The Effect of Rainwater Harvesting on Reducing Poverty[*]

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preliminary draft, please do not quote

Abstract

This paper explores the potential of rainwater harvesting as an instrument to reduce poverty in areas without immediate access to an improved water source. Using a unique Brazilian dataset, we find that building rainwater harvesting infrastructure at the homestead does reduce household poverty through three channels: a time allocation effect, an agricultural production effect, and a livestock production effect. Households spend less time on fetching water from distant sources, and savings in time are also allocated to other productive activities. An increase in the households' water supply allows them to scale-up agriculture and livestock production, thus increasing wealth and alleviating income poverty.

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1 Introduction

The unfortunate well-known image of women and girls carrying heavy loads of water on head and hips for several hours from a far distant river, pond or lake is no longer a reality for several households in rural areas in Brazil. Households collect rain water during the rainy season, and store it for smoothing consumption along the dry period. This simple technology has enabled households to relocate time into productive activities and have access to much higher quality water.

This is however not a widespread reality in rural areas of the developing world. The UN Millennium Development Goals (MDGs) to eradicate extreme poverty by 2015 consists of several targets to improve livelihood, such as halving the proportion of the population without sustainable access to safe drinking water. At halfway to the deadline of the MDGs project, the MDG target on water is still challenging in several aspects for many countries. Countries like Mozambique, Papua New Guinea, Somalia and Afghanistan still account for only 42, 40, 29 and 20 per cent of their population, respectively, provided with access to water from an improved source (WB (2009)). Small state budgets combined with the geographic characteristics of developing countries especially in rural areas (low population density, low degree of economic development, low purchasing power etc.) impose persistent economic barriers to the expansion of the piped water system to rural areas and, consequently, calls for alternative, low-cost solutions for water supply.

Semi-arid regions across the world have constantly suffered from chronic deficit in water supply. Recently, climate change has increasingly contributed to prolong the dry seasons, and to concentrate rainfalls into shorter periods of time, adding an uncertainty component to the occurrence of rains. This has transformed ordinary dry seasons into often natural disasters: severe prolonged droughts or floods. In those situations, lack of sustainable access to safe drinking water forces households to decrease productive labor due to the necessary increase in time for fetching water from distant sources. The economic consequence of consecutive natural shocks is thus directly related to an intensification of extreme poverty. Moreover, Dercon (2004) shows that rainfall shocks have a substantial impact on consumption growth, which persists for many years. So the damages suffered in a single season tend to propagate effect during longer consecutive periods.

Lack of access to safe water often reinforces a vicious circle of poverty in rural areas (UNDP, 2006). Without access to piped water, households rely on water from springs, rivers, and similar unsafe water sources located at some distance to the homestead. The water from those sources is often of low-quality, most times contaminated with bacterial that cause water-borne diseases (diarrhea, cholera etc.). Consumption of low-quality water for drinking or food preparation leads to poor health, reducing the effective amount of labor force of the household. Apart from poor quality, the amount of water supplied by these traditional (unimproved) water sources (ponds, springs, rivers, etc.) is also often insufficient to guarantee a basic level of hygiene, which increases the risk of infection with water-washed diseases.[1]

Moreover, poor access to water can be associated with reduced human capital accumulation. Cognitive capacities do not develop properly in the absence of enough water consumption (Hoddinott and Kinsey (2001), Alderman et al. (2006)), and children skip class to help the household on fetching water, usually performing several trips a day to the water source. The opportunity costs of fetching water are therefore very high: the time needed to fetch water could be allocated into labor market activities, increase in agricultural production, or human capital accumulation. In this sense, a reliable, safe water provision can potentially break the vicious cycle of poverty, especially in areas lacking alternative access to safe water (Gamper-Rabindran et al. (2009), Jalan and Ravallion (2003), Hutton et al. (2006)).

Setting up piped water provision, however, requires high initial costs and a minimum demand level that varies with operational and infrastructure building costs. A central pipe water system is often unfeasible in rural areas, specially those with low population density. Rainwater harvesting (RWH) has become a popular low-cost technology for bringing in-house safe water supply. In Brazil, a project financed by the national government and local NGOs has constructed about 300,000 cisterns for rural households who suffered from lack of access to water. Cisterns are ferrocement tanks build at the homestead, aimed at storing rainwater for primary purposes, such as drinking and cooking. Runoff rainwater is diverted from the rooftop of houses via gutters (made of either bamboos, plastic or metal) into that closed tank: the cistern. Cisterns may vary from 5 to over 50 cubic meters volume of water storage, depending on the usage purpose and the size of the catchment area, as well as potential rainfall. In Brazil, a 16 cubic meter cisterns is able to supply a five-member household with safe drinking water for up to eight

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[1] The UN considers the consumption of 20 liters a day as the water poverty line. The definition of safe access to water includes a maximum distance of one kilometer to the water source and the quality of water.

months of drought, with average construction cost of US$ 500.

