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Rainwater harvesting and households' time allocation in Mexico City

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Abstract

Disparities in access to water are an undeniably important driver of inequality, across and within countries. One of the burdens of limited water access is the time that households spend fetching water. In this paper, I investigate the potential time saving impact of rain water harvesters (RWHs) in sub-urban Mexico City by following three steps. First, I consider the survey that is being carried out in connection to a project that subsidizes the installation of RWHs in households in the Mexican capital, highlighting the significant level of water distress in the region. In order to understand how RWHs could benefit households, I design a theoretical model in which households can allocate time to three alternatives to water fetching, namely work, childcare and leisure. I outline different scenarios that depend on the value of specific parameters in the model. In the last section, I use a consumption survey at the national level to estimate the impact of water access differences. The econometric results suggest a strong preference for female members of Mexican households to invest the time gained thanks to easier access to water on wage-earning activities, followed by leisure. Men, instead, would spend the additional time on leisure only. In this way, I am able to identify one of the scenarios from the theoretical part that is most likely to predict the social benefits that will accrue to Mexico City households participating in the subsidized program.

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RWHs	Rain Water Harvesters
SCALL	Sistema de Captación de Aguas de Lluvia (i.e. System for rainwater cathcment)
MXP	Mexican Pesos
USD	US Dollars
SEDEMA	Secretaría del Medio Ambiente (i.e. Secretary for the Environment)
ST	Subsidized truck
PT	Private truck
HH	Households

1 Introduction

Water is a human right. It is a key resource to sustainable development, health, education, economic growth and the environment (UN, 2019b). Despite this, the World Health Organization notes that water scarcity affects four out of ten people in the world on average (UN & WHO, 2019). More than 2 billion people are living with the risk of reduced access to freshwater resources and over 1.7 billion people are currently living in river basins where water use exceeds recharge (UN, 2019a). Access to water is also the subject of the sixth UN Sustainable Development Goal:

> 6.1 By 2030, achieve universal and equitable access to safe and affordable drinking water for all.
>
> [...]
>
> 6.4 By 2030, substantially increase water-use efficiency [...] and substantially reduce the number of people suffering from water scarcity.
>
> *UN Sustainable Development Goals 2015*

In Mexico, about 10% of the population does not have access to safe drinking water (UNAM, 2019). Water supply in the country faces different problems ranging from overexploitation of aquifers to dysfunctions in the water distribution network, pollution and lack of control over concessions (Tetreault & McCulligh, 2018). Moreover, Mexican hydrology is characterised by a strong geographical unbalance that exacerbates the existing economic inequalities. Particularly striking is the situation of Mexico City, where population growth, urbanization and global climate change are putting the city's urban water resources under pressure (van Ginkel, Hoekstra, Buurman, & Hogeboom, 2018).

One of the critical aspects of limited water access is time. Households that are not connected to water pipes that safely and regularly provide water will have to spend large portions of their time fetching it from sources outside their premises. It is estimated that the mean time needed to fetch water in sub-Saharan Africa is about 30 minutes per trip (UN & WHO, 2012), and it is often necessary to carry out multiple trips per day (Hemson, 2007; Sorensen, Morssink, & Abril Campos, 2011). In a comprehensive study, Geere and Cortobius (2017) estimate that the time burden of fetching water can different greatly across developing countries, from ten minutes to several hours per day, and is often greater in rural areas. Needless to say, it is mostly the poorer communities around Mexico City that suffer from an insufficient or non-existent water supply system (Barkin, 2007). Time spent fetching water reduces the time budget that could be devoted to other activities, such as work, childcare and leisure. Therefore, time poverty due to fetching water is often believed to exacerbate income, health and education inequalities within and across countries (Kes & Swaminathan, 2006).

In this context, rain water harvesters (RWHs) as a source of domestic water constitute one option to cope with water stress. Indeed, it is becoming increasingly more recurrent to take advantage of rainwater, also in urban areas (Belmeziti, Coutard, & de Gouvello, 2013). Despite the obvious presence of air pollution in Mexico City, recent studies have demonstrated that an appropriately designed rainwater harvesting system can provide water of very high quality, which complies with Mexican and international water quality standards (Gispert, Armienta Hernandez, Climent, & Torregrosa Flores, 2018). In 2019, the local government launched the SCALL[1] project, which finances the installation of about 10,000 RWHs in an area of the Mexican capital that is particularly distressed in terms of water supply.

To my knowledge, very little research has been dedicated to understanding the potential impact of RWHs in the urban context of Mexico City, in particular with respect to its time-saving component and its potential social repercussions. Hence, in this paper I focus on the following three aspects: first, I explore the current level of water distress in sub-urban Mexico City in Chapter 4. I do this by considering the partial baseline survey that is being conducted in connection to the SCALL project. This allows me to spotlight the current level of water distress in that particular region of the country. Second, I outline how RWHs could potentially benefit households in the region in terms of time. I address this in Chapter 5 introducing a theoretical model of household time allocation. I focus on three alternatives to water fetching, namely work, childcare and leisure. Third, I investigate how one can expect Mexican households to re-allocate the time saved thanks to RWHs. This is the subject of Chapter 6, where I apply an econometric strategy to capture the average effect of water access on time allocation at the national level.

Before diving into the analytical part, I introduce some fundamental facts that help the reader's understanding of the current water supply situation in Mexico and its capital in Chapter 2, and relate this thesis to the existing literature on the topic in Chapter 3. Chapters 4 to 6 constitute the body of the research. In Chapter 7 I discuss the results in light of limitations of the research methods that I have used. I conclude the paper in Chapter 8.

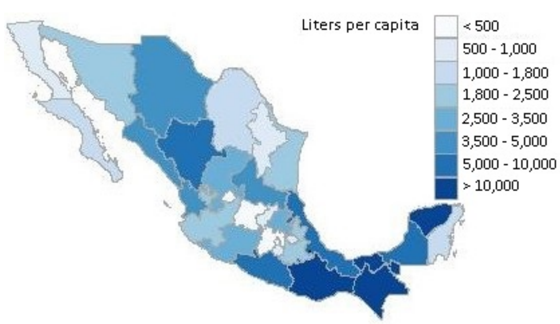
[1] Sistema de Captación de Aguas de Lluvia, i.e. rainwater harvesting system.

2 Background

Water supply in Mexico raises a range of issues that have been at the heart of political discussions ever since the country started its race to development in the last century. To begin with, Mexican hydrology is characterised by a strong geographical unbalance. As of the most recent estimate, Mexico is endowed with approximately 3,656 m3 of renewable water per year[2]. Assuming a conservative consumption rate of 50 to 100 liters per person per day, defined by the WHO as the sufficient water supply level to ensure most basic needs (WHO, 2015), in theory this would suffice to supply the whole country in a sustainable way. However, while southern regions have several fresh water sources and abundant rainfalls, central and northern Mexico areas have by harsher climate conditions and drier landscapes. In Figure 1 I show that the renewable water per person ranges from less than 500 liters per year in Mexico City to more than 10,000 in the South.

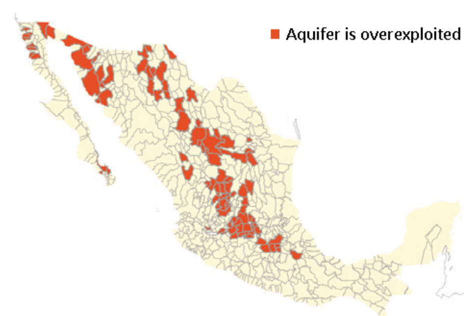
These conditions, coupled with poor governance and the dominance of private interests, have led to the overexplotation of resources. In 2017, water in 105 of 653 aquifers in Mexico was withdrawn in amounts that exceeded the sustainable rate (INEGI, 2018a), indicating that better management is necessary to ensure that Mexico will not run out of fresh water in the future. Figure 2 highlights that the overexploited aquifers correspond to areas in which the renewable water per capita is already scarce, in particular in the surroundings of Mexico City in the middle of the country. It is undeniable that rapid demographic change has represented a key concern for authorities in the last half century. While in 1950 the national average renewable water per capita availability was 17,742 m3, at the current rate of population growth and resources overexplotation, by 2030, the water availability will be reduced to 3,285 m3 per person (INEGI, 2018a).

Figure 1: Liters per capita per year, 2017



Source: Author's rendering of Conagua's data (2018)

Figure 2: Aquifers status, 2017



Source: Conagua (2018)

In fact, economic and demographic development have outpaced public infrastructure investments. In 2015, it was estimated that about 5% of Mexican households are not connected to the water grid at all. Of those connected, only about 73% receive water daily, while the remaining households receive water

[2]The renewable water resources of a country are defined as the total resources that are offered by the average annual natural inflow and runoff that feed each hydro system (FAO, 2019).

every few days (INEGI, 2015). Therefore more than 30% of Mexican households are not guaranteed daily water availability. The current government has recently announced a USD43bn infrastructure plan for national growth that is now facing the prospects of regression (Webber, 2019). Part of this large investment has been dedicated to rebuilding water supply infrastructures. However, critics have already pointed out that the plan lacks detailed analysis and is likely to be a short term economic boost action, rather than a well studied and planned intervention that will benefit citizens in the long term (Montes & de la Rosa, 2019).

Currently one of the most urgent water scarcity situations in the country is happening in its capital. Mexico City is located in the Valley of Mexico, an endorheic basin[3] formed by a flat zone delimited by solidified deposits, a hillside and a mountainous area (Brena-Puyol & Brena-Naranjo, 2009). Located in the flat area is most of the urban area of the Mexican capital, whose population has multiplied 5.4 times in the last 50 years. The metropolitan area has grown by around 100 square miles since 2010 (Russell, 2019). While some parts of the city receive abundant good quality water, approximately 310,000 households in the expanding suburban areas of the capital lack access to indoor running water (INEGI, 2018a). Poor water quality is also an issue in several parts of the city, particularly in low-income zones. Hence, decades of urbanization of natural recharge areas has led to today's rapidly deteriorating situation in which providing continuous access to water of acceptable quality is increasingly problematic.

Chaotic growth, especially in the form of irregular, off-the-grid communities, has led to the water crisis paradox that characterizes Mexico City. Despite receiving substantial amounts of rainfall, the concrete that covers the city does not allow rainwater to reach the underground basin, resulting in increasingly empty aquifers and frequent flooding during the rainy season (BIRF, 2013).

Therefore, Mexico City's roughly 22 million inhabitants depend for their water on two main sources: an intensely overexploited aquifer, and a highly energy-intensive system that pumps water 1,100 meters uphill over a 162 km distance (INEGI, 2018a). Moreover, extreme and uneven land subsidence due to intensive extraction of groundwater continually damages the grid, leading to an estimated 40% loss due to leaks and other structural failures (Banco Mundial, 2013). On top of this, climate change is expected to intensify Mexico City's hydrological cycle and decrease the availability of fresh water, while creating water scarcity in zones that deliver water to the city (Romero Lankao, 2010).

Actions that address the water supply emergency in Mexico City should take into account the close interactions between the hydrological cycle, urban ecosystems and society (Muller, 2007). Water management in a large urban area such as Mexico City is a complex issue that involves social, institutional, biophysical and urban factors (Moreno-Mata, Villasis-Keever, & Morató, 2018).

