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The Drivers of Non-Revenue Water

How Effective Are Non-Revenue Water Reduction Programs?

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Abstract

To many, reducing water losses is seen as key to more sustainable water management. The arguments to reduce water losses are compelling, but reducing water losses has turned out to be challenging. This paper applies a panel data analysis with fixed effects to determine the major drivers of non-revenue water, which is define as the volume of water losses per kilometer of network per day. The analysis uses data from the International Benchmarking Network for Water and Sanitation Utilities, covering utilities in 68 countries between 2006 and 2011. The analysis finds that non-revenue water is driven by many factors. Some of the most important drivers are beyond the control of the utility, such as population density per kilometer of network, the type of distribution network, and the length of the network, which are largely the result of urbanization and settlement patterns in the localities that the utility serves. The opportunity costs of water losses are also key in explaining what drives non-revenue water. The paper finds that very low opportunity costs of water losses have an adverse effect on the reduction of non-revenue water. Country fixed effects turn out to be important, meaning that the environment in which the utility operates has an important impact on non-revenue water levels. An important conclusion is that the design of non-revenue water reduction programs should study the main drivers of non-revenue water to provide utility managers with a better understanding of what can be achieved in terms of non-revenue water reduction and whether the benefits of these reductions exceed their costs.

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The Drivers of Non-Revenue Water:

How Effective Are Non-Revenue Water Reduction Programs?

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1. Introduction

Water is becoming increasingly scarce. Rapid population growth, income growth and urbanization in combination with a fixed supply of total renewable water resources will further accelerate the decline in available per capita renewable water resources, and increase the gap between supply and demand. Climate change is likely to make the challenge even more daunting, as it will increase the variability of water supplies with the effect that traditional water sources become less reliably available. At the same time, climate extremes are likely to increase, which may increase the likelihood of water related disasters reflected in more frequent floods and droughts.

To make the most of water scarcity, the sector will have to improve the way it uses its available water resources significantly so that it can deal with the challenges ahead. In the municipal sector, water productivity is less than optimal as the difference between water put into the distribution system and the amount of water billed to consumers (i.e., "non-revenue water") tends to be large. High levels of non-revenue water (NRW) reflect huge volumes of water being lost through leaks and drinking water not being invoiced to customers, or a combination of both. Kingdom et al. (2008) mention that the total cost to water utilities caused by NRW worldwide can be conservatively estimated at \$141 billion per year. McKinsey (2011) includes municipal leakage as an important instrument to reduce the gap between supply of and demand for water. NRW reduction programs are a standard recommendation in virtually any policy paper or report that focuses on improving the sustainable use of water resources (for instance European Community (2006), UNWater (2012) and McKinsey (2013)). The cited benefits associated with a reduction in NRW are manifold as this will boost the utility's revenues as the volume of water that can be billed can increase, whereas a reduction in water losses will postpone investments. This will increase the profitability of the utility that will allow it to reinvest its earnings and improve the quality of service delivery. Frauendorfer and Liemberger (2010) note that utility owners need to be made sufficiently aware that they are "sitting on a goldmine" and that utility owners will need to incentivize their staff by informing them about the level, causes and cost of NRW, along with the potential for improvement so that comprehensive NRW management can be supported.

Hence, if the reasons for reducing NRW are so compelling and so much money can be saved and significant volumes of water can be used for more productive purposes, then why has it turned out to be so difficult to reduce NRW? The present paper looks into understanding the reasons why NRW is so difficult to reduce. The literature on what is driving NRW is limited in size. Most literature on NRW is focused on the practicalities of how to reduce NRW such as IWA (2006) and Liemberger et al. (2010). There is some literature on determining the optimal level of NRW (Wyatt, 2010), while the issue has been a focus of research in Spain (Saez-Fernandez et al., 2011; Gonzalez-Gomez et al., 2011). Reducing NRW has obviously many benefits, but may also require investments in some form or another to increase billing efficiency, introduce or expand water metering or implement the physical improvements to the water infrastructure in the form of among others replacement or rehabilitation of the distribution networks.