This paper explores how rainwater harvesting at the household level has contributed to alleviate poverty in Brazil. Rainwater harvesting smooths water consumption and increases the resilience of households to water-related shocks. Our main hypothesis is that easier access to water increases the free time endowment of households, shifting the time allocation patterns either towards more leisure or to other productive activities, such as agriculture or livestock production. Much of the existing evidence is, however, anecdotal or lack a valid counter factual to establish a causal relationship between rainwater harvesting and improvements in living conditions[2]. Using household data from Brazil, this paper adds to the literature by quantifying the relationship between rainwater harvesting and poverty alleviation in Brazil, unraveling some of the channels for poverty reduction.

The remainder of this paper is structured as follows. Section 2 discusses the theoretical relationship between rainwater harvesting and poverty. Section 4 describes our empirical strategy, section 3, the data. Section 5 discusses our findings: we first analyze wealth differences between households that harvest and those that do not harvest rainwater. Then, we explore the three channels driving poverty reduction - the time allocation effect,the agriculture production effect, and the livestock production effect. Finally, section 6 concludes drawing policy implications.

2 Rainwater Harvesting and Household Poverty

2.1 The time allocation effect

In isolated, rural areas the time spent collecting water from a distant source amounts a substantial economic loss [CITE KENYA STUDY]. In the Brazilian semi-arid region, rural households without access to piped water spend about 40 hours per month collecting water from rivers, springs, ponds, and other unsafe sources. Apart from the health risks of consuming that water, time is an important asset that poor households spend from not having access to water. Having a technology for capturing and storing rainwater installed at the homestead reduces significantly the demand for fetching water at those

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[2] Lima et al. (2007) uses unmatched treatment and comparison groups to assess social impacts of Brazil's 'One Million Cisterns' program.

distant sources.

Our theoretical model of household time allocation builds on the classical production and consumer theories. A household's consumption bundle is composed of five types of goods: market commodities, subsistence agriculture, livestock, water and leisure. Market commodities are associated to a vector of positive market prices and goods are freely traded. Subsistence agricultural goods are produced for self-consumption, and small surpluses can be bartered at market prices. Individuals, albeit producers, are price takers. We assume there is no financial market, such that the household consumption is limited to her own wealth at each period.[3]

The household consumption can be expressed in terms of hours of work required to produce a numeraire consumption equivalent. The time devoted to paid activities, L_x, is remunerated at the market wage rate, ω_x, which is increasing on the individual's ability. Subsistence agriculture remunerates at $\omega_a \leq \omega_x$. We assume optimal intra household division of labor.

Households spend either time or financial resources to obtain the water consumed. The decision on whether to collect or to buy water is based on each household members' opportunity costs. Competing activities for water collection are income generating work and human capital accumulation. Piped water from a utility network is the safest and cheapest source of drinking water.[4] Thus, households connected to a pipe grid prefer consuming water entirely from that source[5]. In the Brazilian rural semi-arid access to piped water is rather limited. The time allocated to water production is given by L_w. This is valued according to the market price households would pay if they had to buy water from alternative sources (pipe truck, bottled water, resellers, etc.) or by the wage households would receive if they were engaged in other productive activities, $\omega_w = min\{\omega_x, \omega_a\}$, whichever is higher. In case there is no market for water, the value of time spend fetching water is measure by the latter. Leisure is the household's forgone income at its highest opportunity cost, $\omega_l = max\{\omega_x, \omega_a, \omega_w\}$.

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[3] This is a realistic setting, in the sense that poor households are often marginalized from financial market instruments (the problem of lack of collateral), and their income is often too low for allowing savings after the basic needs are met. The assumption can be relaxed on a later extension of the model, but this paper analyzes a single period.

[4] See UNDP Human Development Report 2006.

[5] Except in case water pressure or continuity of the services are irregular. In this case, and when households have no piped supply, households meet their water demand by fetching from alternative sources.

Suppose there is no market for land, and each household has some land endowment, E_a.[6] Households do not employ other workers at their farms apart from the labor force in the household itself. This is common in small cultivated plots, because the farmers' income is often not enough for subcontracting labor force. The household allocates time among market activities (L_x), subsistence agriculture (L_a), water collection (L_w) and leisure (L_l) to obtain a consumption bundle which maximizes her utility. Her choices are constrained by the household wealth (budget constraint), which is determined by the household's optimal allocation of total time endowment, T, such as:

$$\begin{aligned} max_{c_j,L_j} \quad & U = f(c_x, c_a, c_v, c_w, c_l) \\ s.t. \quad & \sum p_j c_j \leq \sum w_j L_j + rE \\ & \sum L_j \leq T \qquad \forall j \in \{x, a, v, w, l\} \end{aligned} \tag{1}$$

Rainwater harvesting technology provides households with safe drinking water at a lower time requirement. Moreover, water storage capacity enables households to plan their time allocation to activities. The lower volatility of water supply enables them to foreseen how much time household members will spend on water production despite eventual drought events. Households are thus able to relocate the additional time (previously devoted to water collection) into other productive activities, in order to maximize utility. Those could be an increase in market labor, agricultural labor, leisure or even on further accumulation of human capital. All of these contribute to increasing the household wealth, and alleviate poverty.

