 intentionally repeated household observations that I remove to maintain a random sample. Including the repeated observations does not alter the findings.

about 11. Based on mean reported cases, I determine epidemic levels of transmission to be greater than 12 cases on average over the past 4 weeks.[28] About 24% of observations within the sample are collected during epidemic periods of dengue transmission based on the 12 case threshold. Large epidemics occurred in 2005-2006, 2007-2008, and 2008-2009, with a smaller epidemic occurring in 2009-2010. Dengue transmission decreased for about an 18 month period between the epidemic ending in early-2006 and the one beginning in late-2007.

The ENAHO survey collects household demographic information including the age, gender, and education of all household residents. The average number of household residents in the Iquitos sample is about 5.5. About 80.5% of households have a primary male resident and about 89.4% of households have a primary female resident. About 50.8% of households have other income earners and about 50.1% of include children under the age of 5. The average age of primary male residents is about 46.5 years and the average educational attainment of primary males is about 9.5 years. The average age of primary female residents in the sample is about 3 years less than that of primary males and the average educational attainment of primary females is about 1 year less than that of primary males.

The ENAHO survey also collects detailed information on the number of hours worked for pay in the last week by each resident. Survey respondents are asked about their primary occupation and about whether or not they carry out any other activities to generate income. Total work hours in formal or informal labor market activities are capped at 98 per week.

[28] The results are fairly robust to altering the threshold for epidemic dengue transmission within 1 to 2 cases per week on average. Altering the epidemic threshold by 3 or more cases per week on average weakens the results since periods of epidemic transmission are lumped with periods of non-epidemic transmission (results available upon request). Based on the strength of the results at various threshold levels and the pattern of transmission provided in **Figure 2**, I conclude that a threshold of 12 cases per week on average is appropriate.

Figure 4.3 shows the distribution of primary male and female work hours within the sample. While there are individuals who do not work to generate income at all, the distribution of work hours is relatively Gaussian normal for males who work more than 7 hours per week and is slightly right-skewed for females, indicating a lower number of weekly work hours on average. Average weekly work hours and the probability working more than 7 hours per week are reported in the results tables for primary males and females. However, **Table 4.2** does indicate that females are more likely to participate in the informal rather than the formal labor market compared to males. About 6.8% of primary females who work report working claim to work in the informal labor market compared to only about 1.2% of primary males.

The ENAHO survey collects information on physical housing traits including durable goods ownership and the quality of housing construction materials. I use the physical housing traits to construct an economic index for each household (Clayton, 2015b). The survey also asks whether or not each resident experienced an illness in the past four weeks and, if so, how many days they were unable to carry out their normal activities, although the survey does not specify the type of illness experienced. I use the physical housing traits and household illness data later in the paper to test for variations in the household response to dengue epidemics based on household economic status and illness experiences. The data are discussed in greater detail in **Section VIII**.

VI. Empirical Specification

VI.1. Fixed Effects Estimation

I estimate changes in the paid weekly work hours and the probability of working over 7 hours per week for both primary male and female residents during dengue epidemics in Iquitos between July 2005 and June 2010. I utilize ordinary least squares (OLS) regression and include fixed effects for district, month, and year. The independent variable of interest is an indicator for the occurrence of dengue epidemics.[29] The identification strategy is valid if 1) household labor market outcomes do not affect the occurrence of dengue epidemics, 2) there are no other confounding factors that occur at the same time as the dengue epidemics that may also affect labor market outcomes, and 3) the work hours of males and females surveyed during epidemics would have followed a similar trend as those of males and females surveyed outside of epidemics, where it not for the occurrence of the epidemics.

I have already argued the exogeneity of dengue epidemics at the household level above. At the city level, it may be the case that increases in tourism increase the risk of dengue epidemics occurring as people from outside of the city can bring in new serotypes of the disease. If anything though, this would only dampen results indicating negative labor demand impacts from decreases in tourism during epidemics.

To help address the second identifying assumption, I include controls for potentially confounding factors. I include district-level fixed effects to capture time-invariant differences between household labor market outcomes across districts. I also include indicators for year to

[29] Results analyzing continuous or count data on the number of dengue cases (available upon request) do not offer additional insight to the effect of dengue transmission on labor market activities as the impacts appear to stem from a threshold effect at epidemic levels of transmission.

account for changes in labor market outcomes over time, and controls for season to capture regular fluctuations in labor market outcomes due to seasonal influences (*i.e.*, seasonal employment) external to changes in dengue transmission. I further discuss other potentially confounding factors (weather, labor strikes, and other diseases) in the appendix.

The third assumption is largely addressed by the irregular fluctuations in the occurrence of dengue epidemics throughout the study period and by the included controls for district, season, and year. I also provide evidence in the appendix that there are no changes in survey implementation or participation during epidemics that might cause sampling bias.

The fixed-effects regression for estimating the impact of dengue epidemics on household labor market outcomes is defined in **Equation 1**.

$$(Labor\ Market\ Outcome)_{igst} = \alpha + \boldsymbol{\beta X_{igst}} + \delta\ (DengueEpidemic)_{igst} + \sum_{\tau=2}^{5} \theta_{\tau} (Fiscal\ Year)_{igst}^{\tau} + \sum_{\sigma=2}^{3} \pi_{\sigma} (Season)_{igst}^{\sigma} + \sum_{\gamma=2}^{4} \mu_{\gamma} (District)_{igst}^{\gamma} + \varepsilon_{igst}\ , \quad where \quad (Fiscal\ Year)_{igst}^{\tau} = \begin{cases} 1\ if\ t = \tau \\ 0\ if\ t \neq \tau \end{cases} \quad t = 2, \ldots, 5\ , \tag{1}$$

$$(Season)_{igst}^{\sigma} = \begin{cases} 1\ if\ s = \sigma \\ 0\ if\ s \neq \sigma \end{cases} \quad s = 2, 3\ , \quad and \quad (District)_{igst}^{\gamma} = \begin{cases} 1\ if\ g = \gamma \\ 0\ if\ g \neq \gamma \end{cases} \quad g = 2, \ldots, 4\ .$$

The dependent variable, $(Labor\ Market\ Outcome)_{igst}$, measures, in different specifications, the paid weekly work hours of primary male and female residents and the probability that each works more than 7 hours per week within household *i* in district *g* during season *s* and year *t*. The vector $\boldsymbol{X_{igst}}$ represents the set of demographic and economic characteristics of household *i* in district *g* during season *s* and year *t* described in **Table 4.2**. The independent variable of interest, $(DengueEpidemic)_{igst}$, is equal to 1 if there are more than 12 reported dengue cases per week on average over the 4 weeks preceding the survey date for household i in district g during season s and year t.

The dummy variables $(Fiscal\,Year)_{igst}^{\tau}$ control for changes in household labor market outcomes across fiscal year (July-June). The dummy variables $(Season)_{igst}^{\sigma}$ capture regular seasonal fluctuations in labor market outcomes, where seasons are differentiated by calendar year trimesters.[30] The dummy variables $(District)_{igst}^{\gamma}$ control for time-invariant differences in labor market outcomes across the four districts of Iquitos. The variable $(DengueEpidemic)_{igst}$ thus isolates the impact of dengue epidemics on labor market outcomes. The last term, ε_{igst}, is the error term.

VI.2. Difference in Differences Estimation

Although the timing and duration of dengue epidemics varies throughout the study period, there is recurring seasonal variation in transmission patterns. Epidemics also occur with greater frequency in later years. One might then worry that despite the inclusion of controls for season and year in the fixed-effects regressions above, any apparent impact of dengue epidemics on labor market outcomes might actually reflect seasonal variations or changes in labor market outcomes over time. Additionally, there is seasonal variation in survey collection across districts. Even when district controls are included, if districts with lower average labor market participation are more likely to be surveyed during seasons when dengue epidemics are more

[30] Calendar-year trimesters are used based on climatic variation in Iquitos (Stoddard et al. 2014). Differentiating seasons based on calendar-year trimesters also prevents the season dummy variables from being collinear with the fiscal-year dummy variables. Results are robust to varying the specification of seasonality or to removing the seasonality dummies (results available upon request).

probable, differences in labor market outcomes during epidemics might also be driven by district-level variation in the sample across seasons.

To further control for potentially contemporaneous effects from variations in season, district, or time, I carry out a difference-in-differences (D-D) regression on the impact of dengue epidemics on labor market outcomes for the Iquitos sample from July 2005 to June 2008. Epidemics occurred around the same time of year and for similar durations in 2005-2006 and 2007-2008 while transmission remained low throughout 2006-2007. I can therefore compare labor market outcomes among households surveyed during the same time of year in years when there is and is not an epidemic. This differs from the fixed effects estimation above, which assesses differences in labor market outcomes among households surveyed during versus outside of epidemics that occur at various times of year and at varying frequencies and durations.

Figure 4.4 shows dengue transmission from July 2005 to June 2008. The period of time to be compared across years, about December through March, is outlined in red. The control group is comprised of the households that are surveyed during months when dengue epidemics never occur (April through November). The treatment group consists of the households that are surveyed from December to March of any survey year, since epidemics occurred in the 2005-2006 and 2007-2008 survey years during these months. The treatment is then the epidemics that occur in 2005-2006 and 2007-2008.[31]

[31] The assessed time of year does not perfectly capture epidemic levels of dengue transmission at the beginning and end of the 2005-2006 and 2007-2008 epidemics since the epidemics do not occur over the exact same weeks in each year. If anything though, the fuzzy specification of dengue epidemics should weaken the results, making significant coefficients all the more convincing.

In analyzing households surveyed at the same time of year in epidemic and non-epidemic years, I remove concerns that the results are driven by seasonal patterns in survey collection or in the probability of dengue epidemics occurring. Because the non-epidemic period is both preceded by and followed by epidemics, concerns about results being driven by time trends are also alleviated. The specification is valid as long as there are not events that might affect household work hours that occur in either 2005-2006 or 2007-2008 at the same time as the dengue epidemics and that also do not occur in 2006-2007.