In Mexico City, the harvesting of rainwater could make a major contribution to reduce the water supply

[3] An endorheic basin is a limited drainage basin that normally retains water and allows no outflow to other external bodies of water, such as rivers or oceans, but converges instead into lakes or swamps, permanent or seasonal, that re-balance through evaporation.

shortage that occurs in the large neglected sub-urban areas (Lizarraga-Mendiola, Vazquez-Rodriguez, Blanco-Pinon, Rangel-Martinez, & Gonzalez-Sandoval, 2015). Indeed, advocates of RWHs insist that rainwater harvesting systems help conserve water resources and environment, reduce pollution, control flooding, and reduce the impact of weather change, in particular if public intervention is limited and inefficient (Mohammed, Mohd, Noor, & Ghazali, 2006).

3 Literature review

Capturing rain water could be considered one of the oldest and most basic practices of human civilization. Hence, it might come as a surprise to the reader to hear that it has recently been introduced as an innovative solution to water distress. The topic is relatively new to the economic literature, and is now gaining increased attention due to its many potential externalities. The African Development Bank (2008) defines rainwater harvesting as any "collection of the runoff [rainwater] for productive use". In this thesis, I consider rain water harvesting as the rooftop harvesting technique of collection and storage of rainwater into tanks for domestic use. Domestic use includes a number of non-potable indoor uses, such as flushing of toilets and laundry, and outdoor uses including garden irrigation and car washing. The RWHs that are being installed through the subsidy provided by Mexico City government do not include a filter for potable water, but households can buy one themselves.

However, to my knowledge, no study has focused on the social impact that domestic use of RWHs might have. As a benchmark, I consider relatable studies that have analyzed the social impact of water access improvements, although not necessarily related to RWHs. With respect to the time savings potential impact on labor force participation, Ilahi and Grimard (2000) implemented a simultaneous-equation reduced form analysis using Pakistani data from 1991. They found that greater distance to a water source raises water-collection rates for women and lowers their participation in income-generating activities. On the other hand, two studies carried out in Georgia (Lokshin & Yemtsov, 2005) and Morocco (Devoto, Duflo, Dupas, Pariente, & Pons, 2012) find no evidence of changes in labor force participation arising from improved water access.

At the same time, Dinkelman (2011) as well as Grogan and Sadanand (2013) studied the effects on labor force participation that arise from other types of infrastructure improvements, such as connection to the electricity grid, in South Africa and Nicaragua respectively. The authors explain that the provision of electricity frees up significant time that had previously been used to fetching other types of energy resources, such as wood. In this instance, a significant positive effect on labor participation was found. One could argue that such mechanism would work similarly in the case of water access.

With respect to the effect of differences in water access on childcare and leisure, much less research can be found in the literature. This is probably due to the difficulties in measuring these variables with data, as I will highlight in Chapter 6. Demie et al. (2016) found that in Ethiopia, water fetching is linked to higher illiteracy rates among women and worse health status, which, the authors of the study argue, can be reconnected to the lack of free time derived from the water fetching burden. In Madagascar, Boone et al. (2011) try to measure the impact that investments in water infrastructure will have on rural communities, finding that men will be most affected in terms of obtaining education. In a multi country analysis, Koolwal and van de Walle (2013) have found that in some countries water access is connected to higher school attendance, suggesting that is due to the fact that the household has more time for childcare.

These studies form the benchmark against which I will structure the remainder of this thesis, as well as compare my results. In the next Chapter, I will focus on the sub-urban area of Mexico City in which the SCALL project is being implemented, in order to get an overview of the current situation in the region.

4 Rain water harvesters in Mexico City

4.1 The SCALL project

In March 2019, Mexico City government launched the SCALL project[4], which subsidizes the installation of RWHs in two of the 12 municipalities of Mexico City, Xochimilco and Iztapalapa. The area is home to approximately 2.2 million people, and is particularly distressed in terms of water supply. The government announced an investment of MXP200m, roughly USD10m, to install approximately 10,000 RWHs. Below, I describe the partial results of a survey that has been carried out in parallel to the project.

According to SEDEMA, the branch of the local government for environment and sustainability which supervises the program, project SCALL's main objectives are to reduce the flow of water to drains reducing flood risks, to decrease the amount of energy required to pump and transport water to homes, and to facilitate adequate water service between 5 and 8 months of the year. Other benefits include relaxing the overexploitation of the aquifer and contributing to its recovery by reducing demand (SEDEMA, 2019). The project is carried out village by village, first by raising awareness through education campaigns. A few days later applications of interested households are collected. Registered households are then be technically inspected to verify the feasibility of the RWH installation. During the visit, a government employee carries out the socioeconomic survey, whose partial results I have obtained and will present here. For a more complete and detailed overview of its implementation one can find the phases that structure the SCALL project in Appendix 1.

The sample I have obtained includes 4,296 observations and 329 variables. The survey mainly concerns household water supply and consumption choices. Due to the insufficiency of the water pipes, several households have water delivered by trucks, for which there exist mainly two types. Subsidized trucks are financed by the government for those households that are not connected to the water grid or live in areas that have obvious insufficient water supply. In order to receive one load of water of 10,000 liters, households have to file an application through the local authority, which takes time and its delivery schedule is typically uncertain and long. The rather cumbersome process, coupled with the low quality of public water, often forces households to request private trucks, at an average cost of MXP1,100 (USD60) for the standard 10,000 liters capacity truck. According to household members, a private truck is usually easier to obtain and faster, but still requires people to invest substantial time in the ordering and administering delivery process.

Many of the interviewed households already harvest rainwater, although they lack the fundamental engineering components to leverage their catchment surface, and are rarely able to filter it. Almost every household in Mexico City buys bottled water for drinking and cooking, which represent a very small proportion of their daily consumption. Other sources include public wells and fountains. In some areas,

[4]The SCALL Project started on March 14th, 2019 and is scheduled to be completed towards the end of 2019. The following analysis is based on the data collected until June 6th, 2019.

a system of delivery with "burros", i.e. donkeys, is in place, although it is used only in case of emergency due to its relatively high cost.

The survey indicates that households connected to the water grid (right-hand side of Figure 3) receive about 93% of their water supply from the tap. Households not connected to the water grid (left-hand side of Figure 3, receive approximately equal shares of their water from private trucks and subsidized trucks. Rainwater is a small component of their overall water consumption, something that is expected to radically change after the installation of the RWH.

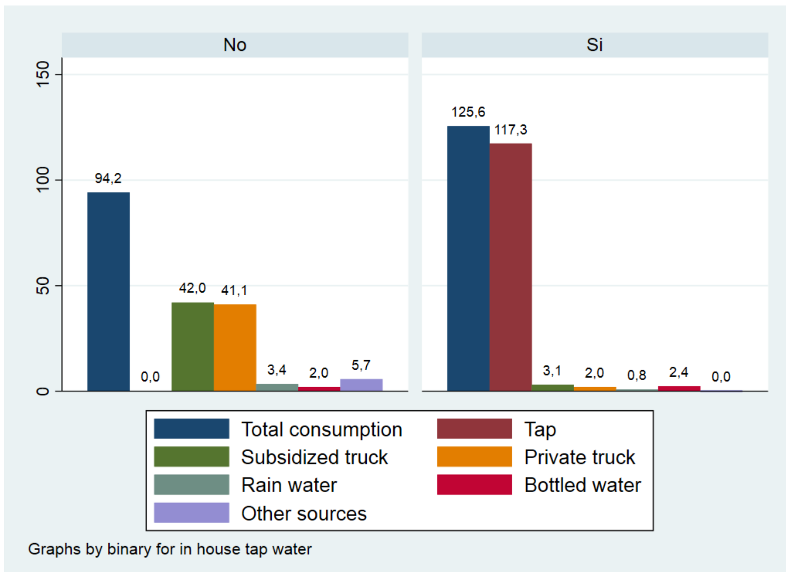


Figure 3: Sources of water, non-connected vs connected (in liters per person per day)

One important aspect that emerges from Figure 3 is that a large share of the water consumed by households not connected to the grid is not supplied by the government. This not only explains the incapacity of Mexican authorities to supply a basic service to their citizen, but also results in a large financial burden borne by these marginalized communities. The second striking element is represented by the difference in average total consumption. Households connected to the grid consume about 125 liters per person per day, while those that are not connected consume only 94 liters per person per day.

The different water sources between households that are connected to the grid and households that are not connected to the water grid becomes even more relevant when one considers the average time that is required to obtain one liter of water from each of these sources. There is a large difference in average time spent to fetch one liter of water between households that have water grid access and households that are not connected to the water grid. In the sample, households not connected to the water grid on average spend about 2.4 times more time to collect a liter of water than households that are connected. This is displayed by the most left columns in Figure 4, which show that the average time to collect one liter of water is 1.746 minutes if the household is not connected to the grid, while it is 0.738 if the household is connected. Given their average water consumption levels, households that are not connected to the grid will spend about 2.7 hours per person per day to fetch water, compared to approximately 1.5 hours per person per day for households that are connected.

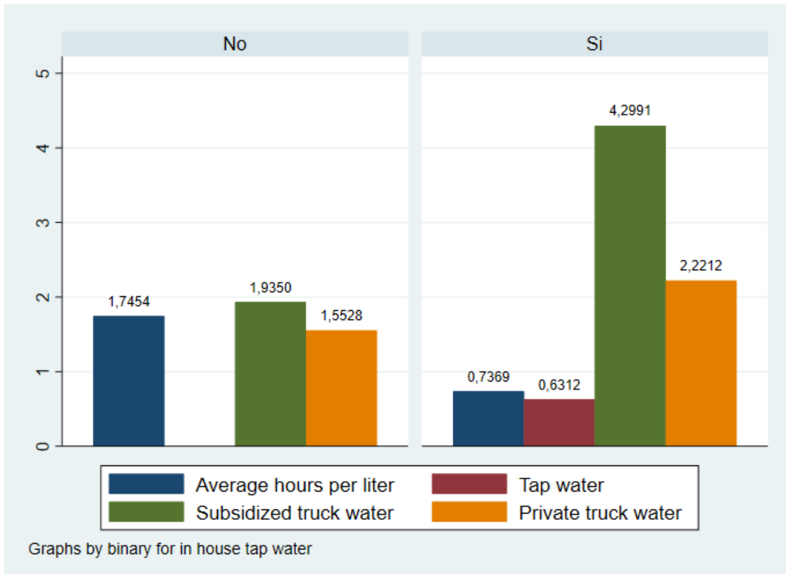


Figure 4: Hours spent per liter of water, non-connected vs connected

The green and orange bars, the most right bars in Figure 4, indicate the average time that is required to obtain one liter of water from subsidized and private trucks respectively. As expected, on average it is more time consuming to obtain one liter of water from subsidized trucks compared to private trucks, due to the inefficient administrative process that needs to be dealt with in order to obtain the subsidized water truck delivery. The large difference between the average time per liter from subsidized trucks between households that are connected and households that are not is probably due to the fact that a household that is not connected has easier access to deliveries of water from the government. This is probably due either to households' experience in the process or to the higher attention devoted to these communities by government officials.

In order to explain the reason behind the fact that households connected to the water grid are still required to invest time fetching water, one needs to consider two additional factors: tap water quality and frequency of tap water flow. With respect to the first aspect, about 50% of respondents in the survey declared that water from the tap is never of good quality, either because of its color, smell, or both. When delivered from a private truck, households are more likely to declare that the water is of good quality. Moreover, not all households connected to the water grid receive water from the tap daily. When asked how many days in the last week households received tap water, only about 11% said that it worked all the time, as displayed in Figure 5. About 12% of households say that they did not receive water at all in the last seven days, and more than 30% had tap water flow on only one day. Since both the quality and frequency of supply of tap water are uncertain, a lot of households are forced to actually seek other water sources despite being connected to the grid, and must invest time and resources to do so.