2.2 The agriculture and livestock production effects

Small scale agriculture and livestock raising play an important role on household subsistence in rural areas. The vegetables produced and the output of livestock (eggs, milk, meat and others) are either consumed or bartered at local markets. They improve the household nutritional intake and surpluses are a complementary source of income. Livestock also supplies labor force on

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[6] A realistic setting allows for land endowment to be either negative or positive, the former indicating land tenure.

traction and transportation and provides manure for fertilizers. In the absence of formal financial institutions, agricultural production and livestock further serve as insurance against shocks (Deaton, 1991). Households hold buffer stock (e.g. grains) that can be used to smooth consumption when hit by droughts, disease or other shocks that affect the consumption (Angelucci and De Giorgi, 2009); while small animals are a source of liquidity to the households, quickly traded by essential goods to sustain the livelihood.

The time required for a unit production of an agricultural good is decreasing on a set of inputs, I_a (seeds, fertilizers, animal ration, worker's ability, etc.), land, E_a and water, w. The higher the amount of inputs, the less time is needed to produce on unit of output. We assume that the agricultural production function, $g(\cdot)$, has decreasing returns to scale, as soil exhaustion is a common phenomenon in low income settlements. Similar setting applies to the livestock production, although parameters may differ.

$$\begin{gathered} L_a = g(I_a, E_a, w) \\ g'(I_a, E_a, L_a, w) < 0 \\ g''(I_a, E_a, L_a, w) < 0 \end{gathered} \tag{2}$$

Rainwater harvesting potentially increases the supply of water available to the household. Given that households were water constrained, the construction of cisterns increase the household water consumption up to the point where the marginal utility of domestic water consumption equals the marginal product of agriculture production. When the marginal product of agriculture becomes larger, the household employs the additional water into agricultural production. Larger production increases the household income, alleviating poverty: the agricultural production effect.

$$g'_w(I_a, E_a, w) = f'_w(c_x, c_a, c_w, c_l) \tag{3}$$

The same rationale apply to livestock raising. Increased amount of water enables households to raise small animals both because the cost of input water becomes 'cheaper' and because a more reliable supply reduces the risk of loosing livestock due to lack of water. When the marginal product of livestock production becomes larger than the marginal utility of domestic water consumption, the household employs the additional water for raising livestock. Larger livestock production increases the household wealth, alleviating poverty: the livestock production effect.

An alternative hypothesis to these production effects is a pure substitution effect where households rely entirely on the cistern water, and stop collecting water from alternative sources. If the storage capacity is just enough for consumption, households maintain constant the amount of water consumed. The gains from the cistern translates solely on freeing labor time, what leads back to the time allocation hypothesis discussed in Section 4.1. A mix of the three effects, however, seems to happen more often.

3 Setting & Data

The household data is a cross-section on 605 households living in the semi-arid region of Brazil. The data contains information on household demographic characteristics, dwelling and living conditions, work and income indicators, water management, and quality of life indicators. The survey was conducted by FAO/Embrapa between August 2005 and October 2006. Of the 605 households in our sample, some 179 households use a cistern technology to harvest rainwater. Households also indicated the main source of water, which is distributed as in table 1

Table 1: Households' Main Source of Water

cistern	Main source of water					
beneficiary	hole,lake,pond	piped water	wells	other	cistern	Total
no	207	25	156	12	0	400
yes	76	8	40	8	22	154
Total	283	33	196	20	22	554

Source: FAO/Embrapa dataset.

The semi-arid region in the Northeast of Brazil encompasses the northern region of Minas Gerais and the dry savannahs of Alagoas, Bahia, Ceara, Paraiba, Pernambuco, Piaui, Rio Grande do Norte and Sergipe, with a total of 1,133 municipalities and a population of around 20 million.[7] The semi-arid is one of the most vulnerable and economically disadvantaged regions in Brazil. Weather conditions are characterized by a long dry season lasting more than six months, annual rainfall below 800mm, high temperatures and high rates of soil evapotranspiration. The region has always suffered from chronic deficit in water supply. Climate change, however, has contributed to prolong the dry seasons. This has transformed ordinary long dry seasons into often more severe, prolonged droughts and floods. One economic consequence of such natural shocks is the intensification of extreme poverty.