The D-D regression for estimating the impact of dengue epidemics on labor market outcomes is defined in **Equation 2**.

$$
\begin{aligned}
&(Labor\ Market\ Outcome)_{igt} \\
&\quad = \alpha + \sigma\,(Dengue\ Season)_{ig} + \gamma_1\,(FY\ 2005-2006)_{ig} + \gamma_2\,(FY\ 2007-2008)_{ig} \\
&\quad + \delta_1\,[(Dengue\ Season) \times (FY\ 2005-2006)]_{ig} \\
&\quad + \delta_2\,[(Dengue\ Season) \times (FY\ 2007-2008)]_{ig} + \sum_{\gamma=2}^{4} \mu_\gamma (District)_{igt}^{\gamma} + \boldsymbol{X_{igt}}'\boldsymbol{\beta} + \mu_{igt}\,, \qquad (2) \\
&\quad where\quad (District)_{igt}^{\gamma} = \begin{cases} 1\ if\ g = \gamma \\ 0\ if\ g \neq \gamma \end{cases}\ g = 2, \dots, 4\,.
\end{aligned}
$$

The dummy variable $(Dengue\ Season)_{ig}$ indicates that household *i* in district g was surveyed during the months in which there were dengue epidemics in 2005-2006 and 2007-2008, around December to March. The variable captures households surveyed from December to March in every survey year. The dummy variables $(FY\ 2005-2006)_{ig}$ and $(FY\ 2007-2008)_{ig}$ indicate that household *i* in district *g* was surveyed during a fiscal year in which there was an epidemic. The interaction terms $[(Dengue\ Season) \times (FY\ 2005-2006)]_{ig}$ and $[(Dengue\ Season) \times (FY\ 2007-2008)]_{ig}$ capture the impact of being surveyed during a dengue epidemic (December to March of 2005-2006 or 2007-2008) compared to being surveyed during non-epidemic weeks in the non-epidemic fiscal year. The coefficients δ_1 and δ_2 thus estimate the effect of dengue epidemics on household labor market outcomes.

The $(District)_{igt}^{\gamma}$ dummy variables capture time-invariant differences in labor market outcomes across the four districts of Iquitos. The vector $\boldsymbol{X_{igt}}$ represents a set of demographic and economic characteristics of household *i* in district *g* and year *t*. The last term, μ_{igt}, is the error term for household *i* in district *g* and year *t*. I do not include year or seasonal controls, in part because the specification already controls for variations in season and year. Also, Bertrand, Duflo, & Mullainathan (2002) point out that the error terms in longitudinal D-D analyses are serially correlated, causing the statistical significance of findings to be overstated. They find that, with a small number of comparison groups, the best solution to the serial correlation problem is to pool the sample, ignoring the longitudinal aspects of the data.

VII. Results

VII.1. Fixed-Effects Estimation

Table 4.3 and **Table 4.4** provide the main fixed-effects results on the labor market outcomes of all primary male and female residents, respectively. The initial regressions are estimated for all households with a primary male or female resident. The means of each dependent variable are reported at the top of the tables. Primary males work more hours on average and are more likely to work more than 7 hours per week compared to primary females. The average weekly work hours of all primary males in the sample is about 39 while the average of primary females is about 24. About 81.4% of primary male residents in the sample work more than 7 hours per week for pay compared to only about 50.9% of primary females. Among those who do work more than 7 hours per week, the average work hours of males is about 48 hours while the average for females is about 46 hours.

The results indicate that during a dengue epidemic, primary females decrease work hours by a substantially larger amount than males, both in terms of the point estimate and in percentage terms relative to mean hours.[32] The occurrence of a dengue epidemic is associated with a weakly significant decrease of about 3.4 work hours for primary male residents, representing approximately an 8.6% decrease relative to mean hours. Female work hours decrease significantly by about 5.1 hours, representing approximately a 21.4% decrease relative to mean hours. Neither males nor females display statistically significant changes in the probability that they work more than 7 hours per week during dengue epidemics.[33]

Among those who do work more than 7 hours per week, the decrease in work hours among primary females during dengue epidemics is over twice that of primary males. The decrease in work hours during dengue epidemics among primary males who work more than 7 hours per week is similar to the decrease for the full sample, at about 3.3 hours, but it constitutes a smaller change relative to mean hours, representing a 6.8% decrease. Primary female work hours decrease significantly by about 6.9 hours which, compared to mean work hours, represents a change of about 15.1%.

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[32]Reported results are based on non-clustered standard errors. Results are robust to the clustering of standard errors by district and by year (results available upon request).

[33] Probit regressions of the impact of dengue epidemics on the probability of working more than 7 hours per week confirm the reported results (results available upon request). The findings are also robust to altering the threshold at which primary male and female residents are determined to work positive hours.

Regarding other control variables, the presence of another primary resident who works more than 7 hours per week is associated with significantly fewer work hours and a lower probability of working for both males and females. The presence of other income earners in the household has no significant association with work hours or the probability of working. If anything, the presence of children younger than five is associated with decreased work hours and a lower probability of working for both males and females, although the coefficients are mostly insignificant. Work hours and the probability of working more than 7 hours per week are both quadratic in age for males and females. Years of education are not significantly related to male work outcomes, but are associated with a significantly higher probability of working for females and with fewer work hours for those who work more than 7 hours. I do not report the results of household demographics in the rest of the results tables; they are included in all regressions unless otherwise specified (results available upon request).[34]

VII.2. Difference-in-Differences Estimation

Tables 3.5-3.6 show the same results as **Tables 3.3-3.4**, but with the difference-in-differences specification described in **Equation 2**. The results indicate that work hours are generally increasing over time and tend to be higher during the time of year in which dengue epidemics occur if there is no epidemic. Primary male work hours for those who work more than 7 hours per week decrease by about 3.5 hours during the 2005-2006 and 2007-2008 epidemics, with weak statistical significance in both cases. Female work hours for those who work more than 7 hours per week decrease by about 6.1 hours and 4.7 hours during the 2005-

[34] Results are robust to altering the inclusion of various household demographic control variables.

2006 and 2007-2008 epidemics respectively, again with weak statistical significance in each case. Results are expectedly weaker for all primary males and females, including those who do not work, and dengue epidemics have no significant impact on the probability that males or females work more than 7 hours per week. Although not always statistically significant, the difference-in-differences results support the main fixed-effects results.

VIII. Heterogeneous Response to Dengue Epidemics

The initial results show that dengue epidemics correspond with substantially larger and more statistically significant decreases in the paid weekly work hours of primary female residents compared to males. However, the results do not describe how the response of primary male or female work hours to dengue epidemics might vary based on the number of primary residents in the household and their respective work hours. Furthermore, the driving mechanisms for the changes in work hours among males and females are yet to be determined and need to be tested with additional analyses. Here, I analyze the impact of dengue epidemics on male and female work hours for those who work more than 7 hours per week taking into account differences in household structure, illness experiences, and economic status. The theory, data, and results for each analysis are discussed in turn.

VIII.1. Household Structure

It seems likely that primary males and females may respond differently to dengue epidemics in terms of work hours based on the presence of another primary resident and the work hours of that individual. **Table 4.7** shows the mean of the included control variables for the samples of single male and female household heads and for dual-headed households.

Household attributes vary largely based on household structure. Average household size is smaller in households with single male heads, about 3 residents, than it is for households with single female heads, about 5 residents, and for dual-headed households, about 6 residents. Only about 17.9% of households with single male heads have children under the age of 5, compared to about 45% of households with single female heads and about 56.4% of dual-headed households. The average age of single male heads is about 2.5 years higher than that of primary males in dual-headed households and the average years of education among single male heads is about .5 years lower. The average age of single female heads is over 10 years higher than that of primary females in dual-headed households while the average educational attainment is also about .5 years lower.

Primary males in single-headed households and in dual-headed households have nearly the same probability of working more than 7 hours per week, but males in dual-headed households are over twice as likely to work in the informal rather than the formal labor market. In contrast, single female heads are over 10 percentage points more likely to work more than 7 hours per week than primary females in dual-headed households, but are only about 2 percentage points less likely to work in the informal rather than the formal labor market. The probability that other income earners are present is highest among single female headed households, at about 66.9%, compared to 47.7% in dual-headed households and 41.3% in single male-headed households.

Table 4.8 shows the impact of dengue epidemics on work hours for primary males and females who work more than 7 hours per week in various types of households and shows differing changes in work hours during epidemics based on household structure. Single male heads increase work hours by over 8 hours during epidemics, though the coefficient is not significant. The sample of single male heads is small though, at 160 observations. Primary male residents in households with a primary female who works less than 7 hours per week significantly decrease work hours by about 5.6 hours. Primary males in dual-earner households where the primary female also works more than 7 hours per week decrease work hours by about 3.2 hours, though again the coefficient is not statistically significant.

Work hours among single female household heads display opposite changes during epidemics than those of single male heads, with female work hours decreasing with weak statistical significance by about 8.9 hours. This constitutes a decrease of about 18.1% relative to mean work hours, which is also almost equal in magnitude to the increase in work hours among single male heads. Primary females in households with primary males who work less than 7 hours per week do not display significant changes in work hours during epidemics. The decrease in work hours among primary females in dual-earner households is substantially larger and more statistically significant than that of primary males. Females significantly decrease work hours by about 8.1 hours. Relative to mean hours, this constitutes about an 18% decrease, compared to an insignificant decrease of about 6.7% among males.

The heterogeneous responses of primary male and female work hours to dengue epidemics based on household structure are intriguing and pose additional questions about the mechanisms through which epidemics affect work hours. Overall, it appears as though primary females decrease work hours by a larger extent than primary males during epidemics. However, the results for males and females who are the only primary earner in a dual-headed household differ, with males decreasing work hours by a larger and more significant amount than females.[35] Because it is common for male residents to work in Iquitos, households with primary males who do not work may be more likely to be experiencing financial difficulties. The work hours of primary females in these households may be more necessary for maintaining family income and may be less able to respond to epidemics. In any case, the results suggest varying labor supply effects among males and females that need to be explored further.

VIII.2. Household Illness Reports

I next consider the influence of household illness reports on the impact of epidemics on work hours. Male and female residents may respond differently to personal illness or to the illness of other household residents during an epidemic. For example, the gender roles of an individual may make them responsible for caring for sick family members (more likely among females) or for providing family members with transportation to a health clinic (more likely among males). I test for different responses by looking at the work hours of primary males and females who have family members who report experiencing illness versus those in households that do not report experiencing any illness at the time of the survey.

The ENAHO survey collects information on whether each resident experienced an illness in the past four weeks and, if so, how many days they were unable to carry out their normal activities. The survey does not specify the type of illness experienced. The lack of specificity regarding illness is not likely to present a problem in the analysis for two main reasons. First, general illness reports will include some dengue illness and may actually capture more dengue cases than clinically confirmed data since many patients do not seek treatment for non-severe

[35] Regressions analyzing the impact of dengue epidemics on the difference between primary male and female work hours in dual-headed households yield insignificant results (results available upon request).

manifestations of the virus. Second, it may be that households respond more strongly to a member contracting a febrile illness during dengue epidemics regardless of whether or not that individual has dengue.

Table 4.9 shows the probability that various household members report experiencing illness during and outside of dengue epidemics for all primary male and female residents and for dual-earner households. Because of sample size restrictions, I do not assess single male or female-headed households. Illness within households is frequent throughout the study period with between around 69% and 76% of household observations in each sample indicating that at least one resident experienced illness in the past 4 weeks. About 55% to 61% of households report that a dependent resident experienced illness in the past 4 weeks. Primary females are more likely to report experiencing illness than primary males with about 30% of females and about 23% of males reporting experiencing illness in dual-earner households.

The percentage of household members that report experiencing illness does not change significantly during dengue epidemics. The summary probabilities suggest that, if anything, illness reports decrease during epidemics. The apparent decrease in reporting is probably driven by the fact that dengue epidemics occur more frequently in later years of the sample period and illness reports are decreasing over time. OLS and probit regressions confirm that dengue epidemics do not have a significant impact on household illness reports (results available upon request).However, it may still be the case that residents respond differently to household illness during epidemics than they would outside of an epidemic.