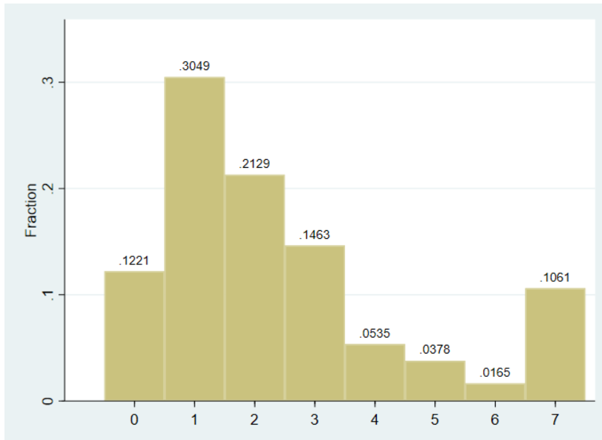


Figure 5: Days with tap water in the last seven days

A further point of concern with respect to water supply in this region of Mexico City is related to gender inequality. Indeed, in most households, it is women who spend time fetching water. Table 1 displays the number of times that each demographic group in the household was mentioned as responsible for fetching water in their respective category. The demographic group that is mentioned most times is women that are 60 years old or older, who are generally responsible for filling the tanks on the days when tap water is working. Overall, women are mentioned as responsible for fetching water more than twice as often as men are.

This factor has many repercussions in the fight against gender inequality in Mexican society, an issue that is deeply rooted in the culture of the country. The Mexican government has already adopted direct measures to tackle gender inequality, for instance through the General Act on Equality between Women and Men (UN, 2016). Nevertheless, it is evident that poor infrastructure, in this case insufficient water supply, will undermine the road to the elimination of gender inequality. In the following Chapters I will try, among other things, to highlight how RWHs could also benefit Mexican households in moving towards a more gender equal society.

	Tap	ST	PT	Rain	Other	Total
Woman, <18	2	0	1	3	0	6
Woman, 18-24	38	9	1	17	1	65
Woman, 25-59	657	262	119	1113	0	2151
Woman, 60+	1500	665	271	484	6	2920
Man, <18	5	3	0	6	0	14
Man, 18-24	16	4	1	13	0	34
Man, 25-59	493	198	77	330	4	1102
Man, 60+	520	198	89	324	10	1141
Everybody helps	1028	282	152	915	7	2384
No need	349	16	283	49	0	697

Note: ST stands for subsidized truck, PT stands for private truck. Multiple choice possible.

Table 1: Times that each category is mentioned as responsible for fetching water

4.2 Household simulation

Based on the survey information, I designed a brief simulation to visualize the potential time saving impact of RWHs at the household level. I consider the average time spent per liter in a household that is not connected to the water grid, which is roughly 1.75 minutes as in Figure 4, and the respective average daily consumption per person of 94,2 liters, as in Figure 3. Moreover, I assume a rooftop size of 60sqm[5], in a household composed of 4 members, with tank size capacity of 5000 litres which is the typical for SCALL project installations. Similarly to Samano-Romero et al. (2016) and Lizarraga-Mendiola et al. (2015), I introduce a run-off coefficient of 0.9 to account for rainwater that is drained from the system[6]. Considering the amount of rainfall that fell in Mexico City in 2018 (Conagua, 2019), a household with these characteristics should be able to harvest and use approximately 59,000 liters per year, 43% of the expected total consumption of the fictional household considered in this example.

One can see in Figure 6 that before RWHs is introduced, the person responsible for collecting water in the household has to spend almost 70% of their time fetching water each month, assuming they have 16 hours per day available. This is represented by the unchanging green column, most left in each month. With the introduction of the RWHs, households can make up for a large share of their consumption with rainwater, in particular during the rainy season between June and September (blue bars, or middle column for each month). According to this simulation, given the amount of rain that fell in the months of July, August and September 2018, households would be able to completely rely on rainwater in those

[5] 60sqm has been indicated by Isla Urbana, the association that is in charge of installing the RWHs within the SCALL project, as an approximation of the average rooftop size in sub-urban Mexico City (Isla Urbana, 2019)

[6] The RWH allows for drainage of the first water caught, which is usually rather dirty and more polluted. See Appendix 2 for more details on the functioning of the RWH.

months and even store some for the following period. The orange bars, the most right bar for each month, evidence that in winter season, there would be little time savings due to poor rainfall. In April, May, June, October and November, the household would partially reduce the time invested to fetch water.

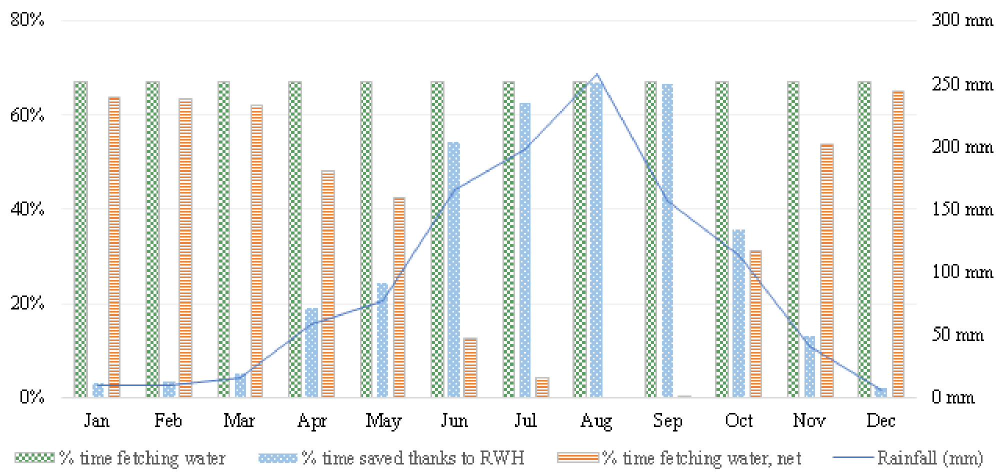


Figure 6: Household simulation of RWHs catchment and fetching water times

It emerges that RWH is very likely to reduce the time burden that water fetching imposes on Mexico City households, in particular during rain-intense months. Over the year, more than 40% of the time that was previously spent fetching water could be saved and dedicated to other activities, according to this simulation. In order to understand what impact such system might have on the people affected, I will introduce a theoretical model that will frame the discussion and allow for the analysis of the potential channels through which such impact will take place.

5 Household time allocation theory

5.1 Previous theoretical models

Household time allocation models were first introduced upon acknowledgment that economic models and data were largely overlooking the importance of domestic work, and needed to start recognizing that the household truly as a ”small factory” (Becker, 1965, p.496). Since then, several different theoretical branches have emerged. Chiappori (1988), for instance, developed a model that allows household partners to collaborate in their time allocation decision. Maassen, van den Brink and Groot (1997) introduce a model in which households can allocate time to two types of domestic work: domestic good production and childcare. According to their model, there will be an equality for women in paid employment between the marginal value of household production, the marginal rate of substitution between child care and consumption, the reservation wage (the marginal rate of substitution between consumption and leisure) and the market wage rate. Apps and Rees (1997) highlight the importance of incorporating household production in models of labor supply, in order to avoid misleading results concerning intra-family distribution of income and behavioral responses to economic policy.

Despite the significant advances and the variety of models that have been proposed within the field, I have not found a model that is suitable to the analysis I am positing in this paper. This is primarily due to the fact that, unlike previous models, I specify the determinants of the household utility function. This fundamental difference stems from the fact that I do not aim to predict how households will allocate their time in theory. Rather, the theoretical model serves as a tool to frame the logic that I use in the national level analysis in terms of the potential benefits that I try to predict in connection to the SCALL project presented in the previous part. Moreover, I am considering a rather special example of change in time allowance. It would be erroneous to consider the introduction of RWHs as a productivity increase in the production of domestic goods, as, for instance, in Koolwal and van de Walle (2013). Indeed, Koolwal and van de Walle interpret the difference in time that arises from differences in distances to water sources as a discriminant factor in the level of goods that the household is able to produce. Instead, in my model I want to merely reflect a change in time that needs to be devoted to the activity, because this is how one can realistically expect RWHs to impact households.

5.2 The households’ net time allocation model

Hence, I develop a model based on the idea of Maassen van den Brink and Groot (1997), who distinguish between two types of household activity: one that is good-producing, and one that is classified as child care. However, unlike (Maassen Van den Brink & Groot, 1997), I will consider four possible time allocations, one of which is water fetching and is necessary to the survival of the household itself. The intention is to recreate a scenario in which the household cannot derogate from water fetching. The utility reported by such activity corresponds to the following binary function:

$$g(h) = \begin{cases} 0 \text{ if } h < c \\ a \text{ if } h \geq c \end{cases} \tag{1}$$

where the household earns utility $a > 0$ only if it spends at least c hours fetching water, $c \geq 0$. The value c is the critical figure that changes after the introduction of the RWH. Initially, the household has to spend $c = High$ time to fetch water. Once the RWH is installed, it will only need to spend $c = Low$ time fetching water, with $Low < High$. The overall household utility function is then composed as follows:

$$\begin{aligned}
\text{utility function} \quad & u(x, y, z, h) = w * x + \alpha * log(y + 1) + \beta * log(z + 1) + g(h) \\
\text{subject to time constraint} \quad & T \geq x + y + z + h \\
\text{where} \quad & x \text{ indicates the hours spent on wage-earning activities,} \\
& y \text{ indicates the hours spent on child care,} \\
& z \text{ indicates the hours spent as leisure, possibly including education,} \\
& h \text{ indicates the hours spent on water fetching,} \\
& T \text{ indicates total household time allowance,} \\
& w \text{ is the hourly wage,} \\
& g(h) \text{ is the binary function specified in Equation 1,} \\
& \alpha, \beta \text{ are two parameters}
\end{aligned}$$

The choice of the specific utility functions corresponding to each time variable builds on the classic modelling compromise. On one hand, I want to represent the true preferences of households, on the other hand I want to work with a model that is simple enough to understand and from which to draw conclusions. I use a linear function for x with slope w as it is traditionally applied in micro-economic theory (Deakin & Wilkinson, 2005). Indeed, one could reasonably expect that working potential of the household is far from being exhausted in Mexico, in particular with respect to women, so that an extra hour spent in the labor market is likely to earn them the wage rate, on average. As a matter of fact, Mexican female labor force participation is at 44%, against a world average of 48% and a Latin American and Caribbean average of 51% (ILO, 2018), and unemployment rates that are low swinging between the 2 and 4%.

With respect to child care and leisure or education, variables y and z respectively, I apply a logarithmic function to highlight the decreasing returns from either activity. Several studies have shown that the marginal rate of return to education is increasing significantly at low levels of education, and decreasing significantly at high levels of education, as demonstrated, for instance, by Mincer (1974), Psacharopoulos (1985), and Trostel (2005). Although much harder to find similarly strong results in the literature, one can reasonably expect households' preferences for leisure and childcare to behave in a comparable manner: high utility is initially derived, decreasing with the amount of time dedicated to it, similarly to the argument used by Chen and Chevalier (2008). Hence, it appears reasonable to apply the chosen functions, whose intensity will depend on the respective parameters α and β.

The key to solve the model relies on the fact that the household will always invest time $h = c$ in fetching water in order to obtain utility a, since a is large representing the good that is necessary to the survival of the family. Note that if the household does not need to invest time fetching water, c will be simply equal to zero, so that h will also be equal to zero and all the households' time will be dedicated to the remaining activities. Note also that I will refer interchangeably to household or household member. Although it would be interesting to analyse the dynamics that would emerge between households members and how they would reallocate their time depending on each other's decisions, I have decided to overlook this aspect for the sake of simplicity.