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[7] Our dataset, however, represents a much smaller sample, comprised of only rural areas, poor households. The state Alagoas was not surveyed though.

Table 2 shows a selected subset of descriptive statistics of households using a cistern technology and those that do not, respectively (before PSM matching). None of the households in the treatment group has access to piped water. Agriculture is the main source of employment among all households. Around 40 percent of households with a cistern and 50 percent of those not using a cistern rely on social assistance by the government.[8] About half of the household heads in the sample have no schooling. Communities are characterized by lack of employment opportunities, health and transport facilities.

Table 2: Descriptive Statistics

	Cistern	No Cistern
household size	6.40	4.81
male headed	0.53	0.60
schooling of Household Head (share)		
No schooling	47.68	43.15
1 to 4 years	38.41	36.29
5 to 8 years	11.92	14.97
9 to 12 years	1.99	4.57
more than 12 years	0.00	1.02
occupation (share)		
None (no income derived from work)	7.28	7.97
Employed/Employer (private/public sector)	9.93	9.00
Rural Laborer	72.19	69.41
Self-employed	10.60	13.62
land size	9.37	19.64
electricity installed	0.73	0.74
main water source		
water hole, spring, river, dam, pond, lake	49.35	51.75
piped water	5.19	6.25
tubular well, amazonas type well, fountain	25.97	39.00
other	5.19	3.00
cistern	14.29	-
toilet	0.69	0.40
wall	0.65	0.46
roof	0.76	0.76

Source: FAO/Embrapa dataset. Note: Roof: dummy refers to ceramic tiles; zero otherwise. Toilet: dummy refers to the existence of toilet facilities either in or outside the house; zero for no toilet. Wall: dummy refers to brickwork, either plastered or not; zero otherwise. Waste: dummy refers to burnt.

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[8] The Brazilian social protection programs include: Family Grant Program (*Bolsa Famila*), Continuous Cash Benefit for the elderly and the handicapped (BPC), gas voucher, rural old age retirement pension, ordinary pension or retirement pay, Child Labor Eradication program (PET).

4 Empirical Strategy

We use propensity score matching methods (PSM) to pin-down the counterfactual distribution. PSM balances the distribution of observed covariates between those households that have a cistern (treatment group) and those that have none (control group). The balancing is based on predicted probabilities (”propensity”) of having a cistern (Rosenbaum and Rubin, 1983). More formally, denote $c_i = 1$ if the household has a cistern, and $c_i = 0$ if not. Let $\mathbf{X_i}$ be a vector of exogenous household characteristics (covariates). Treated households are matched to control households on the basis of the propensity score

$$p(x_i) = P(c_i = 1|\mathbf{X_i}) \qquad (0 < p(\mathbf{X_i}) < 1) \tag{4}$$

It is well known PSM relies on the ‘conditional independence’ or ‘strong ignorability’ assumption. That is, given $\mathbf{X_i}$, outcomes are independent of treatment. Matching on propensity scores implies that treatment and control group have the same distribution of covariates, eliminating the bias arising from observed heterogeneity. We follow the standard PSM procedure and use the predicted probabilities of a logit model as estimate the propensity score. In an attempt to establish conditional independence we include a large vector of covariates. The latter includes demographic characteristics of the household, dwelling characteristics as well as work and income indicators. Table 7 presents the coefficient estimates of the logit model.

Figure 3 shows the histogram of the estimated propensity scores for treatment and control group. We see that the common support property holds for the entire range of propensity scores of treatment group. That is, we are able to find a match with a sufficiently close propensity score for the entire treated sample.

We conduct balancing tests suggested by Dehejia and Wahba (1999) and Dehejia and Wahba (2002) to check whether the distributions of observable characteristics are similar for the treatment and the control groups. We divide the observations into blocks based on the estimated propensity scores. These blocks are chosen so that there is not a statistically significant difference in the mean of the estimated propensity scores between the experimental and comparison group observations within each block. Then, within each block, t-tests are used to test for mean differences in each covariate between the experimental and comparison group observations. When significant differences are found for particular variables, higher order and interaction terms in those variables are added to the logistic model and the testing procedure is repeated, until such differences no longer emerge.

The algorithm proceeds in the following way. We divide the range of estimated propensity scores into blocks. The latter are created in the following manner. We start with one block consisting of the entire range of propensity scores. Within this block, we test for equality of means of propensity scores between treatment and control group. If we reject the null of equality of means, divide the block into two blocks and test again for equality of means between treatment and control group within each of the two blocks. If we reject the null of mean equality for one block, we divide the block again into two blocks. The procedure is repeated until we cannot reject the hypothesis of mean equality of propensity scores for every block. Using this algorithm, we find a total of six blocks. In each of the six blocks, there are no significant differences in propensity scores. We then test if the means of the exogenous variables given in Table 7 are the same within each block. We test for a equality of a total of 84 exogenous variables within each block. This makes a total of 504 (6x84) T-tests. Of the 504 tests, we find only eight rejections.