This paper is organized as follows. In Section 2 we undertake a literature review. In Section 3 we define what NRW is, how it is measured and we look at the trends that are occurring in NRW, using the database of the International Benchmarking Network for Water and Sanitation Utilities (IBNET)[2]. This database covers financial and operational performance data from utilities all over the world. In the fourth section, we define a panel data model with fixed effects to analyze what drives NRW. The estimation results of the model are presented in the fifth section, and we conclude in the last section.

2. Literature Review

There are many articles published on NRW reduction, but they tend to be mostly practical guidelines as to how to reduce NRW (Farley and Trow, 2003; IWA Water Loss Task Force, 2003; and AWWA, 2006) focusing on the processes required to design and implement an NRW losses strategy. They are often focused on reducing NRW in developed countries. We also found success stories of reducing water losses in for instance Phnom Penh, Cambodia (Biswas, 2009)

[2] IBNET is being developed by the World Bank with the objective to provide comparative international benchmark performance information that can inform utilities and policymakers on how to improve service delivery (for more information, see www.ib-net.org)

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and Singapore (Luan, 2010). There is also some literature on how to determine the economically optimal level of water losses reduction (Wyatt, 2011). As for what drives NRW, the literature is rather scant – even in developed countries. This is an interesting finding, as one would assume that one would like to know more accurately what drives NRW to determine the best way forward in reducing water losses. This may reflect the rather engineering focus on reducing water losses. Overall, the existing studies provide different explanations as to what impacts NRW. Skipworth et al. (1999) show in a study in England, that a large number of mostly technical and environmental factors affect municipal leakage rates. These factors include the age of the systems, the length and type of networks, pressure in the systems, climate, soil conditions, traffic loading, and density of connections. These authors also mention that topography can explain regional differences in water losses between utilities. Farley and Liemberger (2005) note the importance of physical factors, but these authors also put a lot of emphasis on management factors. Poor (management) practices, poor materials and infrastructure, local and political influences and social, cultural and financial factors are identified as factors driving the levels of NRW. They do not get into detail in how far these factors drive NRW and how this affects the design and implementation of water loss strategies. In a study by Gonzalez et al. (2011) on why NRW is so high in developing countries, the authors conclude that the lack of incentives is the main reason for differences in water losses between utilities. Water utilities normally have few incentives to undertake the necessary actions in order to reduce NRW, because they lack the income to pay for the cost associated with a reduction of water losses, while corruption and a lack of knowledge of users about the levels of NRW and the associated costs to users and taxpayers further add to the lack of interest to plug water leaks. In a follow-up study for Spain, using data from 133 municipalities, Gonzalez-Gomez et al. (2012) conclude that NRW measured as percentage of system input volumes is driven by not only physical and management indicators but also the environment in which the utility is located. In their study, the management quality of the utility is captured by indicators like tariff structure, indebtedness of the utility and different forms of management (private sector management and outsourcing of management). In their model, environmental factors are captured by population growth, the percentage of population outside the main village, and population density. The physical indicators are referring to the minimum water percentage of the storage reservoir and the type of distribution system (distribution systems by gravity or pumped) – with this last variable being a very important driver of NRW in these 133 municipalities in Andalucia, Spain. Saez-Fernandez et al. (2011) focus on the low opportunity cost of water losses and the perverse incentives this gives utility managers to waste water.

3. Overview of Non-Revenue Water

3.1 Definition of NRW

Non-revenue water is the difference between the volume of water put into a water distribution system and the volume that is billed to customers. NRW comprises three components:

- Physical losses comprise leakage from all parts of the distribution system and overflows at the utility's storage tanks. They can be caused by poor operations and maintenance, the lack of active leakage control, and poor quality of underground assets;
- Commercial losses are caused by customer meter under-registration, data-handling errors, and theft of water in various forms;
- Unbilled authorized consumption includes water used by the utility for operational purposes, water used for firefighting, and water provided for free to certain consumer groups.