Hence, I frame the maximization problem in terms of the net time $T - h$. I want to understand how the household will allocate the remaining time $T - h$ to other activities x, y and z, and how this allocation changes once $T - h$ increases thanks to the introduction of the RWH which requires only $c = Low$ amount of time to fetch water, instead of the previous $c = High$. Through application of the Heine-Borel Theorem, the Extreme Value Theorem and Lagrangian optimization, I know that I can find a global maximum in the model (Sydsæter, Hammond, Seierstadm, & Strøm, 2008). In other words, for any $T - h$ there is a specific value of x, y and z that will maximize the household's utility[7]. Depending on the values of the parameters α, β and , I can distinguish six cases:

I	$\alpha \leq w; \beta \leq w$
II	$\alpha > w; \beta \leq w$
III	$\beta > w; \alpha \leq w$
IV	$\alpha > \beta > w$
V	$\beta > \alpha > w$
VI	$\alpha = \beta > w$

In case I, the household member is a workaholic. All the time available to them, after deduction of time h allocated to the necessary fetching water, is invested in wage-earning activities. Indeed, as one can see in the first panel of Figure 7, the marginal returns to work $\partial u_x(x) = w$ is higher than the other marginal returns for all non-negative values of $T - h$.

[7]In the Appendix 3, I report the details of the derivations.

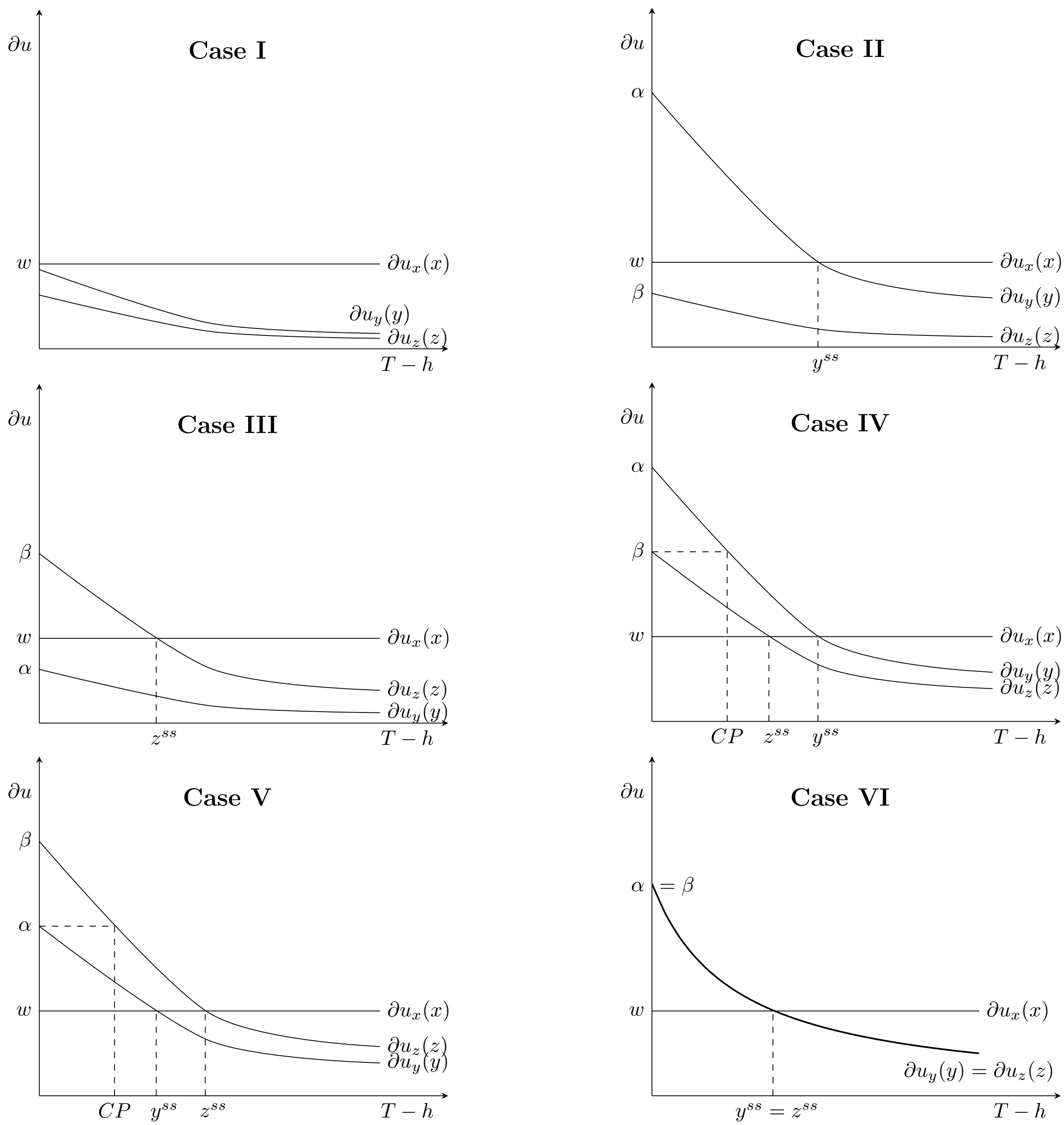


Figure 7: Marginal returns to work (x), childcare (y) and leisure (z), by case

In case II, the household member has a preference for childcare: the net time available will initially be allocated to care for children. However, since the returns to y are decreasing, this will be true only up to a point, the childcare steady state y^{ss}. Any extra time that is not allocated to either water fetching or childcare will thereafter be devoted to work. This is visualized graphically in the corresponding panel of Figure 7, where the marginal return to childcare $\partial u_y(y)$ is highest up to the intersection with the marginal return to work, when $y^{ss} = T - h$. Hence, the marginal return to work w is highest and will be preferred. Case III is symmetric to case II: the household member prefers to first allocate time to leisure or some form of self-care, including the pursuit of education. Similar to case II, they will reach a steady state point z^{ss} after which they will switch to wage-earning activities, as highlighted in the third panel of Figure 7.

Cases IV and V are also symmetric. In the former, the household member has a preference for childcare over leisure, but also a preference for leisure over work. Hence, they will allocate time to childcare as long as the marginal return is highest. Once the marginal return to childcare is equal to the marginal return to leisure, i.e. $\partial u_y(y) = \beta$, the combo point is reached: $T - h = CP$, and they will start to allocate time to leisure as well. They will do so until both reach their steady states, y^{ss} and z^{ss} respectively. At that point, the net time available will be equal to the steady state for both childcare and leisure, i.e. $T - h = y^{ss} + z^{ss}$. Any value $T - h$ that is above the sum of the two steady states will be allocated to work. Case V is similar to case IV, but this time the household member will allocate time to leisure first, until the marginal return to leisure is equal to the marginal return to childcare, i.e. $\partial u_z(z) = \alpha$.

The last case is a special one, in which the household has no preference between childcare and labor, but both are initially preferred to work. The net time available will be equally shared between these two activities until their marginal returns are equal to the wage rate, w. At that point, time allocated to both childcare and labor will have reached the steady state.

In this Chapter I have introduced the theoretical model that has now made it clearer how one can expect the RWH to benefit households' time availability and allocation. I have shown that there are different scenarios that could describe the change in households' time allocation after the introduction of the RWH. In the next section, I carry out an econometric analysis of a national consumption survey that will help to understand which of the scenarios is most likely to best describe Mexico City households' response to the introduction of RWHs.

6 National level analysis

In this section I will look at historical household data in Mexico. The goal of this section is to provide evidence on the importance of in-house access to water and try to understand how differences in water access affect the behavior of Mexican households in terms of labor force participation, time dedicated to childcare and leisure. Also, I will investigate the difference in behavior between men and women, given that it is expected that the water fetching burden is heavier for female household members, as highlighted in Chapter 4.

6.1 Empirical strategy

I want to understand whether differences in households' access to water explain differences in households' time allocation. The main concern that arises in an econometric analysis of this type is that it is hard to determine the causality of the relationship between the explanatory and the dependent variables. Indeed, one could argue that time allocation decisions determine the status of household's water access, rather than the other way around. This could be because households that, for instance, work more can afford to pay for the installation of private water pipes or have water delivered as a private service at no time cost.

The preferred empirical strategy would be based on a randomized control trial, which would assign improved water access to random households in the sample. In this way, one could be fairly confident that any relationship between water access and outcomes would causally run from the former to the latter. However, as it is often the case in infrastructure projects, such type of analysis is rather impractical. Alternatively, one could try to exploit exogenous variation in the explanatory variable in connection to newly introduced regulations, or other important shifts in material conditions.

In the absence of data to implement either of the first two approaches, I have structured the econometric analysis following the idea of Koolwal and van de Walle (2013). One could think of the effect that I am trying to capture as composed of two parts. The regional (or between) effect arises from the variance between geographic units, in this case municipalities, while the individual (or within) effect describes the variation between the individuals or households inside a given municipality.

A standard Ordinary Least Squares (OLS) model that does not distinguish between the two types of variance could be described by Equation 2:

$$Y_{ihj} = \alpha + \pi Z_{hj} + \phi X_{ihj} + \phi H_{hj} + \lambda G_j + \mu_j + \eta_{hj} + \epsilon_{ihj} \tag{2}$$

where Y_{ihj} is the outcome variable of individual i in household h in municipality j, α is a constant, Z_{hj} is the water access variable that varies for each household in the sample, and π the effect that I am trying to identify; X_{ihj} is a set of observables of the individual i in household h in geographic unit j, H_{hj} is a set of characteristics of the household, and G_j is a set of observables on the geographic unit j. The error term is composed of μ_j, which captures the error between geographic units, η_{hj} is the error term between households in geographic unit j, and ϵ_{ihj} which captures the remaining noise within each household h.

With this setup, the covariance of error term and key explanatory variable would very likely violate the exogeneity constraint. In other words, after controlling for regional, household and individual characteristics, the covariance between the key explanatory variable and the error terms would be different from zero. This implies that the estimation of water access effect on the outcome variable, i.e. the coefficient π, is not estimated consistently.

In order to obtain the "between-municipalities" equation, I first averaged out the individual observations at the household level. I distinguish between women and men, as I will estimate the regressions separately:

$$\bar{X}^w_{hj} = \frac{\sum_i^{n^w_{hj}} X^w_{ihj}}{n^w_{hj}} \qquad \bar{X}^m_{hj} = \frac{\sum_i^{n^m_{hj}} X^m_{ihj}}{n^m_{hj}} \tag{3}$$

$$\bar{Y}^w_{hj} = \frac{\sum_i^{n^w_{hj}} Y^w_{ihj}}{n^w_{hj}} \qquad \bar{Y}^m_{hj} = \frac{\sum_i^{n^m_{hj}} Y^m_{ihj}}{n^m_{hj}} \tag{4}$$

where n^w_{hj} is the number of female household members in household h and geographic unit j, while n^m_{hj} is the number of male members. The superscripts w and m indicate whether the variable refers to women or men. Once I obtain the household averages, I can compute the averages at the municipal level. For the explanatory variables that contain household-level variance, I first construct a new matrix that includes the household-specific vectors and the vectors with the average values of its members: $K^w_{hj} = [\bar{X}^w_{hj}, H_{hj}]$ and $K^m_{hj} = [\bar{X}^m_{hj}, H_{hj}]$. Now I can average out the household level to obtain the new variables that I will use in the final estimation. Since the key explanatory variable water access is also a household level variable, I can compute its municipality-level average in a similar fashion:

$$\bar{K}^w_j = \frac{\sum_h^{n^w_j} K^w_{hj}}{n^w_j} \qquad \bar{K}^m_j = \frac{\sum_h^{n^m_j} K^m_{hj}}{n^m_j} \tag{5}$$

$$\bar{Y}^w_j = \frac{\sum_h^{n^w_j} \bar{Y}^w_{hj}}{n^w_j} \qquad \bar{Y}^m_j = \frac{\sum_h^{n^m_j} \bar{Y}^m_{hj}}{n^m_j} \tag{6}$$

$$\bar{Z}_j = \frac{\sum_h^{n_j} Z_{hj}}{n_j} \tag{7}$$

where n^w_j and n^m_j indicate the number of households in municipality j that have at least one female and one male member respectively. The "between-municipalities" estimator is then obtained through the following equations:

$$\bar{Y}_j^w = \alpha + \pi \bar{Z}_j + \phi \bar{K}_j^w + \lambda G_j + \mu_j \tag{8}$$

$$\bar{Y}_j^m = \alpha + \pi \bar{Z}_j + \phi \bar{K}_j^m + \lambda G_j + \mu_j \tag{9}$$

Note that with respect to Equation 2 all subscripts i and h have been averaged out. The new exogeneity requirement implies that the covariance between the explanatory variable and the error terms is zero in both equations. In order to identify the coefficient of interest (π) in a consistent manner, one should ensure that this key assumption holds. The exogeneity requirements implies that the model should include sufficient geographic controls (G_j and $\bar{K}_j$) to make it plausible that the variance in the outcome variable that is not controlled for can be explained by water access without a bias.