Having obtained an estimate of the propensity score, we then apply weighted propensity score regression techniques (Hirano and Imbens, 2001) to shed light on the effects of the cistern technology on poverty, time spent on fetching water, and agricultural production. We estimate the following model

$$y_i = \alpha_0 + \tau_1 c_i + \alpha \mathbf{Z_i} + u_i \tag{5}$$

where y_i is the value of the wealth index, time spent on fetching water, and household production, respectively.

The variable c_i is a dummy if household i has a cistern, and $\mathbf{Z_i}$ a vector of eight covariates that failed the propensity score balancing property. Following Hirano and Imbens (2001), the household weights are

$$\omega = c_i + \frac{(1 - c_i)\hat{p}(\mathbf{X_i})}{1 - \hat{p}(\mathbf{X_i})} \tag{6}$$

such that the weight for the treated household is a unity. $\hat{p}(\mathbf{X_i})$ denotes the estimated propensity score.

As a robustness check, households in the treatment group are matched to those of the control group based on a nearest-neighbor matching estimator. That is, the match j for the ith household having a cistern is the one that minimizes $(p(\mathbf{X_i}) - p(\mathbf{X_j}))^2$. We use the nearest five neighbors estimator, which take the average outcome measure of the closest five control group households as the counterfactual for the treated household.

5 Results

5.1 Household Wealth

wealth index

We adopt an asset based approach to measure the level of household poverty, in the absence of consumption and income data. We aggregate various households assets (durable goods) and build a wealth index using principal component analysis (PCA). PCA is a multivariate statistical technique used to reduce the dimension of variables.[9] From an initial set of n correlated variables, PCA generates uncorrelated components. Each component is a linear weighted combination of the initial variables. For example, for a set of variables x_1 to x_n,

$$\begin{aligned} PC_1 = a_{11}x_1 + a_{12}x_2 &+ ... + a_{1n}X_n \\ &... \\ PC_m = a_{m1}x_1 + a_{m2}x_2 &+ ... + a_{mn}X_n \end{aligned}$$

where a_{mn} represents the weight for the mth principal component and the nth variable.

The weights for each principal component are given by the eigenvectors of the correlation matrix. The variance for each principal component is given by the eigenvalue of the corresponding eigenvector. The components are ordered so that the first component (PC_1) explains the largest possible amount of variation in the original data, subject to the constraint that the sum of the squared weights ($a_{11}^2 + a_{12}^2 + ... + a_{1n}^2$) is equal to one. Since the first component explains the largest amount of variance (29 percent), it is used as wealth index for our study. The variables used to construct the wealth index are if the household possesses a telephone, gas stove, wood burning stove, television, radio, cd-player, refrigerator, sewing machine, bicycle, motorcycle, car, mobile phone, and parabolic antenna. The Eigenvalues and explained variance of PC_1 to PC_{10} are shown in table 6. The factor loadings of the first component (PC_1) are presented in table 5 in the appendix.

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[9] See **?** for an overview of PCA and its usage for constructing socio-economics indixes.

Table 3: Effect of cistern on wealth index (Weighted Propensity Score Regression)

	OLS (se)
cistern	0.321 *** (0.110)
Controls	YES
	$N = 498$ $R^2 = 0.34$

Note: control variables include household demographics and education variables

Table 3 shows the parametric estimates of Equation 5.

Our findings suggest a positive impact of the cistern technology on reducing household poverty. The coefficient on the cistern dummy is positive, statistically significant at the one percent significance level, and robust to different specifications of our model.[10]

Figure 1 illustrates this result. The figure shows non-parametric kernel densities (propensity score weighted) of the wealth index for treatment group (households with a cistern) and control group (households without a cistern). The wealth density distribution for households owning a cistern (dashed) is shifted rightwards, compared to households not owning a cistern (dotted line).

In the following we analyze the mechanisms underlying the cistern induced increase in household wealth.