Table 4.10 shows the impact of the interaction of dengue epidemics with reports of household illness on primary male and female weekly work hours. The work hours of males and females do not change significantly in correspondence with household illness reports outside of epidemics. In contrast, both male and female work hours decrease significantly by about 6 and 5 hours respectively for the samples of all primary males and females during epidemics when at least one member of the household reports experiencing illness. Among dual-earner households, work hours significantly decrease by about 8.5 hours among primary males and about 6.5 hours among females. While primary males decrease work hours more than females in terms of point estimates, the percent changes among males and females based on mean work hours do not differ substantially; the decrease in male hours is larger by about 2 percentage points. The results may contradict the theory that primary female residents are exclusively responsible for caregiving activities when household members are sick. It is also possible that primary male residents provide their family with transportation to healthcare facilities as not many women in Iquitos drive cars or motokars (motorized rickshaws).

Females decrease work hours by about 8 hours during dengue epidemics when no household members report experiencing illness in both samples of working primary females. For all primary females, the result is significant at the 5% level and for females in dual-earner households; the result is significant at the 10.7% level. The decrease in female work hours during epidemics when no household members are sick may indicate avoidance behaviors among females in the form of taking actions to protect their home from mosquitoes. Families keeping their children home from school during epidemics to keep them from getting sick may also explain the results, since primary female residents are more likely to be responsible for childcare. Lastly, the unconditional decrease in female work hours during epidemics may indicate a labor demand effect since females in Peru are more likely to work in the services sector, which is more likely to be negatively affected by epidemics than other labor sectors. Unfortunately, I do not have usable data on regular school attendance or occupation type to further test the labor supply or labor demand hypotheses. Further research on the causes for work hour decreases during epidemics is needed.

VIII.3. Household Economic Status

There may also be heterogeneity in the response of households to dengue epidemics based on economic status.[36] As argued, the occurrence of dengue epidemics is plausibly exogenous to household behavior. Still, households in low or middle economic classes may be more susceptible to contracting dengue during an epidemic. Dengue is spread by the *Aedes aegypti* mosquito, which deposits its eggs in small containers like plastic tubs, flower pots, toilet bowls, and rubber tires (CDC 2014a). The mosquito may be more prevalent in households of low or middle economic status as they are more likely to possess discarded items in which the mosquito can lay eggs. Households of varying economic status may also have different responses to illness in terms of seeking medical treatment or changing their labor supply. Lastly, individuals in lower economic classes may be more likely to work in occupations that are heavily reliant on tourism, like transportation, market vending, or restaurant work, and therefore may be more likely to experience decreased labor demand during epidemics.

I test for heterogeneity in the response of labor market outcomes based on economic status by running separate analyses for households in each economic level. I split households into three economic classes using an economic index generated from observable physical

[36] I define economic status as the material standing of a household in terms of physical living conditions. See Clayton (2015c) for more details on this measure.

characteristics of the home via principal components analysis (PCA) (Clayton 2015c). I then divide households into classes based on the mean and standard deviation of the index scores.[37] **Table 4.11** shows the summary statistics for household weekly income, asset index score, and the percentage of households in each economic class for all working primary males and females and for dual-earner households. About 10% of observations in each sample are missing the physical housing characteristic data needed to construct an asset index. Dual-earner households are the wealthiest on average with a higher average weekly income and asset index score than the samples of all primary males and females.

Table 4.12 shows the results of separate regressions for all primary male and female residents and for primary males and females in dual-earner households at each economic level. The average work hours of all primary male residents are 4 to 5 hours higher for males in the middle and upper economic classes compared to the lowest economic class. For primary males in dual-earner households, average work hours are relatively similar across economic classes. Primary females in the highest economic class work about 4 to 5 hours less than females in the middle or lower economic classes among both the sample of all working primary females and of females in dual-earner households.

The work hours of primary male and female residents are not significantly associated with dengue epidemics for those among the highest economic class in any sample. Primary female work hours among the middle economic class decrease significantly during epidemics by about 10.9 to 11.2 hours. Primary male work hours among the same class decrease insignificantly by

[37] Results are robust to altering the thresholds of economic status (results available upon request).

about 3 to 3.5 hours. In contrast, male work hours among the lowest economic class weakly decrease by about 7 hours among all primary males and decrease significantly by about 23 hours among dual-earner households. Primary female work hours in the same economic class decrease insignificantly by about 3 to 5.5 hours.

The results indicate that primary males in the lowest economic class and females in the middle economic class are disproportionately affected by epidemics in terms of lost work hours. The results are consistent with the theory that lower to middle income households may be more susceptible to dengue transmission but could also be driven by changes in labor demand based on the proportion of men and women in each economic class whose work may rely heavily on tourism. Again however, I unfortunately do not have specific data on who contracts dengue or on occupation types in order to specifically test for the potential mechanisms discussed. Future research on the causes of differential impacts of dengue epidemics on labor market outcomes among various economic classes is needed.

IX. Conclusion

Dengue epidemics correspond to large decreases in the paid weekly work hours of both primary males and females. The results for all primary male and female residents suggest that females disproportionately respond during epidemics compared to males. The work hours of females decrease during epidemics by about 15.1% relative to mean work hours compared to only about a 6.8% decrease in male work hours relative to the mean. The results are confirmed through multiple fixed-effects and difference-in-differences analyses.

Results disaggregated by the presence of a sick individual in the household potentially indicate that both primary males and females participate in caring for sick family members during epidemics. Perceptions of disease risk also appear to increase during epidemics. While the probability of reporting illness does not change significantly during epidemics, both male and female work hours decrease largely and significantly in response to reports of household illness during epidemics and not in response to reports of household illness outside of epidemics. Primary female residents also significantly decrease work hours during epidemics when no household members report illness. The decrease in female work hours outside of household illness is potentially caused by labor demand impacts since females are more likely to work in the services sector, including jobs that depend on tourism, which are more likely to be negatively affected by dengue epidemics.

For both men and women, work hours decrease the most during dengue epidemics for those in the middle and lower economic classes. There may be increased risk of dengue contraction among households in low or average economic classes due to differences in home construction. There may also be different caregiving expectations of males and females in different economic classes. Lastly, the results may be driven by labor demand impacts as poorer individuals may be more likely to work in jobs that depend on tourism.

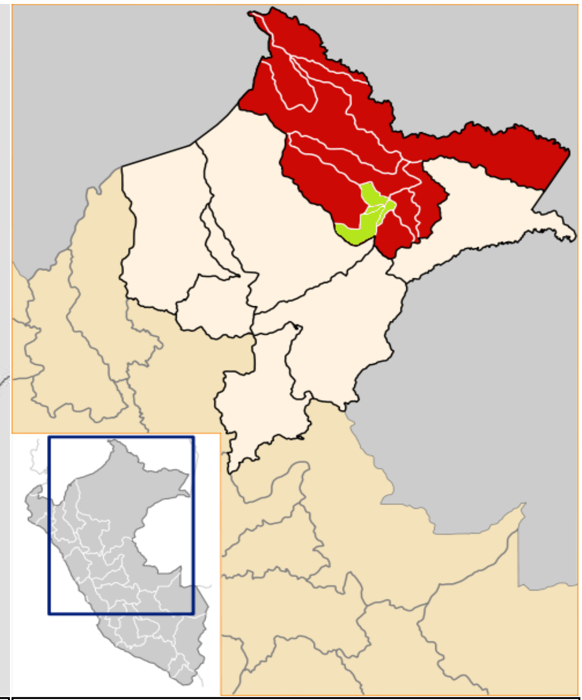
I find that primary male and female work hours decline during dengue epidemics, potentially due to changes in both labor supply and labor demand. Additional data could help disentangle the various mechanisms through which dengue affects household labor market outcomes. More detailed information on illness experiences and child school attendance could enhance the analysis of caregiving activities. Avoidance behaviors could be observed using data on the presence of containers capable of holding standing water, which are viable egg deposit sites for *Aedes aegypti* mosquitoes. A reduction in the number of risky containers in a household while male and/or female residents also report work hour reductions could indicate that residents take off work to protect their homes from mosquitoes. Labor demand impacts due to tourism reductions could be assessed with more detailed information on occupation types. Airline data could also indicate reductions in tourism to the city.

This research offers a substantial contribution to the existing literature on the economic burden of infectious disease by looking at changes in the labor market outcomes of all households in an area where epidemic disease transmission has occurred rather than focusing exclusively on the families of individuals who contract illness. The results suggest that ignoring changes in the labor market activities of other households in an affected area underestimates the economic burden of infectious disease epidemics.

The findings also have important implications for policymakers attempting to mitigate the negative impacts of dengue. The results suggest that mitigation efforts may have the greatest impact among females and among low-income households, as these individuals are most likely to experience large decreases in labor market activities during epidemics. The results further suggest that current government interventions aimed at reducing dengue transmission during epidemics may be detrimental to household labor market activity. Intra-household spray campaigns during epidemics are highly visible and, it has been argued, not highly effective at reducing dengue transmission (Esu et al. 2010). While spray campaigns offer a visible form of government intervention that might assuage the concerns of local citizens, they might also increase panic about epidemics, leading to greater labor market disruptions.

Researchers studying dengue transmission suggest that long-term interventions, such as those that encourage households to control mosquito egg deposit sites, would be more effective at keeping dengue transmission below epidemic levels (Morrison et al. 2008). My research, which finds that labor market impacts extend beyond those affected by illness during epidemics, suggests that mechanisms such as avoidance behaviors or labor demand impacts caused by increased perceptions of disease risk during epidemics play a key role in labor market reductions. The results then suggest that continuous interventions, which are less likely to insight panic during epidemics, might also reduce disruptions in household labor market activities during epidemics.