At the same time, one should be careful to not include unnecessary controls, since the more controls that are included the less efficient and precise the estimation will be. A further concern that arises in connection to the use of the between-variance approach is the elimination of a substantial share of variance in the model. Indeed, averaging out the individual and household variation will significantly decrease the model's power of estimation.

6.2 Data and descriptive statistics

I use a national consumption survey from 2018 carried out by INEGI, the Mexican national statistics and geographical Institute (INEGI, 2018b). It includes 269,206 individuals from 74,647 households in 996 municipalities, roughly equally representing each of the 32 Mexican States. Below I introduce the key variables of interest. Note that I display the values already averaged at the municipal level, as I will use in the regressions. As already established in the previous theoretical part, I focus on three possible time allocation outcomes, i.e. work, childcare and leisure.

The first outcome variable, x in the theoretical model, aims at capturing variation in the workforce. Since it is widely acknowledged that work in developing countries is fragmented and often informal (Geere & Cortobius, 2017), it is unlikely that I would be able to capture any significant effect on a binary employment status variable. Rather, I consider a variable that measures the hours the survey respondent spent on wage-earning activities in the week preceding the survey. In this way, I am able to also capture smaller variation in hours dedicated to work of those who already considered themselves as working.

While effects on labor force are relatively straightforward to capture in the data, this is not the case for childcare, represented by variable y in the theoretical model. Like other household related tasks, childcare is not measured by any standard economic survey and is often not reflected in national statistics. In order to overcome this issue, a common approach in the literature is to consider variables that are likely to strongly depend on childcare and are directly measurable with data. Two such variables are child health and child school attendance: as children are more cared for, they will grow healthier and will be more likely to engage in fundamental education. Nygren et al. (2016) found that water fetching times above thirty minutes are correlated with higher levels of diarrhea among children in SSA. Similarly, Kremer et al. (2011) find that improved water infrastructure improves child health in rural areas of Western Kenya. However, it is hard to disentangle what share of children improved health comes directly from the improved water access, say, because children can use more water since it is more available, or indirectly from the time saving component. Koolwal and van de Walle (2013) find evidence of water access impacts on children school attendance in Yemen, Morocco, Nepal and Pakistan, although they also do not control for potential causation that might stem from the direct health channel.

Nevertheless, I decide to use children school attendance as a proxy for childcare, since it is reasonable to assume that the direct health channel plays a less important role in Mexico, as opposed to sub-Saharan Africa or South Asia. Indeed, in general, water in Mexico is available for everyone, but varies in its accessibility. In the dataset I use, children school attendance is measured over children aged 3 to 15. On average, as detailed in Table 2, about 90% of Mexican children are attending school. There is very little difference between boys and girls, and also a rather small variation across municipalities: 95% of municipalities have a school attendance rate between 85% and 97%. Little variation in the outcome variable poses an issue in the precision of estimation, as will emerge in the results section.

The third channel through which time savings could affect Mexican households is variable z in the theoretical model. So far I have been rather vague with respect to this variable. Indeed, my intention is to capture a broad range of effects related to time that people dedicate to themselves, such as any free time activity and education. A research project in Ethiopia found that there is a strong connection between high illiteracy rates among women and time spent fetching water (Demie et al., 2016), hinting that time poverty matters towards education rates in the population. Variable z channel could also be connected to the psychological tranquility in the household, a factor that might lead to conflict reduction within and between households. Indeed, the uncertainty arising from a fundamental human life component such as water often puts families under serious distress. Devoto et al. (2012) found that in Morocco in-house tap water increases time available for leisure and reduces conflict between and within households and ultimately could be reflected in health of household members.

The outcome variables I choose to estimate the time effect of water access on the theoretical model variable z are education and health. With respect to education, I consider the years of schooling of people that are 3 years or older as measured by INEGI in the survey. In the dataset, I have information on the highest level of school that people aged 3 or more have obtained. To each level, I assign the corresponding years of schooling that are necessary to complete the level. Hence, people who did not complete primary education are assigned 0 years of schooling, while the a maximum of 23 is assigned to doctoral graduates. As reported in Table 2, women have a slightly higher number of school years than men with approximately 8.5 years spent in school on average.

I also use health as a proxy for leisure. The connection between these two variables is also widely demonstrated in medical literature, as shown, for instance, by Coleman and Iso-Ahola (1993). In order to measure health, I generate a dummy variable that is equal to 0 if the individual has declared to have been sick in 2018, and 1 if the individual has been healthy throughout the year. As shown in Table 2, about 36% of women self-reported that they had been in good health in 2018, as opposed to almost 42% of men.

The last three columns of Table 2 display how many individuals, households and municipalities are available for each of the outcome variables in the table. For instance, the sum of the "# individuals" column that corresponds to the outcome variable for health is 269,206, which is the total number of individuals interviewed in the survey. Since the other variables cover only a selected age range, there are less individuals in those groups. The households column discloses that there are some households with either only men or women, since the total number of households 74,647 is not met in any row. The municipalities column tells us that there are at least some observations in each municipality for each variable in the table.

Variable	Gender	Mean	St. Dev	# individuals	# households	# municipalities
Outcome variables						
Hours worked in last week, 12+ y.o	women	36.11	6.16	109,828	67,396	996
	men	46.30	4.48	102,566	64,904	996
School enrolment (1=yes), 3-15 y.o.	women	0.91	0.07	31,439	23,584	996
	men	0.91	0.07	33,237	24,667	996
Years of schooling, 3+ y.o.	women	8.51	1.31	131,418	67,478	996
	men	8.49	1.25	125,407	66,382	996
Sickness reported in last year (1=yes)	women	0.36	0.09	137,529	67,478	996
	men	0.42	0.09	131,677	66,382	996
Key explanatory variables						
Indoor tap water (binary, 1=yes)		0.69	0.21		74,647	996
Avg. hours to fetch water, per week		0.61	0.62		74,647	996

Table 2: Descriptive statistics

The key explanatory variable is water access. For robustness, I decide to consider two main variables to measure access to water, one at the time, and the results for both will be presented. The first key explanatory variable is a binary variable that is equal to one if the household has tap water in the house. It turns out that only about 69% of Mexican households have in-house tap water as measured by this survey. The relatively large standard deviation displayed in the corresponding row of Table 2 reveals that there is a rather large variation between municipalities. Indeed, in Figure 8 one can see that in most Southern regions less than 40% of households have in-house water access, while regions closer to the Northern border have much broader coverage of in-house tap water.

The second key explanatory variable that I consider for the analysis is an estimation given by the household on how much time it spends fetching water each week. I want to consider this variable as well, because, as emerged in Chapter 4, even if connected to the water grid, households seek other water sources either due to irregular supply or water quality. The last row of Table 2 shows that on average households spend 0.6 hours per week fetching water. The very large standard deviation implies that there is a lot of variation in the mean of this variable across municipalities. As one would expect, the juxtaposition of Figures 8 and 9 shows that regions that have a high incidence of in-house tap water have a relatively low mean of hours spent fetching water.

Figure 8: In-house tap water, % of households

Figure 9: Avg. Hours to fetch water, per week

Note: Displayed federal averages from available municipalities.
Source: Author's rendering of INEGI's data (2018b).

The control variables are listed in Tables 3 and 4. The control variables play a very important role in the analysis because they ensure that I can causally identify the coefficient of interest in the regression. These variables must be included to guarantee that the key explanatory variable captures the actual variance of the outcome variable that is caused by the explanatory variable only. For this reason, it is crucial to build adequate control groups. In the first column of Table 3 one can find the control variables that belong to the G_j group, i.e. the characteristics of the municipality. The goal here is to include variables that might explain the variance in the outcome variables that does not arise as a direct consequence of water access. In this group, I include economic variables such as a commodity price index and the average salary for men and women, as well as other variables that indicate the level of development of the municipality.

On the right-hand column of Table 3, I list variables that are specific to the household, i.e. H_{hj}.

Municipal control variables	Household control variables
Price index	Age of household (HH) head
Average women salary	Age squared of HH head
Average men salary	HH head is divorced / widow (binary)
Distance to closest hospital (in minutes)	HH head is married (binary)
Share of people with bank account	HH head has chronic disability (binary)
Marginalization index*	Maximum years of schooling of adult man
Human development index**	Maximum years of schooling of adult woman
Share of hhd with electricity	Log HH size
Log of per capita expenditure	Share of women
Population	Share of 65+ y.o.
Population density	Share of 12-65 y.o.
Extension of municipality	Indigenous (binary)
Altitude of municipality	Catholic (binary)
	Own land (binary)
	Receive transfers (binary)
	Log HH per capita expenditure
	Walls of solid material (binary)

* Indicator that measures the intensity of deprivation suffered by the population (Conapo, 2019).

** Index of average progress of three basic aspects of human development (PNUD, 2019).

Table 3: Municipal and household control variables

Once more, I want to make sure I add those variables that can causally identify the effect of water access on the outcome variables. Here I consider details on the household head, as well as the demographic composition of the household and its social economic status.

While the control variables in Table 3 are included in the regression corresponding to every outcome variable, the same does not hold for the individual controls listed in Table 4. Indeed, I only include those variables that arguably precede the key explanatory variable in the causal sequence that leads to the outcome. As I consider several outcome variables, control variables that are potentially colliding with the key explanatory variable are excluded correspondingly to each outcome variable. For instance, in the regressions with the outcome variable that measures the education level of the individuals, I will not include the control variable years of schooling, obviously. Instead, I will include this control when I regress the outcome variable working hours, since the number of years of schooling could be a relevant component in this case. For this reason, I build a vector of individual variables for the outcome variables "hours of work", "school enrolment", "education", and "health" respectively. This control group contains information on the individual characteristics of the household member, such as age, health and civil status. Control variables that are included in the respective control group are marked with an "x" in Table 4.

Outcome variables:	Work	School enrolment	Education	Health status
Control variables				
Age	x	x	x	x
Age squared	x	x	x	x
Married (binary)	x		x	x
Divorced / widow (binary)	x		x	x
Chronic illness (binary)	x	x	x	x
Years of schooling	x			x
Years of schooling squared	x			x
Sick in last year	x	x	x	
Mother in home (binary)	x	x	x	x
Father in home (binary)	x	x	x	x
Mother's years of schooling	x	x	x	x
Father's years of schooling	x	x	x	x

Note: The mark "x" means that the corresponding control variable is included in the regression for the outcome variable of that column.