5.2 Agriculture/livestock production, and time use

In section 2 we described that in many rural areas household members spend a significant amount of time on collecting water from a far distant water source (river, spring etc.). The water captured from a cistern technology installed at the homestead may reduce the demand for water from the distant source and thus the time spent on fetching water. If the time saved is relo-

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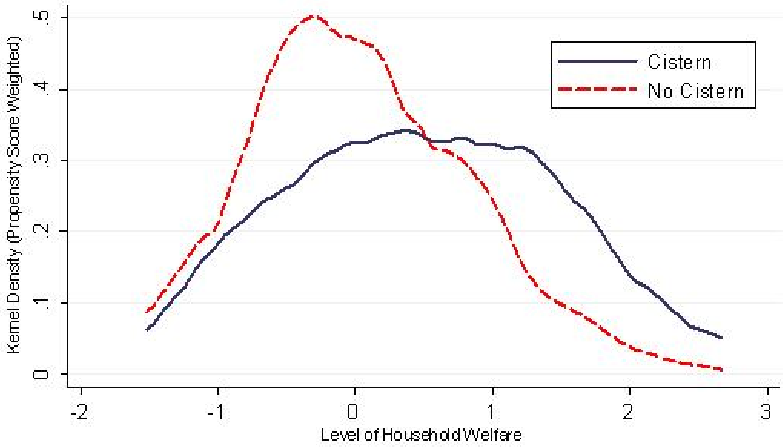
[10] As a robustness check, we apply a nearest-neighbor propensity score matching estimator. The latter confirms the results above. We find a significant difference of 0.45 (t-statistic 3.13) between treatment and matched control group.

Figure 1: Kernel densities of wealth index



cated to productive activities then household poverty potentially decreases (see section section 2).

As for relaxing time constraints and increasing agricultural/livestock production we estimate Equation 5. Monthly time spent on collecting water, the area dedicated to raising livestock, and the total cultivated area, respectively, are the dependent variables. The results are presented in Table 4.[11]

Having a cistern reduces the time spent on collecting water by about 62 percent. Figure 2 shows propensity score weighted kernel densities. While households holding a cistern spend no more than 30 hours per month collecting water, a significant share of households without a cistern spend up to 50 hours per month.

We used the amount of cultivated area and area dedicated to livestock raising as a proxy for working hours dedicated to agriculture and livestock production, respectively. Having a cistern significantly increases the area dedicated to agricultural activities. The results show that this increase amounts on average to 2.23 hectare of land. Likewise, having a cistern

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[11] As a robustness check we report the results of the nearest neighbor propensity score matching estimator in parenthesis.

Table 4: Results for the Time Allocation, Agriculture Production and Livestock Production Effects

	Propensity Score Weighted Regression
Time use effect:	
Log time spent fetching water (in hours)	-0.619***
	(0.144)
Agriculture production effect:	
Cultivated area (in hectare)	2.23***
	(0.001)
Livestock production effect:	
Area dedicated to raising livestock (in hectare)	5.78**
	(2.698)

Note: Controls included.*** Significant at the 1% level, **at the 5% level.

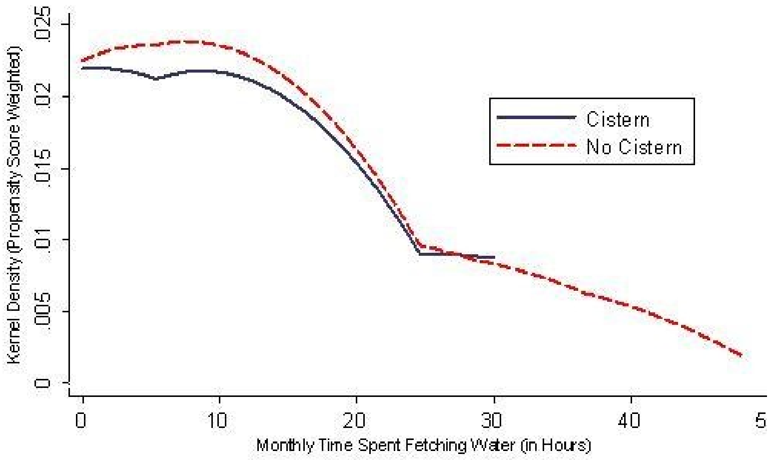
increases the area dedicated to livestock production, on average, by 5.78 hectare. Both increase in agriculture and in livestock production may explain an increase in the overall household wealth and thus suggests that having a cistern for rainwater harvesting allows households to diversify/increase their production, and then lower the intensity of household income poverty.

It would be also interesting to analyze the direct effect of having a cistern on the time dedicated to the paid labor market. Data on this specific variable was however not available.

6 Conclusion

This study suggests that rainwater harvesting allows important savings in time devoted to household collection. Important channels underlying the poverty reduction are shifts in the household time allocation toward more productive activities, what enables households to dedicate to other productive activities such as agriculture and livestock production. Moreover, when households decide to keep fetching some amount of water, having a cistern to store rainwater provides households with an augmented quantity of clean water. This positive supply shock of water in the household also makes possible the household decision to invest in agriculture and livestock. This is because households perceive the cistern as a smoothing consumption/shock coping mechanism and thus investment in water sensitive assets such as agriculture and livestock becomes less risky. Agriculture have several impacts on household wealth and welfare which have not been explored in this paper,

Figure 2: Kernel densities for time spent fetching water



such as improved nutrition and additional income for trade of surplus in the market. Livestock, according to qualitative, structured interviews with beneficiaries in the field has indeed been a great improvement on the insurance mechanism of those households, in the absence of financial markets and no access to formal insurance instruments. Water surplus investment and time allocation into agriculture and livestock production seems to be in fact the strongest effects of having a cistern in those rural areas of the Brazilian semi-arid.