X. Tables and Figures



The Loreto Region of Peru	The Maynas Province in the Loreto Region of Peru (City of Iquitos highlighted in green)

Figure 4.1: Maps of the City of Iquitos, the Maynas Province, and the Loreto Region in Peru. The City of Iquitos lies within the Maynas Province which lies within the Loreto Region.
Image Source: Wikipedia

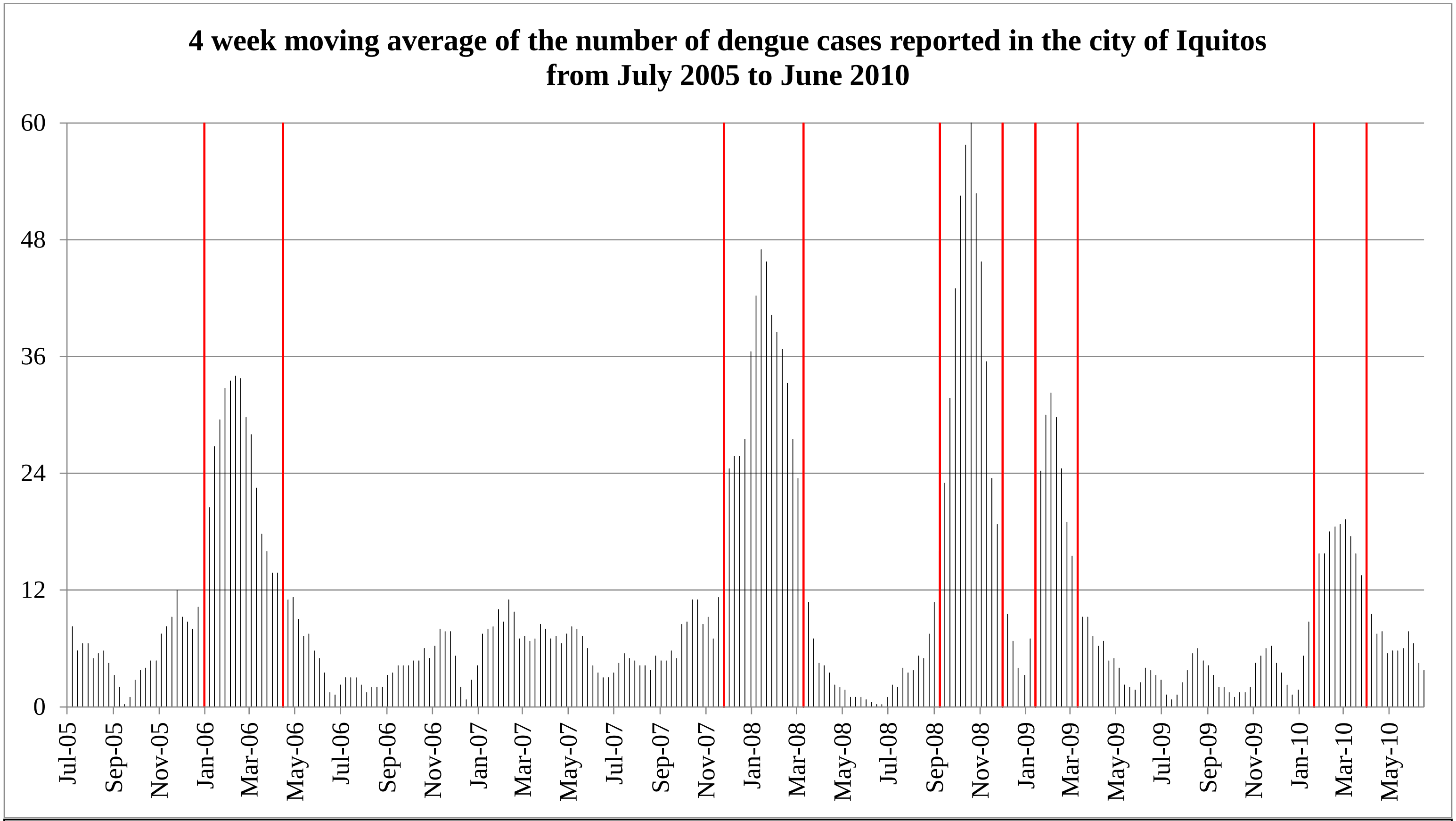


Figure 4.2: This figure shows the 4 week moving average of the number of reported dengue cases in Iquitos from July of 2005 to June of 2010. I consider more than 12 reported cases on average per week to indicate epidemic levels of transmission. The weeks are indicated in red. Data on reported dengue cases are from Stoddard, et al. (2014).

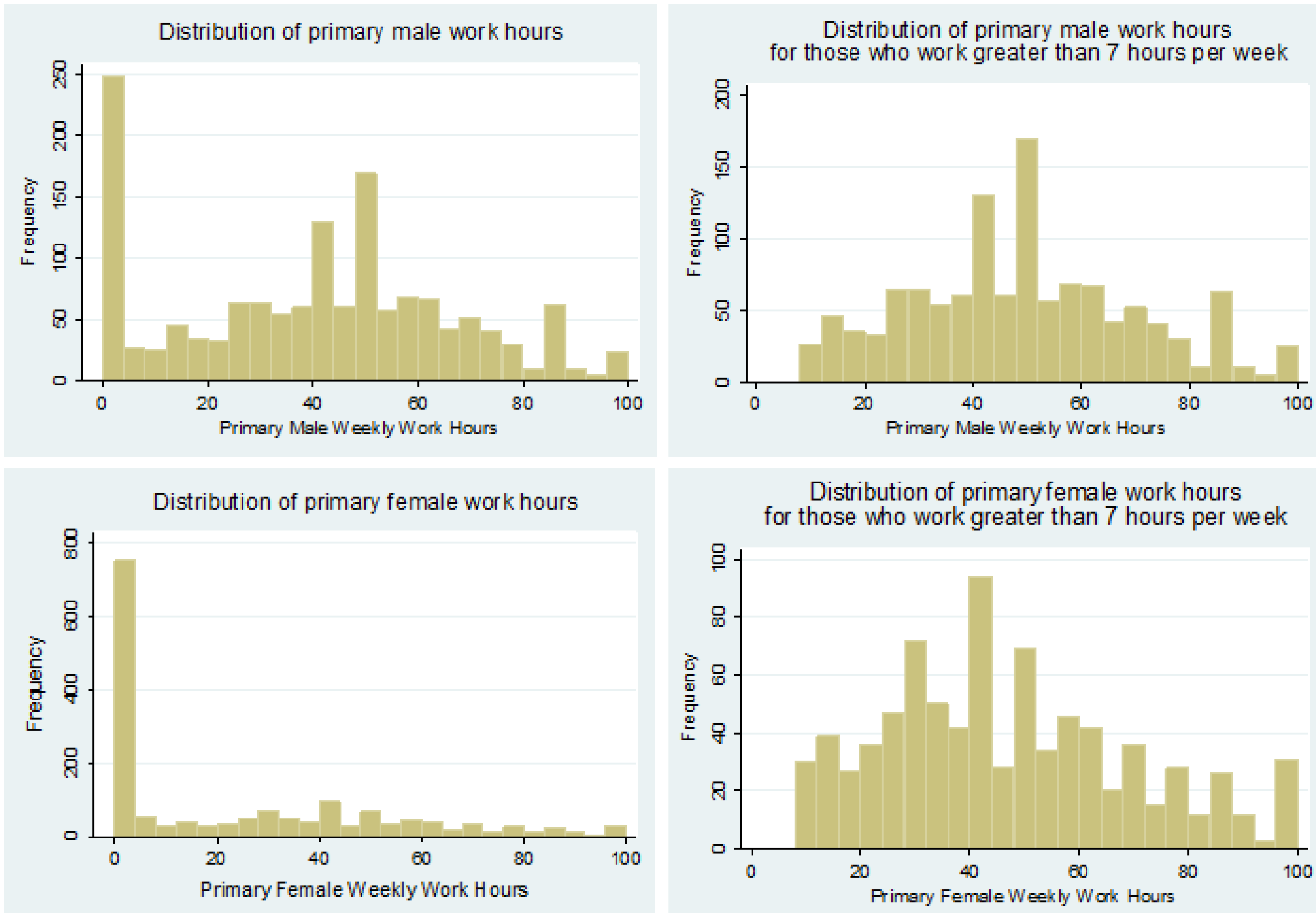


Figure 4.3: This figure shows the distribution of weekly work hours for all primary males and females and for primary males and females who work more than 7 hours per week for the sample of Iquitos from July 2005 to June 2010. The data are from the INEI ENAHO survey (INEI 2015).

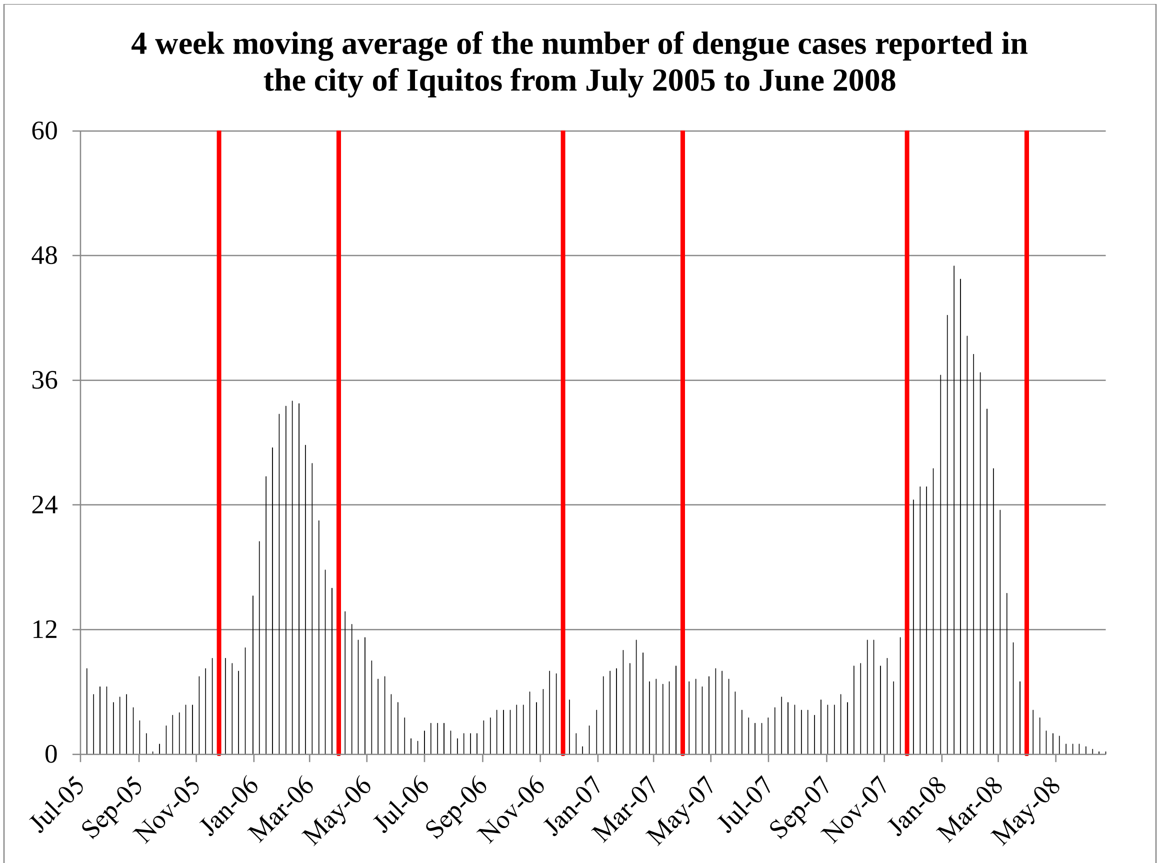


Figure 4.4: This figure shows the 4 week moving average of the number of reported dengue cases in Iquitos from July of 2005 to June of 2008. The weeks during which there were epidemics in 2005-2006 and 2007-2008 are indicated in red and are adjusted to cover the same time span in each year. Households surveyed during the span of weeks within red can be compared across epidemic and non-epidemic years via difference-in-differences regression. Data on reported dengue cases are from Stoddard, et al. (2014).