Table 4: Individual-level control groups for each outcome variable

6.3 Results

In this section I present the estimates of coefficient π in the model Equations 8 and 9. In Table 5a the key variable of interest is the binary variable that is equal to one for households that have in-house water access. In Table 5b, instead, the key explanatory variable is measured as the hours that the household spends fetching water each week. In both cases, the variable is averaged at the municipal level, as described by Equation 7, and represented as $\bar{Z}_j$ in the model Equations 8 and 9.

According to my thesis, one would expect the coefficient estimated to be positive in Table 5a: having access to water in the house decreases the amount of time that the household has to spend fetching water, increasing the time that household members could spend working, caring for children, leisure or other activities. Conversely, the coefficient in Table 5b is expected to be negative. Indeed, the more hours one has to spend fetching water, the less hours they will have available to do other activities.

Each column represents a different outcome variable. In columns (1) and (2), the outcome variable is hours worked for women, w^w, and men, w^m, respectively. While the binary variable regression gives mixed and insignificant results, Table 5b shows that there seems to be a negative relationship between the hours spent fetching water and the hours spent on wage-earning activities. The effect is significant for women at the 5% level, while it is not significant for men. The coefficient -0.9274 tells us that for each hour that the household spends fetching water, women that live in that house will on average spend almost one hour less working. This close to one to one relationship is a very strong statement. From this application it seems that the water fetching burden is rather heavy on female labor force, a result that has not clearly emerged in previous literature.

One of the reasons that might explain the difference in the results obtained here compared to other studies could lay in the fact that in this case I have used hours worked as the outcome variable. This has allowed me to capture a wider variance as opposed to a binary variable for employment that has been used in other reports. Another reason could stem from the different culture that exists in Latin America compared to Sub-Saharan Africa or Asia, where most of other studies of this type have been carried out. Indeed, the role of women in wage-earning activities is arguably less stigmatized in the Americas as opposed to other regions.

In columns (3) and (4) of Table 5 one can find the estimation of the coefficient of interest for the outcome variable that indicates whether the individual is attending school, for girls and boys respectively. With neither of the key explanatory variables am I able to find a coefficient that is different from zero. This might be due to the fact that the outcome variable I consider in this case has little variance, as explained in the previous section. Also, it is debatable how strong the link between childcare and school attendance is in a country like Mexico, where school participation rates for children are already close to universal, unlike countries in which similar studies were located.

Columns (5) through (8) in Table 5 report results for the effect of water access on time spent on education and health. With respect to education, it seems that access to in-house water leads to 0.2799 years of additional education for women. This result is significant at the 5% level, as one can see in Table 5a. In the same Table, the last column shows another significant result for the health of men. In-house access to water increases the chances that men have stayed healthy throughout the year by 3%. Instead, no significant result was found with respect to the key explanatory variable that measures the hours spent fetching water each week, in Table 5b. These results are in line with expectations and with the rest of the literature[8].

[8]Although it goes beyond the scope of this thesis to delve into the reasons for which women might engage more in education compared to men, the reader might find interesting the literature on this topic for instance in Goldin, Katz and Kuziemko's paper (Goldin, Katz, & Kuziemko, 2018).

(a) Results for binary water access variable

	(1) w^w	(2) w^m	(3) se^w	(4) se^m	(5) ed^w	(6) ed^m	(7) he^w	(8) he^m
Indoor tap water (binary, 1=yes)	0.2410	-0.7263	0.0282	-0.0284	0.2799*	0.0590	0.0156	0.0305*
	(1.3393)	(1.0794)	(0.0183)	(0.0182)	(0.1354)	(0.1211)	(0.0153)	(0.0152)
N	996	996	996	996	996	996	996	996
R^2	0.4109	0.3082	0.1969	0.1814	0.8918	0.9077	0.5668	0.5774

Standard errors in parentheses * $p < 0.05$

(b) Results for explanatory variable hours spent fetching water each week

	(1) w^w	(2) w^m	(3) se^w	(4) se^m	(5) ed^w	(6) ed^m	(7) he^w	(8) he^m
Hours to fetch water, per week	-0.9274*	-0.3895	-0.0022	0.0003	-0.0481	0.0523	0.0074	-0.0087
	(0.4507)	(0.3656)	(0.0061)	(0.0062)	(0.0451)	(0.0422)	(0.0051)	(0.0051)
N	996	996	996	996	996	996	996	996
R^2	0.4137	0.3088	0.1949	0.1791	0.8912	0.9079	0.5673	0.5768

Standard errors in parentheses * $p < 0.05$

Notes: all regressions include municipality control variables as well as household and individual variables averaged at the municipality level. Each variable in the table represents its municipality average of the corresponding households and households' individual averages. w^w represents the outcome variable hours worked in last week for women, w^m for men. se^w is the outcome binary equal to one if the girl goes to school, se^m for the boys. ed^w is the outcome variable years of schooling for women, ed^m for men. he^w is the binary outcome variable equal to 1 if the woman was healthy throughout the year, he^m for men.

Table 5: Results

7 Reconciliation and discussion

The results obtained in Chapter 6 allow me to speculatively deduce which of the scenarios outlined in Chapter 5 is most plausible. Recall that in the theoretical model α expresses the preference of household members over childcare, while β over leisure. The respective values, also compared to the wage level w, will determine how households react to changes in their net time budget $T - h$. The strong relationship that emerged between hours to fetch water and hours that women spend working locates us on a diagram in Figure 7, in which the marginal returns to work, $\partial u_x(x)$, are higher than the other curves. This could correspond to case I, or, as long as $T - h > y^{ss} + z^{ss}$, to any other case.

The second significant results that I found in Chapter 6 suggests that household members would also switch to leisure activities, once improved water access increases their time budget. This indicates that

β is relatively large compared to α and w. According to this finding, it could be reasonable to choose either case III or case V as the one that best represents Mexican households preferences. Considering that I failed to verify that the coefficient estimated in Columns (3) and (4) of Table 5 is different from zero, it seems plausible to assume that the value of α in the theoretical model is relatively low compared to w. This would suggest that we are either in case III, at any value of $T - h$, or at an early stage of case V.

In no theoretical case I can possibly have time allocated to work and leisure increase at the same time. Either leisure, i.e. z, increases until it reaches the steady state z^{ss}, or work, variable x in the theoretical model, increases. However, one could look at the installation of the RWHs in a household as a jump in the time required to fetch water, from high $c = High$ to low $c = Low$. Hence, also the value $T - h$ would jump from a relatively low to a relatively high value, allowing me to consider an interval on the horizontal axis in one of the diagrams in Table 7, rather than a point. The only consecutive interval that would result in both an increase in work and leisure, and at the same time no increase in childcare, is the interval around the steady state of leisure, z^{ss} in the diagram corresponding to case III in Figure 7.

Hence, according to the analysis that I have illustrated, the SCALL project in Mexico City is likely to free up time for household member to dedicate in leisure activities until they reach a steady state, in which an additional minute spent on leisure would come at too high an opportunity cost, given that work would give them a larger utility. In particular, my findings suggest that women will engage in education, while men will fall sick less frequently. Once leisure activities are dedicated sufficient time, female household members will then switch and start to increase their labor market participation.

However, together with these inferences, the many limitations of the study should be considered. First, I am using a national survey in Chapter 6 to predict the behavior of a very specific sample of households in a sub-urban area of Mexico City, which I described in Chapter 4. It might be possible that the national average results that I obtain do not apply very closely to the sample that I am interested in. Moreover, the econometric analysis here considers water access trough two variables, namely the binary for in-house tap water and the number of hours that households spend to fetch water. It is debatable to what extent the variance in either of these two variables is comparable to the time savings that will originate through the RWH, whose impact is what I am ultimately trying to measure.

In addition, the results I obtain trough the econometric analysis cannot be relied on with absolute confidence. Indeed, the empirical strategy that I use relies on the assumption that I successfully control for all potential endogeneity that might exist between the key explanatory variables and the outcome variables. This is a bold claim that would need to be ascertained more in detail.

One important limitation in the analysis is also to be found in the assumption I make on childcare and leisure. In the econometric part, I assume that childcare and leisure could be reflected in the school attendance rate of children and education levels of household members or their health status. This might not necessarily be the case, since household members might take care of their children in ways that are not necessarily reflected in the school attendance rate. Also, household members might do other things in their free time that do not necessarily include self-education, or lead to better health.

With respect to the theoretical part, it should be also noted that the functions I consider are monotonous, hence do not allow for switch backs. Ideally, one would design a model in which households can allocate time to activities repeatedly. Moreover, it would be interesting to develop a model that allows for interaction between household members. Since the results I have found are different for men and women, it would make sense to try to elaborate on such a model.

8 Conclusions

In this thesis I address one core matter, i.e. how can we expect RWHs to benefit Mexico City households that are in a situation of water supply distress. I focus on the time aspect of the issue, and find that after the installation of the RWHs, it seems reasonable to expect Mexico City female household member to participate more in wage-earning activities, while both men and women will dedicate more time to leisure.

I reach these conclusions through an analysis that I begin by providing the reader with an overview of the current water supply situation in Mexico and Mexico City, together with a summary of relatable literature. In Chapter 4, I highlight that Mexico City households in neighborhoods where the SCALL project is being carried out spend a lot of time fetching water. This is true also for households connected to the water grid, because tap water is available to them only during limited time per week, and its quality is often rather low. I also show, through a short simulation, that the RWHs could save Mexico City households about 40% of the time that they currently spend fetching water. In Chapter 5, I introduce a theoretical model that helps understand how households could reallocate the time that they could save thanks to the installation of the RWH. I show that there are different possible scenarios, depending on the value of households' preferences between work, childcare and leisure.

In Chapter 6 I proceed to use econometric tools with a national database to estimate the impact of households' time allocation based upon differences in water access. I find that the longer it takes to fetch water each week, the less hours Mexican women will engage in the labor market. Access to in-house tap water also seems to be related to higher female education and better health for men, two elements that I credit to the leisure channel. In Chapter 7 I argue that, given these econometric results, it seems that the current time allocation situation of Mexican households could be represented by Case III in Figure 7. Hence, the expected benefits of the installation of RWHs in Mexico City might be represented by change in the net time available $T - h$ around the steady state of leisure z^{ss}.

This thesis contributes to the existing literature in multiple ways. First, by describing the current situation of water distress in Mexico City, which is admittedly poorly documented. Second, by introducing a theoretical tool that allows for a dynamic analysis of households time allocation as net time availability changes, in which households can allocate time to four different activities and one of them is necessary for the household's survival. Lastly, I estimate the impact of differences in water access on social outcomes, a type of analysis that has not previously been executed in Mexico. Although the econometric analysis could be improved in many aspects, the tentative findings I present here depict a situation that speaks very favorably for the improvement of the current water supply infrastructure.

Further research on this topic is essential to uncover a deeper understanding of the social impact that RWHs will bring. In particular, it could be worthwhile to carry out impact evaluations of the ongoing SCALL project, something that I set out to do but could not pursue due to logistical, time and confidentiality reasons. Also, further research could broaden the utility of this thesis to other aspects, such as environmental and financial impacts that come with RWHs. Isla Urbana, the association that is currently cooperating with Mexico City government to install RWHs in the city, is laying the foundation for a more comprehensive impact evaluation of their work. Interested researchers should be able to reach out to them and cooperate on a continuous basis, in order to further raise awareness on the importance and urgency of such projects.