Wealth increase can be argued as a first, immediate step toward poverty reduction. Raising households sustainably above the poverty line is a major intervention to foster households to beak out of a poverty cycle, and thus scape from a poverty trap. It is important to highlight the importance of sustainability of the wealth increase. The rainwater harvesting practice fulfill this criteria by the mechanisms above analyzed and for additional effects which were not explored in this paper. For instance, elected women in the communities were trained as health advisers in the water treatment and employed as community leaders to teach and monitor neighbor households on proper water maintenance of the cisterns. This brings positive health externalities for the community, as well as true empowerment of those selected women. Moreover, communities were brought together since the period of construction of the cisterns. Neighbors provided labor force, while the beneficiary household was responsible for providing meals for all the workers during the construction. Men learned the mason profession and there is evidence that several continued in this activity.

Further topics remain to be explored, as for instance the health impacts of being provided with clean rainwater and training on health and hygiene, women empowerment and intra-household bargaining, human capital accumulation once children would spend lower time fetching water, ownership sense by the construction of the cisterns with the labor force and some resources put down by the households, and professional training of masons and health community leaders. In addition, a cost-benefit analysis of individual small scale vs. collective large scale water provision, or traditional technologies vs. modern water treatment techniques is quite attractive for policy discussion. Likewise are the macroeconomic effects of rainwater provision and positive supply shock on the economic development of the communities. Last, but not least, sanitation remains an open question.

References

Alderman, H., J. Hoddinott, and B. Kinsey (2006, July). Long term consequences of early childhood malnutrition. *Oxford Economic Papers 58*(3), 450–474.

Angelucci, M. and G. De Giorgi (2009). Indirect Effects of an Aid Program: How Do Cash Transfers Affect Ineligibles' Consumption? *American Economic Review 99*(1), 486–508.

Deaton, A. (1991). Saving and liquidity constraints. *Econometrica 59*(5), 1221–1248.

Dehejia, R. and S. Wahba (1999). Causal Effects in Nonexperimental Studies: Reevaluating the Evaluation of Training Programs. *Journal of the American Statistical Association 94*(448).

Dehejia, R. and S. Wahba (2002). Propensity score-matching methods for nonexperimental causal studies. *Review of Economics and Statistics 84*(1), 151–161.

Dercon, S. (2004). Growth and shocks: evidence from rural Ethiopia. *Journal of Development Economics 74*(2), 309–329.

Gamper-Rabindran, S., S. Khan, and C. Timmins (2009). The impact of piped water provision on infant mortality in Brazil: A quantile panel data approach. *Journal of Development Economics*.

Hirano, K. and G. Imbens (2001). Estimation of causal effects using propensity score weighting: An application to data on right heart catheterization. *Health Services and Outcomes Research Methodology 2*(3), 259–278.

Hoddinott, J. and B. Kinsey (2001, September). Child growth in the time of drought. *Oxford Bulletin of Economics and Statistics 63*(4), 409–36.

Hutton, G., L. Haller, and J. Bartram (2006). Economic and health effects of increasing coverage of low cost water and sanitation interventions. *Human Development Report Office Occasional Paper. Report prepared for the United Nations Development Program Human Development Report*.

Jalan, J. and M. Ravallion (2003). Does piped water reduce diarrhea for children in rural India? *Journal of Econometrics 112*(1), 153–173.

Lima, S., A. Silva, L. Brito, M. Freites, and C. Anzolini (2007). Assessment of the Social Impacts of the Cisterns Program. *Ministry of Social Development, Brasilia DF-Brazil*.

Rosenbaum, P. and D. Rubin (1983). The central role of the propensity score in observational studies for causal effects. *Biometrika 70*(1), 41–55.

UNDP (2006). *Human Development Report - Beyond Scarcity: Power, Poverty and the Global Water Crisis.*

WB (2009). World Development Indicators.