Table 4.1: Number of household observations for the sample population of Iquitos from July 2005 to June 2010

Type of Household	Number of Household Observations
All (including panel)	1,956
All (no panel)	1,844
With Both a Primary Male and Female	1,288
Single Female Head	360
Single Male Head	196

Data are from the INEI ENAHO survey from 2005-2010 (INEI 2015).

Table 4.2: Summary statistics of key independent and control variables for the sample of Iquitos from July 2005 to June 2010

	Full Sample	
	Mean	Stand. Dev.
Key Independent Variables		
Moving Weekly Average Number of Reported Dengue Cases in the Past 4 Weeks	10.952	(11.939)
Dengue Epidemic (1=Yes) (Threshold > 12 cases)	0.240	(0.427)
Control Variables		
Household Demographics		
Number of Household Residents	5.490	(2.811)
Primary Male Present (1=Yes)	0.805	(0.396)
Primary Female Present (1=Yes)	0.894	(0.308)
Other Income Earners Present (1=Yes)	0.508	(0.500)
Household has Children under the Age of 5 (1=Yes)	0.501	(0.500)
Primary Male Age (Years)	46.650	(13.941)
Primary Male Education (Years)	9.609	(4.263)
Primary Male Has Formal Occupation (1=Yes)	0.648	(0.478)
Primary Male Has Informal Occupation (1=Yes)	0.008	(0.087)
Primary Female Age (Years)	43.613	(14.025)
Primary Female Education (Years)	8.332	(4.505)
Primary Female Has Formal Occupation (1=Yes)	0.424	(0.494)
Primary Female Has Informal Occupation (1=Yes)	0.031	(0.175)
Observations	1844	

The data on the number of dengue cases are from Stoddard et al. (2014). The data on household information are from the INEI ENAHO survey from July 2005 to June 2010 (INEI 2015).

Table 4.3: Fixed-Effects regressions of the impact of dengue epidemics on primary male paid weekly work hours in Iquitos from July 2005 to June 2010

Sample:	All Primary Males	All Primary Males	All Primary Males who Work More than 7 hours per Week
Observations:	1,484	1,484	1,208
Dependent Variable:	Primary Male Weekly Work Hours	Primary Male Works More than 7 hours per Week (1=Yes)	Primary Male Weekly Work Hours
Mean of Dependent Variable:	39.373	0.814	48.228
Dengue Epidemic (1=Yes)	-3.370+	-0.016	-3.302+
	(-1.77)	(-0.58)	(-1.90)
Household Demographic Controls			
Number of Household Residents	-0.580+	-0.006	-0.387
	(-1.74)	(-1.33)	(-1.27)
Primary Female Works (1=Yes)	-2.898*	-0.069***	0.400
	(-2.12)	(-3.49)	(0.32)
Other Income Earners Present (1=Yes)	0.913	-0.013	2.086
	(0.56)	(-0.58)	(1.42)
Children Under Age 5 Present (1=Yes)	-0.758	-0.040+	1.358
	(-0.48)	(-1.74)	(0.95)
Primary Male Age (Years)	1.013***	0.023***	0.108
	(3.59)	(5.57)	(0.35)
Primary Male Squared Age (Years)	-0.015***	-0.000***	-0.002
	(-5.33)	(-7.72)	(-0.71)
Primary Male Education (Years)	-0.193	-0.002	-0.160
	(-1.07)	(-0.72)	(-0.96)
Included Controls			
Fiscal Year (July-June)	x	x	x
Season (Annual Trimester)	x	x	x
District	x	x	x
R^2	0.081	0.133	0.021
Adjusted R^2	0.070	0.123	0.007

t-statistics in parentheses: + p<0.10 * p<0.05 ** p<0.01 *** p<0.001. The data on the number of dengue cases are from Stoddard et al. (2014). The data on household information are from the INEI ENAHO survey from July 2005 to June 2010 (INEI 2015).

Table 4.4: Fixed-Effects regressions of the impact of dengue epidemics on primary female paid weekly work hours in Iquitos from July 2005 to June 2010

Sample:	All Primary Females	All Primary Females	All Primary Females who Work More than 7 hours per Week
Observations:	1,648	1,648	839
Dependent Variable:	Primary Female Weekly Work Hours	Primary Female Works More than 7 hours per Week (1=Yes)	Primary Female Weekly Work Hours
Mean of Dependent Variable:	23.674	0.509	46.044
Dengue Epidemic (1=Yes)	-5.076**	-0.039	-6.938**
	(-2.68)	(-1.15)	(-3.17)
Household Demographic Controls			
Number of Household Residents	-0.492	-0.007	-0.320
	(-1.51)	(-1.29)	(-0.86)
Primary Male Works (1=Yes)	-8.738***	-0.156***	-2.158
	(-5.81)	(-5.87)	(-1.31)
Other Income Earners Present (1=Yes)	1.525	0.027	-0.098
	(0.94)	(0.93)	(-0.05)
Children Under Age 5 Present (1=Yes)	-1.378	-0.013	-0.886
	(-0.86)	(-0.46)	(-0.49)
Primary Female Age (Years)	2.218***	0.041***	1.116*
	(7.90)	(8.27)	(2.58)
Primary Female Squared Age (Years)	-0.025***	-0.000***	-0.012*
	(-8.64)	(-9.05)	(-2.57)
Primary Female Education (Years)	0.060	0.014***	-1.036***
	(0.36)	(4.49)	(-5.44)
Included Controls			
Fiscal Year (July-June)	x	x	x
Season (Annual Trimester)	x	x	x
District	x	x	x
R^2	0.086	0.107	0.085
Adjusted R^2	0.077	0.098	0.066

t-statistics in parentheses: + p<0.10 * p<0.05 ** p<0.01 *** p<0.001. The data on the number of dengue cases are from Stoddard et al. (2014). The data on household information are from the INEI ENAHO survey from July 2005 to June 2010 (INEI 2015).

Table 4.5: Difference-in-Differences regressions of the impact of dengue epidemics on primary male weekly work hours in Iquitos from July 2005 to June 2008

Sample:	All Primary Males	All Primary Males	All Primary Males who Work More than 7 hours per Week
Observations:	886	886	722
Dependent Variable:	Primary Male Weekly Work Hours	Primary Male Works More than 7 hours per Week (1=Yes)	Primary Male Weekly Work Hours
Mean of Dependent Variable:	39.916	0.815	48.853
Interactions			
Dengue x FY 2005-2006	-2.528	0.008	-3.562
	(-0.99)	(0.23)	(-1.55)
Dengue x FY 2007-2008	-3.426	-0.010	-3.714
	(-1.35)	(-0.27)	(-1.59)
Dengue Season			
(omitted April-November)			
Yes (December-March)	1.043	-0.021	2.534
	(0.56)	(-0.79)	(1.50)
Fiscal Year (July-June)			
(omitted FY 2006-2007)			
FY 2005-2006	-1.559	0.034	-3.865
	(-0.56)	(0.86)	(-1.55)
FY 2007-2008	-0.257	0.002	-0.746
	(-0.10)	(0.05)	(-0.31)
Included Controls			
Household Demographics	x	x	x
Fiscal Year (July-June)			
Season (Annual Trimester)			
District	x	x	x
R^2	0.083	0.133	0.033
Adjusted R^2	0.067	0.119	0.013

t-statistics in parentheses: + p<0.10 * p<0.05 ** p<0.01 *** p<0.001. The data on the number of dengue cases are from Stoddard et al. (2014). The data on household information are from the INEI ENAHO survey from July 2005 to June 2010 (INEI 2015). Included demographic controls are as in **Table 4.2**.

Table 4.6: Difference-in-Differences regressions of the impact of dengue epidemics on primary female weekly work hours in Iquitos from July 2005 to June 2008

Sample:	All Primary Females	All Primary Females	All Primary Females who Work More than 7 hours per Week
Observations:	984	984	478
Dependent Variable:	Primary Female Weekly Work Hours	Primary Female Works More than 7 hours per Week (1=Yes)	Primary Female Weekly Work Hours
Mean of Dependent Variable:	22.257	0.486	45.464
Interactions			
Dengue x FY 2005-2006	-4.274+	-0.041	-6.106+
	(-1.71)	(-0.91)	(-1.88)
Dengue x FY 2007-2008	1.252	0.065	-4.663
	(0.50)	(1.46)	(-1.62)
Dengue Season			
(omitted April-November)			
Yes (December-March)	1.085	-0.038	6.460**
	(0.60)	(-1.15)	(2.93)
Fiscal Year (July-June)			
(omitted FY 2006-2007)			
FY 2005-2006	-2.005	-0.006	-4.115
	(-0.74)	(-0.13)	(-1.33)
FY 2007-2008	0.267	0.008	-0.372
	(0.10)	(0.17)	(-0.13)
Included Controls			
Household Demographics	x	x	x
Fiscal Year (July-June)			
Season (Annual Trimester)			
District	x	x	x
R^2	0.100	0.126	0.107
Adjusted R^2	0.086	0.113	0.078

t-statistics in parentheses: + p<0.10 * p<0.05 ** p<0.01 *** p<0.001. The data on the number of dengue cases are from Stoddard et al. (2014). The data on household information are from the INEI ENAHO survey from July 2005 to June 2010 (INEI 2015). Included demographic controls are as in **Table 4.2**.

Table 4.7: Summary statistics of control variables for various household types in Iquitos from July 2005 to June 2010

	Single Male Heads Mean	**Single Female Heads** Mean	**Dual-Headed Households** Mean
Control Variables			
Household Demographics			
Number of Household Residents	3.158	5.358	5.882
Other Income Earners Present (1=Yes)	0.413	0.669	0.477
Household has Children under the Age of 5 (1=Yes)	0.179	0.450	0.564
Primary Male Age (Years)	48.918	---	46.305
Primary Male Education (Years)	9.158	---	9.678
Primary Male Has Formal Occupation (1=Yes)	0.811	---	0.804
Primary Male Has Informal Occupation (1=Yes)	0.005	---	0.010
Primary Female Age (Years)	---	51.744	41.340
Primary Female Education (Years)	---	8.008	8.422
Primary Female Has Formal Occupation (1=Yes)	---	0.564	0.449
Primary Female Has Informal Occupation (1=Yes)	---	0.031	0.036
Observations	196	360	1288

Standard errors suppressed for the sake of space. The data on household information are from the INEI ENAHO survey from July 2005 to June 2010 (INEI 2015).