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Appendices

1. The SCALL Project in detail

SEDEMA and Isla Urbana approach each commune one by one within the two delegations. In each commune, the associations will follow 5 steps:

1. **Raise interest**: distribution of flyers and display posters, inviting people to attend the compulsory junta comunitaria (community meeting) with the necessary documents to register (including identity card and papers that certify legal registration of the house).

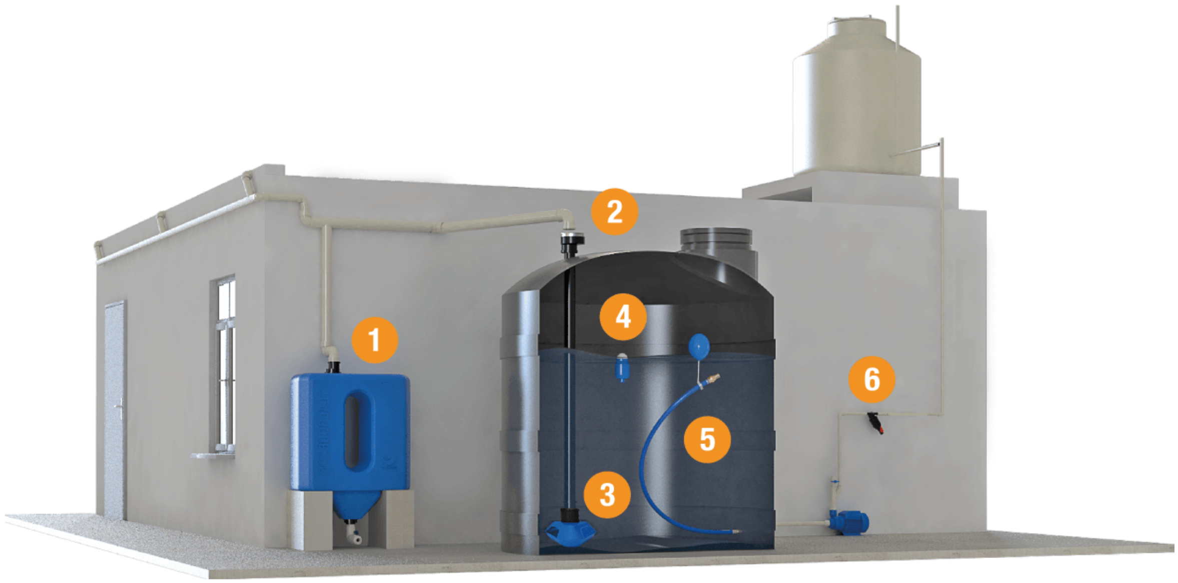
2. **Junta comunitaria**: SEDEMA and Isla Urbana present the project, the functionality of the RWH, as well as the requisites that houses need to meet (clear roof and sufficient space for a water tank).

3. **Registration**: at the end of the junta comunitaria, the interested households will register at the desk of SEDEMA and Isla Urbana, providing the necessary documentation and details of the address.

4. **Technical visit**: within the following couple of days from the registration, households will be visited by a collaborator of SEDEMA and one of Isla Urbana. During the technical visit, SEDEMA helps a member of the household to fill in the socioeconomic survey, while the Isla Urbana collaborator makes sure that the households can support the installation of the RWH.

5. **Installation**: if the household complies with the technical requirements to support the installation, Isla Urbana will contact the household to schedule the installation, typically carried out by a team of 3 people of Isla Urbana.

2. The Rain Water Harvester



1. **Tlaloque**: first rain separator. It diverts the first volume of water that falls in each rain to prevent dirt dragged from the roof from entering the cistern.

2. A **leaf filter** in stainless steel retains leaves and coarse material that contaminates water.

3. The **turbulence reducer** allows water to enter the cistern in a calm way, preventing sediments from being stirred. In this way, the cistern functions as a settler.

4. A **chlorine dispenser** is placed inside the cistern to disinfect the water.

5. The **floating pigeon** sucks the water from the cleanest part of the cistern.

6. A 50 micron **sediment filter** ensures that also the smallest particles are filtered out.

3. Theoretical model

I rewrite the model in the standard optimization format:

$$\begin{aligned}
\max \quad & u(x,y,z,h) = w*x + \alpha*log(y+1) + \beta*log(z+1) + g(h) \\
\text{s.t.} \quad & h_1(x,y,z,h) = x+y+z+h-T \leq 0 \\
& h_2(x,y,z,h) = -x \leq 0 \\
& h_3(x,y,z,h) = -y \leq 0 \\
& h_4(x,y,z,h) = -z \leq 0 \\
& h_5(x,y,z,h) = -h \leq 0
\end{aligned}$$

And $T > 0$ is finite. As the goal function is a composition of continuous function, it is continuous. The feasible set is non-empty, closed and bounded. Hence, by Heine-Borel theorem, the feasible set is compact: a maximum exists, according to the Extreme Value Theorem.

Since the constraints h_1, h_2, h_3, h_4, h_5 are affine functions, the Karush-Kush-Tucker conditions to find the global maximum apply. The Lagrangian function will look as follows:

L(x,y,z,h,$\mu_{1,2,3,4}$) $= wx+\alpha ln(y+1)+\beta ln(z+1)+g(h)-\mu_1[x+y+z-(T-h)]-\mu_2(-x)-\mu_3(-y)-\mu_4(-z)$

$$\begin{aligned}
\text{from which one obtains the partial derivatives} \quad & \frac{\partial \mathcal{L}}{\partial x} = w - \mu_1 - \mu_2 \overset{!}{=} 0 \\
& \frac{\partial \mathcal{L}}{\partial y} = \frac{\alpha}{y+1} - \mu_1 - \mu_3 \overset{!}{=} 0 \\
& \frac{\partial \mathcal{L}}{\partial z} = \frac{\beta}{z+1} - \mu_1 - \mu_4 \overset{!}{=} 0 \\
\text{together with the set of restrictions} \quad & x+y+z+h-T \leq 0 \\
& -x \leq 0 \\
& -y \leq 0 \\
& -z \leq 0 \\
\text{and the complementary slackness conditions} \quad & \mu_1, \mu_2, \mu_3, \mu_4 \geq 0 \\
& \mu_1(x+y+z+h-T) = 0 \\
& \mu_2(-x) = 0 \\
& \mu_3(-y) = 0 \\
& \mu_4(-z) = 0
\end{aligned}$$

I want to use the model to describe what happens when h decreases, i.e. the household does not need to spend as much time fetching water. The value of c in Equation 1 is not known, but we know that it will be invested for sure. Hence, I will consider $T-h$ as the net time available for the household to spend on the other activities x, y, z, with $h \in [0, T]$, and a will be included in the utility function. I distinguish the following six cases:

I	$\alpha, \beta \leq w$
II	$\alpha > w, \beta \leq w$
III	$\beta > w, \alpha \leq w$
IV	$\alpha > \beta > w$
V	$\beta > \alpha > w$
VI	$\alpha = \beta > w$

Case I: utility from work is relatively high, no time is allocated to childcare and leisure, respectively y, z.

$$x = T - h$$
$$y = 0$$
$$z = 0$$

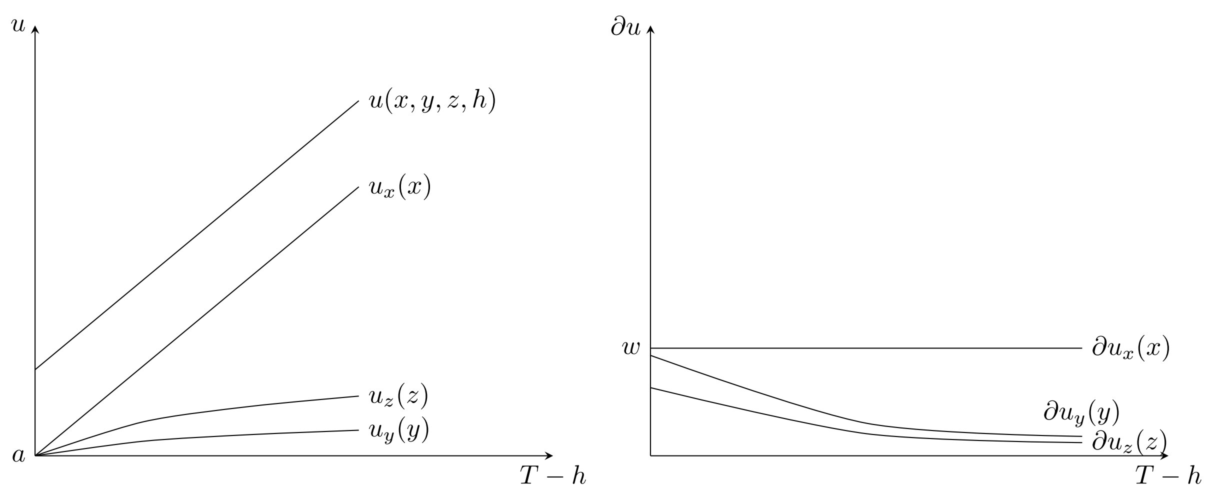


Figure 10: *Case I, with* $\alpha \leq w; \beta \leq w$

Case II: Households value childcare. They will allocate time to childcare up to the steady state y^{ss}.

$$x = \begin{cases} 0 & \text{if} \quad T-h \leq \frac{\alpha-w}{w} \\ T-h-y & \text{if} \quad T-h > \frac{\alpha-w}{w} \end{cases}$$

$$y = \begin{cases} T-h & \text{if} \quad T-h \leq \frac{\alpha-w}{w} \\ \frac{\alpha-w}{w} = y^{ss} & \text{if} \quad T-h > \frac{\alpha-w}{w} \end{cases}$$

$$z = 0$$

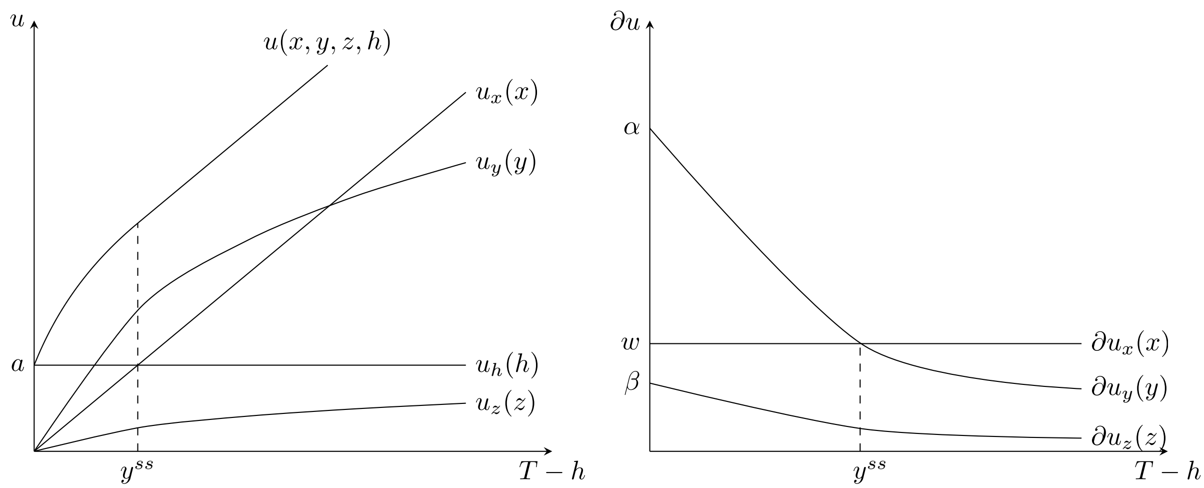


Figure 11: *Case II, with* $\alpha > w; \beta \leq w$

Case III: Same like Case II but reversed. Households value leisure. They will allocate time to it up to the steady state z^{ss}.