Appendix

Table 5: Factor loadings of PC_1

Variable	**Factor Loading**
gas stove	0.6342
telephone	0.7005
radio/cd-player	0.3286
refrigerator	0.7515
sewing machine	0.5342
bicycle	0.2867
motorcycle	0.4695
car	0.3610
mobile phone	0.3819
parabolic antenna	0.7035
$n = 549$	

Table 6: Principal Component Analysis

Factor	**(Eigenvalue)**	**Explained Variance**	**Cum. Expl. Variance**
PC_1	2.92479	0.2925	0.2925
PC_2	1.32339	0.1323	0.4248
PC_3	1.02971	0.1030	0.5278
PC_4	0.88709	0.0887	0.6165
PC_5	0.85922	0.0859	0.7024
PC_6	0.74338	0.0743	0.7768
PC_7	0.67547	0.0675	0.8443
PC_8	0.65594	0.0656	0.9099
PC_8	0.47801	0.0478	0.9577
PC_{10}	0.42301	0.0423	1.0000
$n = 549$			

Table 7: Logit regression for having a cistern

Variable	**Coefficient**	**(t-statistic)**
Demographic Household Characteristics		
Household Size	0.361	(0.493)
Male Household Head	-0.266	(0.308)
No. of Children < 6 years old	0.084	(0.552)
No. of Children 6-10 years old	1.157	(1.785)
No. of Children 11-15 years old	0.286	(0.547)
No. of Boys 6-10 years old	-1.070	(1.717)
No. of Boys 11-15 years old	-0.254	(0.361)
No. of Girls < 6 years old	-0.013	(0.318)
No. of Girls 6-10 years old	-1.082	(1.763)
No. of Women 16-40 years old	-0.122	(0.489)
No. of Women 41-60 years old	-0.093	(0.491)
No. of Women older than 60 years old	-0.165	(0.537)
No. of Men 16-40 years old	0.014	(0.511)
No. of Men 41-60 years old	0.313	(0.564)
No. of Men older than 60 years old	0.106	(0.535)
Household Work and Income Indicators		
Schooling		
no schooling .	.	
1 to 4 years	0.003	(0.324)
5 to 8 years	-0.101	(0.450)
9 to 12 years	-2.092	(0.939)
No. of household members currently attending school	-0.124	(0.118)
Ocupation of household head		
None (no income derived from work)	.	.
Employed/Employer (private sector, public sector)	1.136	(0.804)
Rural Laborer	0.365	(0.650)
Self-employed	0.466	(0.730)
Months worked last in last 12 months	0.110	(0.044)
Bolsa Familia/Bolsa Escola/PETI	-0.567	(0.320)
BPC, rural old-age retirement pension	0.712	(0.396)
Other (gas voucher, churches etc.)	0.247	(0.360)
Dwelling and Living Conditions		
Type of residence (in percent)		
Isolated house	.	.
House in a hamlet	1.872	(0.738)
Other (quilombo, agrarian reform area)		
Status of property (in percent)		
Own, paid for	.	.
Own, being paid for	0.501	(0.536)
Loaned	-0.594	(0.515)
Other	0.048	(0.791)
Size of cultivated area	0.006	(0.006)
Main material used in walls (in percent)		
Plastered brickwork	.	.
Non-plastered brickwork	-0.416	(0.389)
Mud and lathes	-1.065	(0.611)
Other	0.660	(0.849)
Main material used in roof (in percent)		
Ceramic tiles	.	.
Asbestos cement sheets	0.052	(0.631)
Other	0.415	(0.460)
Number of divisions in house	0.279	(0.099)

Logit regression for having a cistern (cont.)

Variable	**Coefficient**	**(t-statistic)**
Type of bathroom or toilet (in percent)		
none	.	.
inside the dwelling	1.516	(0.399)
outside the dwelling	1.196	(0.385)
Solid waste disposal (in percent)		
Burnt	.	.
Buried	0.570	(1.047)
Thrown out of the open air	0.225	(0.303)
Electricity installed (in percent)	-0.189	(0.396)
Status of land no land	.	.
proprietor, squatter, right to use contract	0.292	(0.472)
tenant, partner or sharecropper, freely loaned	-0.126	(0.543)
Main water source (in percent)		
water hole, spring, river, dam, pond	.	.
piped water	.	.
tubular well, amazonas type well, fountain	0.857	(0.308)
other	1.647	(0.702)
Neighborhood Characteristics (in percent)		
Theft, violence, vandalism	0.759	(0.361)
Lack of school	-0.278	(0.445)
Lack of health center	0.656	(0.376)
Lack of transport	-0.291	(0.305)
Lack of employment opportunities	-0.429	(0.597)
Lack of leisure opportunities	-0.427	(0.402)
State		
Ceara	1.597	(0.845)
Minas Gerais	-2.505	(1.356)
Paraiba	1.363	(0.735)
Pernambuco	0.589	(0.505)
Piaui	-0.427	(0.573)
Rio Grande do Norte	0.829	(0.682)
Sergipe	0.034	(1.587)
Intercept	-7.761	(1.390)
N	487	
Log Likelihood	-194.638	

Figure 3: Histogram of propensity scores for treatment (black bars) and control group (gray bars)