Table 4.8: Fixed-Effects regressions of the impact of dengue epidemics on primary male and female paid weekly work hours for those who work more than 7 hours per week in various types of households in Iquitos from July 2005 to June 2010

	Primary Males who Work More than 7 hours per Week		
Sample:	Male Single Household Heads	Dual-Headed Households: Primary Female Works 7 or Less Hours per Week	Dual-Headed Households: Primary Female Works More than 7 hours per Week
Observations:	160	557	491
Dependent Variable:	Primary Male Weekly Work Hours	Primary Male Weekly Work Hours	Primary Male Weekly Work Hours
Mean of Dependent Variable:	47.175	48.282	48.511
Dengue Epidemic (1=Yes)	8.311	-5.560*	-3.238
	(1.47)	(-2.20)	(-1.20)
R^2	0.069	0.046	0.036
Adjusted R^2	-0.035	0.018	0.003
	Primary Females who Work More than 7 hours per Week		
Sample:	Female Single Household Heads	Dual-Headed Households: Primary Male Works 7 or Less Hours per Week	Dual-Headed Households: Primary Male Works More than 7 hours per Week
Observations:	214	134	491
Dependent Variable:	Primary Female Weekly Work Hours	Primary Female Weekly Work Hours	Primary Female Weekly Work Hours
Mean of Dependent Variable:	48.444	47.030	44.729
Dengue Epidemic (1=Yes)	-8.906+	0.877	-8.055**
	(-1.87)	(0.18)	(-2.80)
R^2	0.172	0.200	0.088
Adjusted R^2	0.105	0.091	0.057
Included Controls (All Regressions)			
Household Demographics	x	x	x
Fiscal Year (July-June)	x	x	x
Season (Annual Trimester)	x	x	x
District	x	x	x

t-statistics in parentheses: + p<0.10 * p<0.05 ** p<0.01 *** p<0.001. Data on the number of dengue cases are from Stoddard et al. (2014). Data on household information are from the INEI ENAHO survey from July 2005 to June 2010 (INEI 2015). Included demographic controls are as in **Table 4.2**.

Table 4.9: Summary statistics of household illness reports for samples of all primary males and females and for dual-earner households in Iquitos from July 2005 to June 2010

	All Primary Males		
	Full Sample	**No Dengue Epidemic**	**Dengue Epidemic**
Any Residents Reported Illness in Past 4 Weeks (1=Yes)	0.690	0.704	0.645
Dependent Residents Reported Illness in Past 4 Weeks (1=Yes)	0.550	0.571	0.481
Primary Female Reported Illness in Past 4 Weeks (1=Yes)	0.232	0.233	0.226
Primary Male Reported Illness in Past 4 Weeks (1=Yes)	0.231	0.237	0.213
Observations	1208	921	287
	All Primary Females		
	Full Sample	**No Dengue Epidemic**	**Dengue Epidemic**
Any Residents Reported Illness in Past 4 Weeks (1=Yes)	0.741	0.746	0.725
Dependent Residents Reported Illness in Past 4 Weeks (1=Yes)	0.614	0.625	0.575
Primary Female Reported Illness in Past 4 Weeks (1=Yes)	0.308	0.299	0.337
Primary Male Reported Illness in Past 4 Weeks (1=Yes)	0.181	0.176	0.197
Observations	839	646	193
	Dual-Earner Households		
	Full Sample	**No Dengue Epidemic**	**Dengue Epidemic**
Any Residents Reported Illness in Past 4 Weeks (1=Yes)	0.758	0.766	0.727
Dependent Residents Reported Illness in Past 4 Weeks (1=Yes)	0.609	0.630	0.536
Primary Female Reported Illness in Past 4 Weeks (1=Yes)	0.303	0.302	0.309
Primary Male Reported Illness in Past 4 Weeks (1=Yes)	0.226	0.223	0.236
Observations	491	381	110

The data on the number of dengue cases are from Stoddard et al. (2014). The data on household information are from the INEI ENAHO survey from July 2005 to June 2010 (INEI 2015).

Table 4.10: Fixed-Effects regressions of the impact of dengue epidemics interacted with household illness reports on primary male and female paid weekly work hours among various household types in Iquitos from July 2005 to June 2010

Sample:	All Primary Males who Work More than 7 hours per Week	All Primary Females who Work More than 7 hours per Week	Dual-Earner Households: Primary Male and Female Work More than 7 hours per Week	
Observations:	1208	839	491	
Dependent Variable:	Primary Male Weekly Work Hours	Primary Female Weekly Work Hours	Primary Male Weekly Work Hours	Primary Female Weekly Work Hours
Mean of Dependent Variable:	48.228	46.044	48.511	44.729
Household Illness Outside of Dengue Epidemics				
(omitted: no illness reports within the household)				
Some Residents Report Illness	-2.573	1.524	-3.439	1.541
	(-1.63)	(0.72)	(-1.33)	(0.56)
Household Illness During Dengue Epidemics				
No Residents Report Illness	-2.368	-8.122*	2.944	-8.136
	(-0.89)	(-2.17)	(0.63)	(-1.62)
Some Residents Report Illness	-6.358**	-4.997+	-8.536*	-6.572+
	(-2.83)	(-1.74)	(-2.46)	(-1.77)
Included Controls				
Household Demographics	x	x	x	x
Fiscal Year (July-June)	x	x	x	x
Season (Annual Trimester)	x	x	x	x
District	x	x	x	x
R^2	0.025	0.086	0.051	0.089
Adjusted R^2	0.009	0.065	0.015	0.054

t-statistics in parentheses: + p<0.10, * p<0.05, ** p<0.01, *** p<0.001. The data on the number of dengue cases are from Stoddard et al. (2014). The data on household survey participation are from the INEI ENAHO survey from 2005-2010 (INEI 2015). Included demographic controls are as in **Table 4.2**.

Table 4.11: Summary statistics of economic control variables for samples of all primary males and females who work more than 7 hours per week and for dual-earner households in Iquitos from July 2005 to June 2010

	All Primary Males who Work More than 7 hours per Week		**All Primary Females who Work More than 7 hours per Week**		**Dual-Earner Households**	
	Mean	Stand. Dev.	Mean	Stand. Dev.	Mean	Stand. Dev.
Household Economic Information						
Total Weekly Income (Soles)	228.114	(323.398)	254.966	(296.339)	295.365	(323.211)
Asset Index of Economic Status*	0.764	(0.219)	0.808	(0.225)	0.818	(0.227)
Low Economic Status (1=Yes)	0.137	(0.344)	0.118	(0.323)	0.098	(0.297)
Middle Economic Status (1=Yes)	0.571	(0.495)	0.616	(0.487)	0.615	(0.487)
High Economic Status (1=Yes)	0.140	(0.347)	0.182	(0.386)	0.183	(0.387)
Observations	1,208		839		491	

*Fewer observations due to missing data. Index generated via PCA on physical household attributes. See Clayton (2015c) for more details on index construction. The data on household information are from the INEI ENAHO survey from July 2005 to June 2010 (INEI 2015).

Table 4.12: Fixed-Effects regressions of the impact of dengue epidemics on primary male and female paid weekly work hours among various household types in Iquitos from July 2005 to June 2010 separated by economic status

Sample:	All Primary Males who Work More than 7 hours per Week	All Primary Females who Work More than 7 hours per Week	Dual-Earner Households: Primary Male and Female Work More than 7 hours per Week	
Dependent Variable:	Primary Male Weekly Work Hours	Primary Female Weekly Work Hours	Primary Male Weekly Work Hours	Primary Female Weekly Work Hours
Economic Status:	Low Economic Status			
Observations:	165	99	48	
Mean of Dependent Variable:	44.036	46.626	46.479	45.688
Dengue Epidemic (1=Yes)	-6.993	-3.118	-23.019*	-5.798
	(-1.54)	(-0.44)	(-2.34)	(-0.52)
R^2	0.124	0.217	0.492	0.477
Adjusted R^2	0.022	0.052	0.229	0.207
Economic Status:	Average Economic Status			
Observations:	690	517	302	
Mean of Dependent Variable:	48.207	47.456	48.526	46.281
Dengue Epidemic (1=Yes)	-3.443	-10.932***	-3.097	-11.183**
	(-1.48)	(-3.77)	(-0.91)	(-2.95)
R^2	0.023	0.102	0.033	0.116
Adjusted R^2	-0.001	0.071	-0.021	0.066
Economic Status:	High Economic Status			
Observations:	169	153	90	
Mean of Dependent Variable:	49.243	42.817	47.156	41.311
Dengue Epidemic (1=Yes)	-5.149	6.676	-0.424	7.109
	(-1.01)	(1.33)	(-0.06)	(1.00)
R^2	0.145	0.146	0.204	0.233
Adjusted R^2	0.049	0.038	0.030	0.065

t-statistics in parentheses: + p<0.10 * p<0.05 ** p<0.01 *** p<0.001. The data on the number of dengue cases are from Stoddard et al. (2014). The data on household information are from the INEI ENAHO survey from July 2005 to June 2010 (INEI 2015). Included controls are as in **Table 4.2**.

CHAPTER 5: MODELING HOUSEHOLD PARTICIPATION IN CONTAINER CLEANING PROGRAMS

I. Introduction

Because there is no cure for dengue and limited access to vaccines, the only available method for reducing transmission is to control the *Aedes aegypti* mosquito that spreads the disease (WHO 2015a). One seemingly simple way to decrease the population of *Aedes aegypti* adults is to clean, discard, or place larvicide in containers identified as providing likely egg deposit sites for the mosquito (Morrison et al. 2008). These "risky containers" can be anything capable of holding small amounts of standing water such as buckets, trays, or old rubber tires. However, it has been argued that container control is only effective with full community participation, which has been difficult to achieve (Morrison et al. 2008).[38] Peruvian health officials express frustration over the lack of community participation in mosquito control programs, saying that people simply "don't understand" or "don't care" about disposing of risky containers.[39] Looking at the determinants of household participation in container control can establish the (in)validity of these sentiments and can help inform policymakers about what forms and scales of *Aedes aegypti* control are likely to succeed.

In this chapter, I provide an economic model for household participation in container control programs aimed at decreasing the population of *Aedes aegypti* mosquitoes. I form a

[38] Whether success requires full, rather than high participation is unknown. Mosquitoes can lay eggs in areas that are difficult for humans to access, suggesting that container cleaning participation levels may have to be extremely high to counter the impacts of external breeding sites, if that is even a possible task to achieve.
[39] Opinions expressed by Dr Fernando Gonzales, Dr Cesar Cabezas, and Biologist Jorge Valle during presentations given at the "Dr. Abelardo Tejada Valencia International Entomology Symposium: Recent Technological Innovations for Dengue Vector Control," held by the Instituto de Medicina Tropical in Lima, Peru on July 16, 2012.

model of household participation decisions based on the perceived costs and benefits of container cleaning at differing levels of neighborhood container cleaning participation. I explore how the individual payoff schedule for container cleaning varies based on household demographics and disease transmission risk. The model suggests that the likelihood of having active egg deposit sites in a household is inversely related to the ease of household participation in container cleaning as determined by household size and demographics. The model also suggests that higher disease transmission risk increases the propensity of households to participate in container control.