$$x = \begin{cases} 0 & \text{if} \quad T-h \leq \frac{\alpha-w}{w} \\ T-h-y & \text{if} \quad T-h > \frac{\alpha-w}{w} \end{cases}$$

$$z = \begin{cases} T-h & \text{if} \quad T-h \leq \frac{\beta-w}{w} \\ \frac{\beta-w}{w} = y^{ss} & \text{if} \quad T-h > \frac{\beta-w}{w} \end{cases}$$

$$y = 0$$

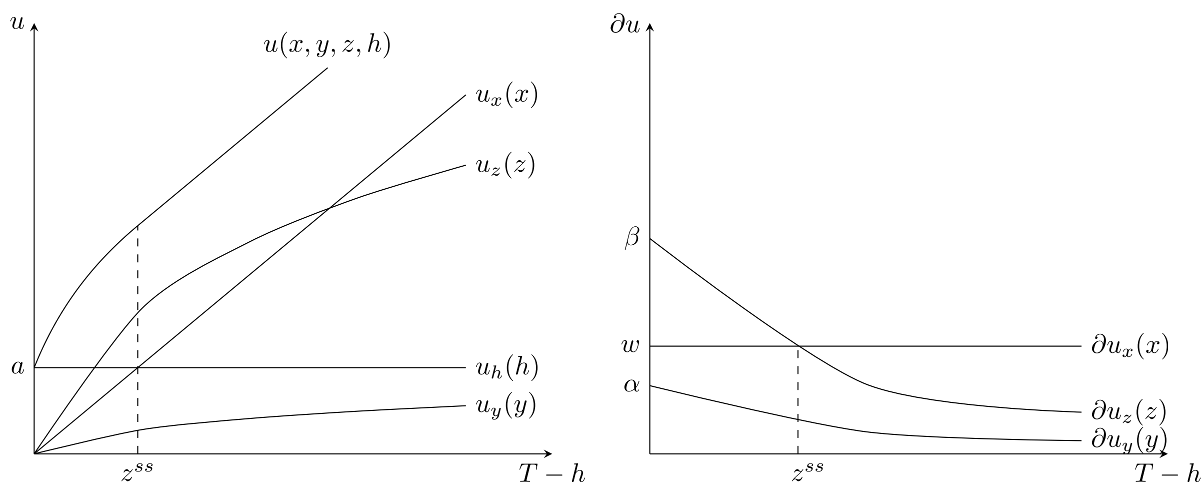


Figure 12: *Case III, with* $\beta > w; \alpha \leq w$

Case IV: Households value childcare and leisure, with a preference for the former.

$$x = \begin{cases} 0 & \text{if} \quad T-h \leq \frac{\alpha+\beta-2w}{w} \\ T-h-y-z & \text{if} \quad T-h > \frac{\alpha+\beta-2w}{w} \end{cases}$$

$$y = \begin{cases} T-h & \text{if} \quad T-h \leq \frac{\alpha-\beta}{\beta} \\ \frac{\alpha(T-h+1)-\beta}{\alpha+\beta} & \text{if} \quad \frac{\alpha+\beta-2w}{w} \geq T-h > \frac{\alpha-\beta}{\beta} \\ \frac{\alpha-w}{w} = y^{ss} & \text{if} \quad T-h \geq \frac{\alpha+\beta-2w}{w} \end{cases}$$

$$z = \begin{cases} 0 & \text{if} \quad T-h \leq \frac{\alpha-\beta}{\beta} \\ \frac{\beta(T-h+1)-\alpha}{\alpha+\beta} & \text{if} \quad \frac{\alpha+\beta-2w}{w} \geq T-h > \frac{\alpha-\beta}{\beta} \\ \frac{\beta-w}{w} = z^{ss} & \text{if} \quad T-h \geq \frac{\alpha+\beta-2w}{w} \end{cases}$$

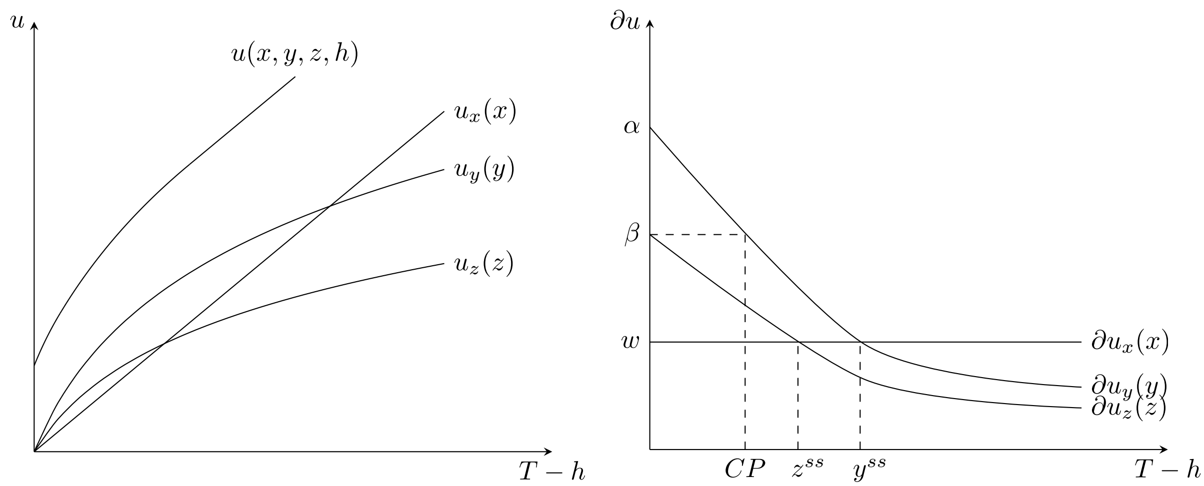


Figure 13: *Case IV, with $\alpha > \beta > w > 0$*

Case V: similar to case IV, households value childcare and leisure, but now they have with a preference for the latter.

$$x = \begin{cases} 0 & \text{if} \quad T-h \leq \frac{\alpha+\beta-2w}{w} \\ T-h-y-z & \text{if} \quad T-h > \frac{\alpha+\beta-2w}{w} \end{cases}$$

$$z = \begin{cases} T-h & \text{if} \quad T-h \leq \frac{\beta-\alpha}{\alpha} \\ \frac{\beta(T-h+1)-\alpha}{\alpha+\beta} & \text{if} \quad \frac{\alpha+\beta-2w}{w} \geq T-h > \frac{\beta-\alpha}{\alpha} \\ \frac{\beta-w}{w} = z^{ss} & \text{if} \quad T-h \geq \frac{\alpha+\beta-2w}{w} \end{cases}$$

$$y = \begin{cases} 0 & \text{if} \quad T-h \leq \frac{\beta-\alpha}{\alpha} \\ \frac{\alpha(T-h+1)-\beta}{\alpha+\beta} & \text{if} \quad \frac{\alpha+\beta-2w}{w} \geq T-h > \frac{\beta-\alpha}{\alpha} \\ \frac{\alpha-w}{w} = y^{ss} & \text{if} \quad T-h \geq \frac{\alpha+\beta-2w}{w} \end{cases}$$

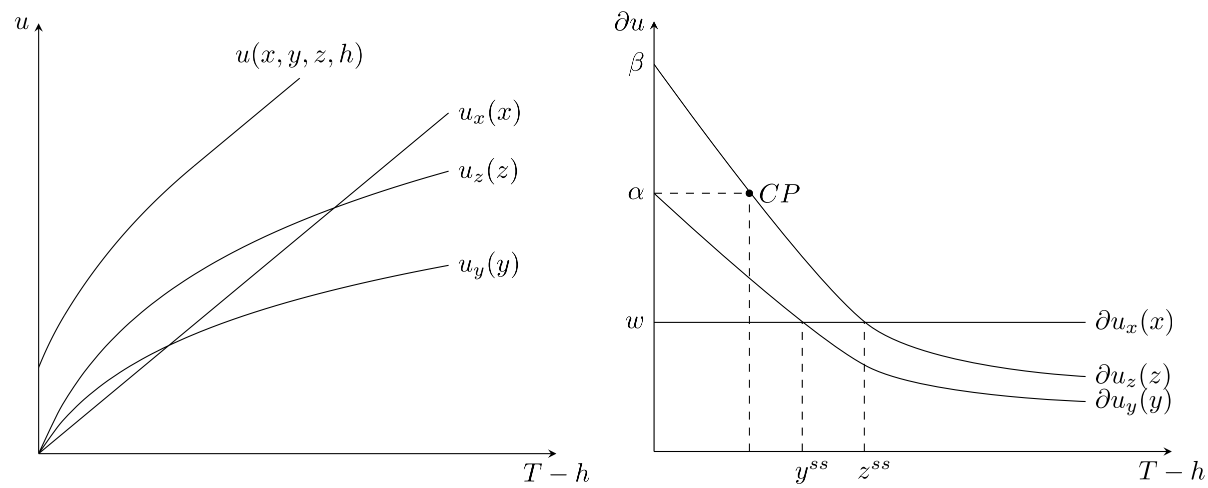


Figure 14: *Case V, with* $\beta > \alpha > w > 0$

Case VI: Households equally value leisure and childcare.

$$x = \begin{cases} 0 & \text{if} \quad T-h \leq \frac{\alpha+\beta-2w}{w} \\ T-h-y-z & \text{if} \quad T-h > \frac{\alpha+\beta-2w}{w} \end{cases}$$

$$z = \begin{cases} \frac{1}{2}T-h & \text{if} \quad T-h \leq \frac{\beta-\alpha}{\alpha} \end{cases}$$

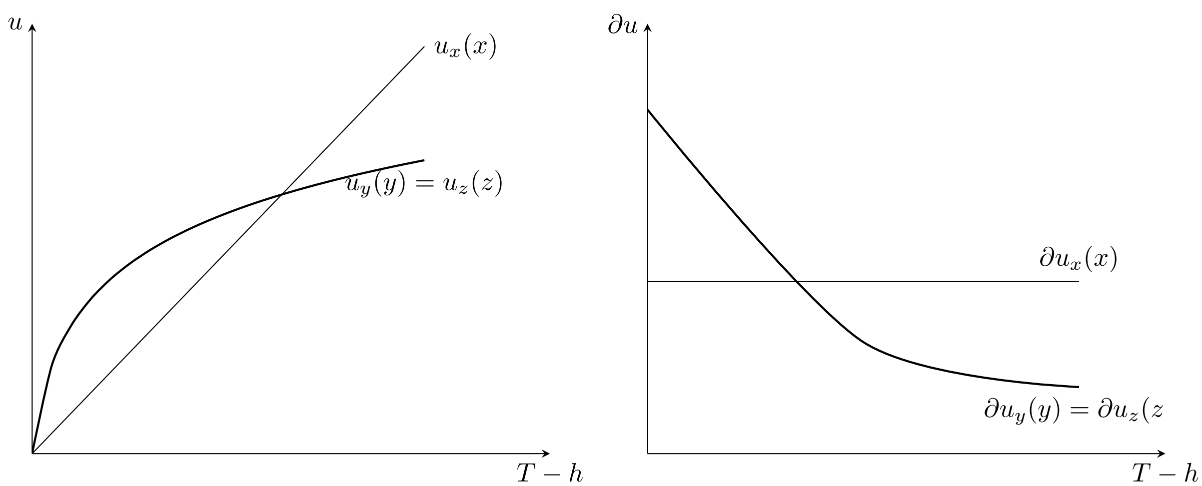


Figure 15: *Case VI, with* $\alpha = \beta > w > 0$