II. Modeling the Benefits and Costs of Container Cleaning

I form a theoretical model of household participation in container cleaning based on previous models of disease prevention behaviors in a public goods context (See Chapter 2 for a review of previous research). I treat the decision to regularly clean open water containers as a binary choice to join a "self-restraining coalition", as suggested by Schelling (1978). As other papers on disease prevention have done before, I argue that the private payoff to container cleaning for the household depends on the participation rate of one's neighbors. The payoff schedules of the private benefit to the individual for cleaning or not cleaning their water containers based on the group participation ratio are displayed in **Figure 5.1**.

Mosquitoes that hatch in one property can easily fly into the yards and homes of neighboring properties. The possible spillovers of adult mosquitoes among neighboring homes suggest a non-linear payoff curve for household container cleaning. Therefore, as group participation in container cleaning increases, so does the marginal benefit of container cleaning for an individual household within the group, as they are then more capable of having an impact on the number of mosquitoes in their home. If none of the surrounding homes participates in container cleaning, the ability of the individual household to affect the number of adult mosquitoes in their home is small because mosquitoes bred in the surrounding area can fly into their property. The marginal benefit to cleaning in that situation is therefore small. If instead all of the surrounding homes participate in container control, the ability of the individual household to affect the number of adult mosquitoes in their home is nearly absolute because the mosquitoes should not be entering the property by any other means. The marginal benefit of container cleaning for the individual household within a group therefore increases along with the group participation rate, causing the individual household payoff from cleaning to increase at an increasing rate.

Next, if there were a social cost to nonparticipation in the form of peer pressure to match group behavior, the marginal benefit of shirking would decrease as the group participation ratio increases. The absolute payoff from shirking would still increase along with group participation because individuals who do not clean benefit from the cleanliness of their neighbors. However, this payoff would increase at a decreasing rate because the spillover benefits would be offset by the increasing social cost of nonparticipation. It should be noted that the theoretical results hold under a linear payoff curve for shirking. The model assumes complete information about the actions of one’s neighbors.

Under the assumptions of an increasing marginal benefit to container cleaning and a decreasing (or constant) marginal benefit to shirking for the individual household as group participation increases, there are two potential stable equilibria for the group. Below a certain group participation threshold, the payoff from shirking for the individual household will be greater than the payoff from container cleaning. In theory, a group that starts with a participation ratio below this threshold will experience coordination breakdowns with no individuals participating in container control. The second equilibrium entails complete group participation, as the incentive for the individual household to clean containers will always be higher than the incentive to shirk if the group starts out above that same participation threshold.

III. Comparative Statics

Several factors could lead to a shift in the payoff curves for the individual household and could help incentivize households towards participation. First, both positive and negative external incentive programs could guide households towards participation. A positive monetary incentive for cleaning one's house would shift the individual payoff schedule for cleaning upwards, thereby lowering the group participation threshold above which households are incentivized towards participation. Similarly, a negative incentive for shirking in the form of a fine or other penalty would shift the individual payoff schedule for shirking downwards. This too would decrease the participation threshold above which all households participate.

Here I explore natural heterogeneity in container cleaning decisions. I focus on the effect of the ratio of working aged female residents and dengue season on individual container cleaning decisions. The task of container cleaning is likely considered a domestic activity. The strictly defined gender roles in many dengue endemic countries place these tasks within the sphere of female responsibility (Winch et al. 1994; Babb 1998; Alcalde 2010). The more females of working age there are in a household relative to the total number of residents, the more people there are to assist with the domestic tasks. Therefore, the payoff to not cleaning is lower for that household at every level of group participation. Households with more working aged females then have a lower group participation threshold above which they will find it beneficial to participate in container control. This means that, all else equal, two households within the same group that have a different ratio of working aged females to total residents are predicted to make different participation decisions. **Figure 5.2** shows the shift in the payoff curve for shirking for households with more working aged females.

During the peak season for dengue transmission (October to February), the payoff for the individual household to clean will be higher at every level of group participation. This is because *Aedes aegypti* pose a more significant health risk when people are contracting the disease at high rates. During dengue season, the payoff curve for cleaning would therefore shift upwards. This lowers the group participation threshold above which members of the group are incentivized towards full participation in container control. **Figure 5.3** shows the shift in the payoff curve for cleaning for the average household during dengue season when dengue transmission increases.

IV. Conclusion

The working hypotheses that the above theory presents are that after controlling for the number of positive containers in neighboring homes:

1) Households with more residents, and particularly with a higher ratio of working aged female residents, are less likely to have positive containers.
2) The number of households with positive containers will decrease during dengue season.

The proposed model could be tested with data on the number of risky containers, adult mosquitoes, and larvae in a home along with GIS data on household locations. The results of such an analysis could help inform control initiatives about effective participation incentives among various types of households.

V. Figures

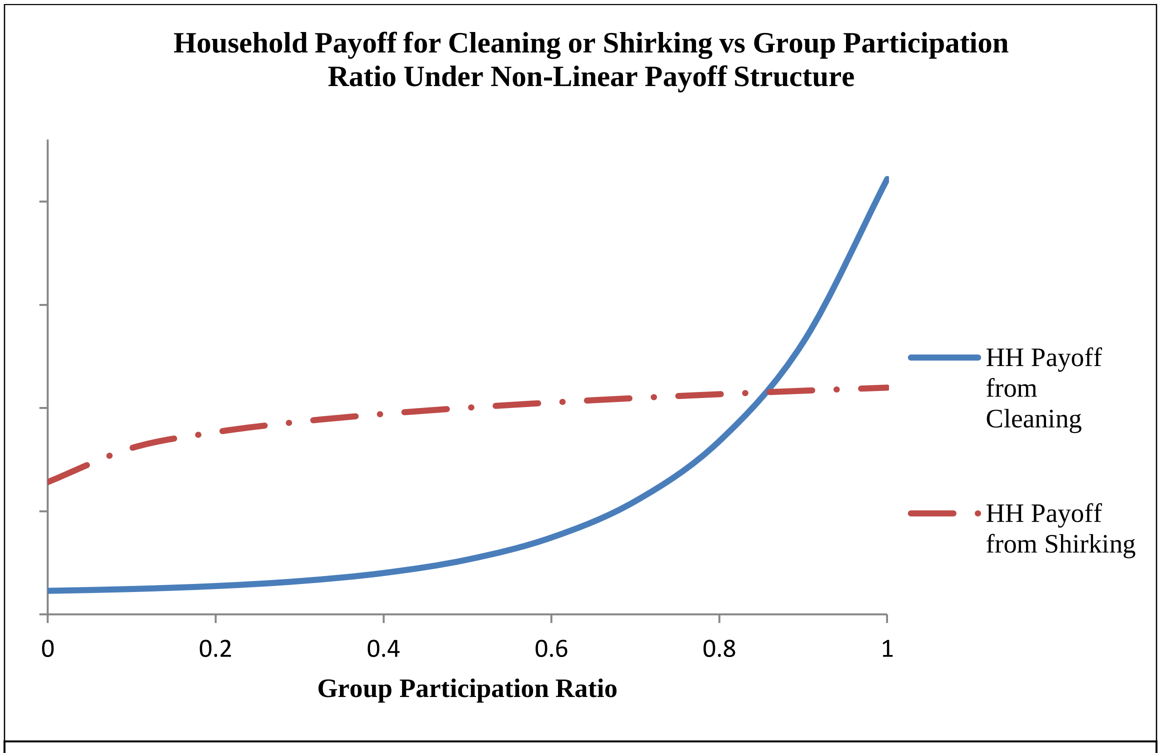


Figure 5.1: This figure shows the household payoff schedules for the decision to participate in container cleaning for the sake of *Aedes aegypti* control and dengue prevention or to shirk and free ride off of the cleaning habits of one's neighbors. The payoffs for each decision depend on the proportion of one's neighbors who participate.

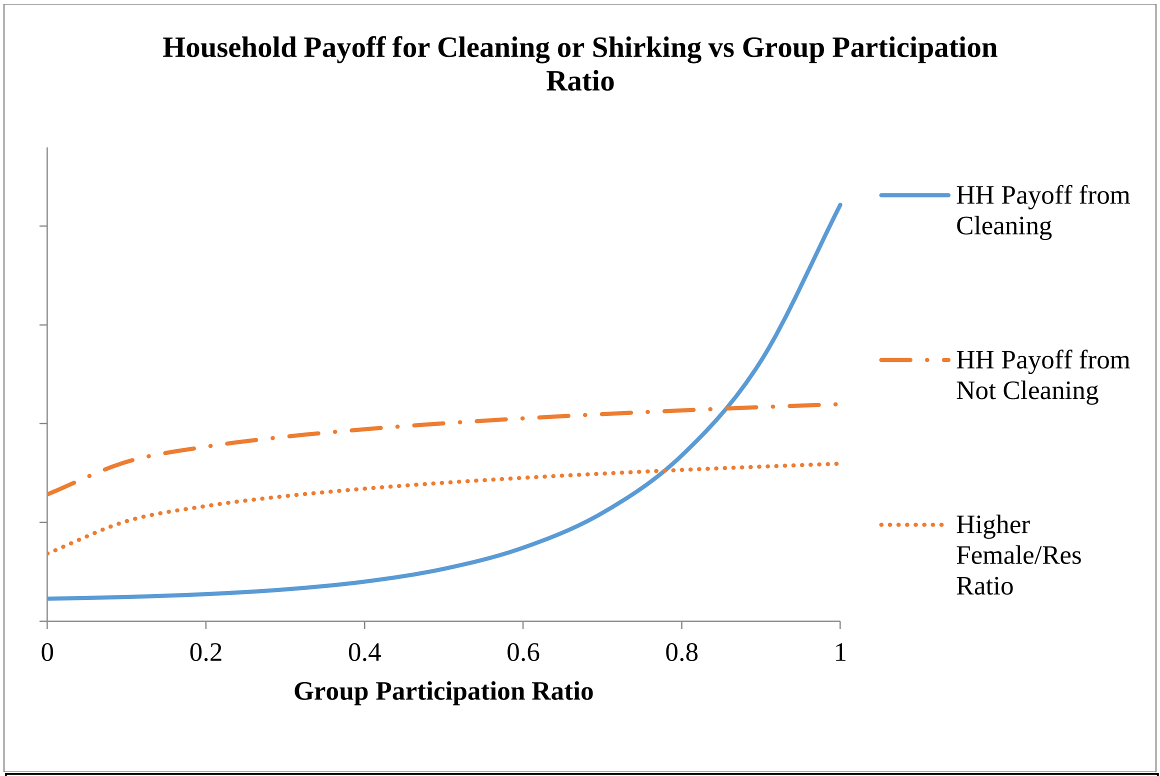


Figure 5.2: This figure shows the household payoff schedules for the decision to participate in container cleaning for the sake of *Aedes aegypti* control and dengue prevention or to shirk and free ride off of the cleaning habits of one's neighbors. The payoffs for each decision depend on the proportion of one's neighbors who participate. Gender roles in many dengue endemic countries dictate that having a higher female resident ratio lowers the marginal costs of cleaning as there are more individuals available to help with the cleaning tasks.

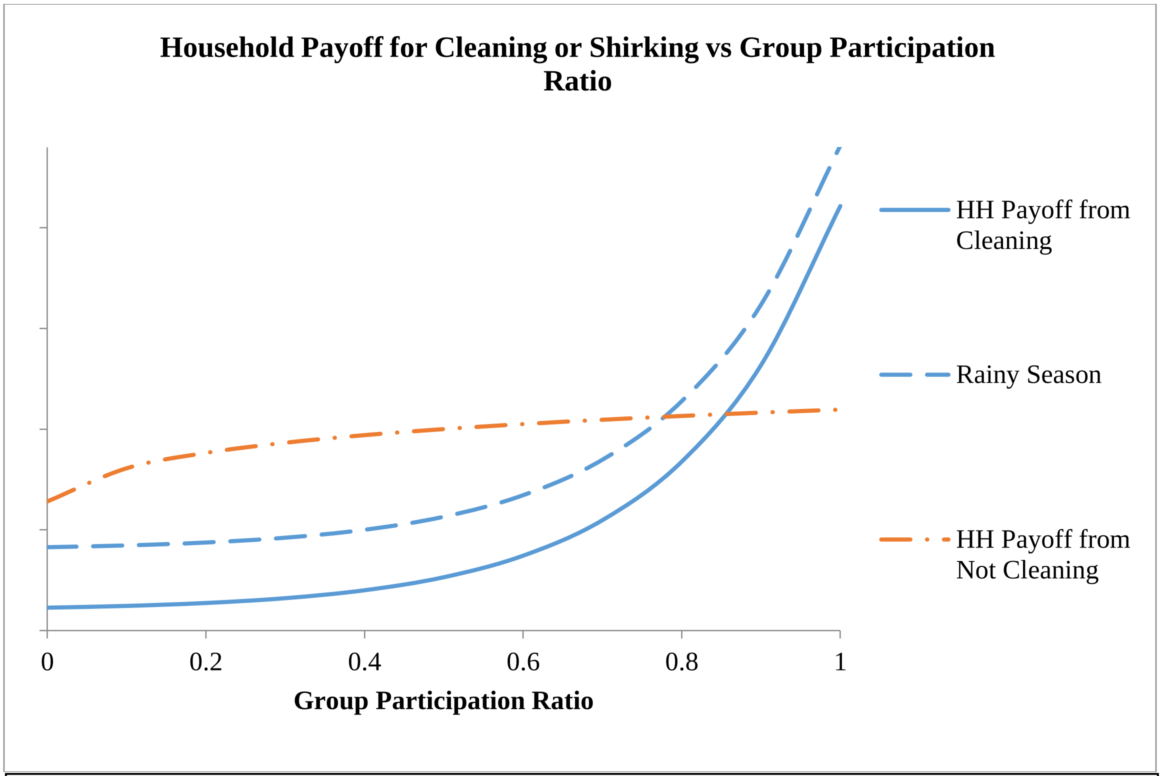


Figure 5.3: This figure shows the household payoff schedules for the decision to participate in container cleaning for the sake of *Aedes aegypti* control and dengue prevention or to shirk and free ride off of the cleaning habits of one's neighbors. The payoffs for each decision depend on the proportion of one's neighbors who participate. Dengue Season increases the marginal benefits of cleaning since the risk of dengue transmission is higher.

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APPENDICES

Appendix A: Chapter 4

I. Potentially Confounding Factors

One might be concerned that results indicating a significant impact of dengue epidemics on labor market outcomes are confounded by changes in weather concurrent with changes in dengue transmission. However, Iquitos is hot and rainy year-round so that changes in temperature and rainfall tend to be minor. The weekly average high temperature ranges from approximately 82.5 to 94.5 degrees Fahrenheit throughout the study period. Similarly, it rained approximately 50.5% of the days covered in the study and rained at least 2 days of the week in over 91% of the weeks covered in the study (Weather Underground 2016). Neither weekly average high temperature nor weekly rainfall occurrence is strongly correlated with weekly dengue cases. Unsurprisingly, regression results are unchanged when measures of weekly or monthly average temperatures or rainfall are included (results available upon request).

One might also worry that dengue transmission fluctuates contemporaneously with other diseases. The INEI offers regional transmission data aggregated annually on Malaria, Leishmaniosis, Yellow Fever, and Tuberculosis (INEI 2015). Malaria only seriously impacts the rural areas in the Loreto region that are located outside of Iquitos. Malaria transmission in Loreto steadily decreases throughout the study period, with small peaks in 2005 and 2009. Leishmaniosis and Yellow Fever each display little to no transmission in Loreto. Tuberculosis is a problem in Loreto in general and in the city of Iquitos. While transmission in Loreto steadily decreases throughout most of the study period, there is a large peak in 2009 that only partially subsides in 2010. However, the period of peak Tuberculosis transmission is not covered in the diff-in-diff specifications that confirm the main results.

Finally, labor strikes are common in Iquitos, though generally short in duration, and could potentially confound the results on labor market outcomes if strikes occur concurrently with dengue epidemics. The Peruvian Ministry of Labor and Employment Promotion (2016) collects annual data on labor strikes carried out throughout the country. A manufacturing strike was reported in September 2006 that affected 111 workers for an average 16 hours each. Transportation strikes, mostly among airline workers and taxi drivers, are more common in Iquitos. A strike occurred in November 2006 that affected 80 workers but only for an average of 8 hours each. A smaller strike was reported in April 2008, affecting only 12 workers for an average of 9 hours each. Two more strikes were reported in 2010: one in July, affecting 11 workers for an average of 24 hours each, and another from September to October, affecting 18 workers for an average of 40 hours each. None of the reported strikes correspond to periods of epidemic dengue transmission. Incorporating an indicator for the occurrence of a labor strike does not alter the results of either the main empirical specifications or the difference-in-differences estimations (results available upon request).

II. Survey Validity

One might be concerned that the results are affected by the identity of the survey respondent. For example, if primary females report their own and their spouses work hours, they might systematically under-report the work hours of their spouses. In that case, the impact of dengue epidemics on work hours would be over-stated for males compared to females. **Table A.2** shows the identity of the survey respondent for both work and health information. The majority of primary males and females report their own information, with both residents responding in the same household. One might also wonder if work hours vary significantly based on whether individuals work in the formal or informal labor market. **Table A.3** shows the impact of dengue epidemics on male and female work hours for the initial samples reported in **Tables 3.4-3.5**, for those who work in the formal labor market, and for those who report their own work hours. The results are nearly identical across all regressions, indicating that neither of the above concerns alters the regression results.

Another concern may be that survey participation varies during a dengue epidemic based on household health or work outcomes, introducing endogeneity into the analysis. **Table A.4** shows survey participation during and outside of epidemics. There is no significant difference in the percentage of approached households who complete the survey based on the occurrence of a dengue epidemic. There is also no significant difference in the percentage of households who do not participate for the indicated reasons. OLS and probit regressions of the impact of dengue epidemics on survey participation confirm that epidemics do not affect survey participation (results available upon request).

Appendix A Tables and Figures: Chapter 4

Table A.1: Percentage of the sample population of Iquitos from July 2005 to June 2010 that is surveyed at each trimester or year and is from each district

Variable	Percentage of Sample
Trimester	
1st (January-June)	32.38%
2nd (May-August)	32.97%
3rd (September-December)	34.65%
Fiscal Year	
2005-2006	19.69%
2006-2007	17.08%
2007-2008	22.51%
2008-2009	21.31%
2009-2010	19.41%
District	
Iquitos District	41.21%
Punchana	15.13%
Belen	22.29%
San Juan	21.37%
Observations	1,844

Data are from the INEI ENAHO survey from 2005-2010 (INEI 2015).

Table A.2: Number of observations for which each type of resident was the survey respondent for each type of survey information in Iquitos from July 2005 to June 2010

	Survey Respondent			
Survey Information	**Primary Male**	**Primary Female**	**Other**	**Total**
Primary Male Health	1,388	86	10	1,484
Primary Male Work	1,384	86	14	1,484
Primary Female Health	29	1,595	24	1,648
Primary Female Work	28	1,594	26	1,648

Data are from the INEI ENAHO survey from 2005-2010 (INEI 2015).

Table A.3: Fixed-Effects regressions of the impact of dengue epidemics on primary male and female paid weekly work hours in Iquitos from July 2005 to June 2010 for the samples of those who work in the formal labor market or who report their own work hours

Sample:	Primary Male Works Positive Hours	Primary Male Works Positive Hours in Formal Labor Market	Primary Male Works Positive Hours & Reports Own Work Information
Observations:	1,208	1,194	1,135
Dependent Variable:	Primary Male Weekly Work Hours	Primary Male Weekly Work Hours	Primary Male Weekly Work Hours
Mean of Dependent Variable:	48.228	48.312	48.127
Dengue Epidemic (1=Yes)	-3.302+	-3.395+	-3.135+
	(-1.90)	(-1.95)	(-1.74)
R^2	0.021	0.021	0.021
Adjusted R^2	0.007	0.007	0.006
Sample:	Primary Female Works Positive Hours	Primary Female Works Positive Hours in Formal Labor Market	Primary Female Works Positive Hours & Reports Own Work Information
Observations:	839	781	818
Dependent Variable:	Primary Female Weekly Work Hours	Primary Female Weekly Work Hours	Primary Female Weekly Work Hours
Mean of Dependent Variable:	46.044	46.261	45.988
Dengue Epidemic (1=Yes)	-6.938**	-6.760**	-6.944**
	(-3.17)	(-3.08)	(-3.11)
R^2	0.085	0.087	0.084
Adjusted R^2	0.066	0.067	0.065
Included Controls (All Regressions)			
Household Demographics	x	x	x
Fiscal Year (July-June)	x	x	x
Season (Annual Trimester)	x	x	x
District	x	x	x

t-statistics in parentheses: + p<0.10 * p<0.05 ** p<0.01 *** p<0.001. The data on the number of dengue cases are from Stoddard et al. (2014). The data on household information are from the INEI ENAHO survey from July 2005 to June 2010 (INEI 2015). Included controls are as in **Table 4.2**.

Table A.4: Survey participation by presence of dengue epidemic for the Iquitos sample population from July 2005 to June 2010

	Dengue Epidemic					
	No		Yes		Total	
Survey Result	Observations	Percent	Observations	Percent	Observations	Percent
Complete	1,205	75.22%	417	76.94%	1,622	75.65%
Incomplete	167	10.42%	55	10.15%	222	10.35%
Refused	24	1.50%	8	1.48%	32	1.49%
Not Home	26	1.62%	7	1.29%	33	1.54%
Abandoned	58	3.62%	22	4.06%	80	3.73%
Other	122	7.62%	33	6.09%	155	7.23%
Total	1,602		542		2,144	

Data are from the INEI ENAHO survey from 2005-2010 (INEI 2015). Both complete and incomplete observations are included in the sample if the necessary variables are available.