3.2 Measurement of NRW

The measurement of NRW is complicated. There are many different indicators measuring NRW and virtually all of them have drawbacks. The still most commonly used indicator is NRW defined as a percentage of water produced. A t-test shows that utilities with 100 percent water coverage tend to have lower NRW as a percentage of water produced. The mean NRW for utilities with less than 100 percent of the population with access to water supply is 33 percent compared to less than 28 percent for those with 100 percent of the population having access to water. This inherent bias may be the result of the practice that water systems are designed with a horizon of several decades in mind and where peak hourly demand can be very significant, depending on the design standards applying in the country. Hence, once access to water supply services improves (in terms of people connected and consumption per person), and with capacity mostly fixed, this indicator tends to decline over time. It should therefore not be a surprise that in mature, developed systems NRW should be showing relatively lower values, whereas systems that have been built more recently and hence have significant spare capacity are likely to have relatively higher water losses as managing a system with large overcapacity tends to be complicated. Because of the drawbacks associated with the use of this indicator, the International Water Association (IWA) has recommended that this NRW indicator not be used.

IWA is recommending alternative indicators such as the water losses per connection, water losses per main length and the infrastructure leakage index (Alegre et al., 2006; Winarni, 2009). The infrastructure leakage index is a complex indicator as it also measures pressure in the system. Yet, collecting pressure data for a utility is complicated as pressure can vary widely within the piped water system and hence is useful as an indicator when improving the system's overall performance but cannot be easily used as an indicator to review network losses between utilities as averaging such an indicator for a utility may not provide very meaningful data except to reflect that there is an underlying problem that needs to be addressed. Hence, in this paper we will focus on the remaining indicators that are being used to measure water losses: water losses per main length and water losses per connection.

Size of NRW

The empirical analysis is conducted using a unique database of water utilities, namely the International Benchmarking Network for Water and Sanitation Utilities (IBNET). The use of data from IBNET guarantees that the data are relatively homogeneous and comparable across countries. For each country, we have annual data on utilities' performance. The IBNET database contains information on performance from 1,861 water utilities in 2010 serving nearly 513 million people with water in 12,480 cities and towns. This is approximately 14 percent of the total population of all households with piped water access in the world or nearly 45 percent of the urban population of developing countries. The database represents the equivalent of more than US$40 billion in annual revenue in 2010. The utilities represented in the database employ about 623,000 professional staff. As participation in IBNET is voluntary and the data collection process takes at least 3 years, we include data from 2006 and 2011 when the number of utilities in the database is relatively stable.[3]

The median NRW (as measured by the volume lost in percentage of water production) was 26 percent in 2006 and 27 percent five years later in 2011 (Table 1), while the standard deviation remains high.

Insert Table 1: Non-Revenue Water (as percentage of water production)

The median NRW (as measured by the volume lost in cubic meters per km per day) has decreased from 20 cubic meters per km in 2006 to 16 in 2010. Yet, this indicator shows wide variations by year and between utilities (Table 2). In 2010, the best performing quartile of utilities had a median NRW in cubic meters per km of 5 or less. The worst performing quartile of utilities were those where this median indicator was 35 or higher.

Insert Table 2: Non-Revenue Water (in cubic meters per km per day)

The different NRW indicators are not necessarily very strongly correlated. So it can happen that a utility is showing excellent performance in one NRW indicator but is showing a much lesser performance when measured in another NRW indicator. An example is Singapore's Public Utilities Board whose NRW was only 4 percent of system input in 2007, which is an excellent performance. Yet, when using NRW per km per day, Singapore's performance is good, but less than excellent – with a loss of about 10 cubic meters per day in the same year – below that of the best performing quartile of utilities (and significantly above the median value for NRW in utilities in high-income countries). The opposite also happens with utilities that show high NRW as measured in for instance percentage of water produced, but where the losses look much less dramatic when using a different loss indicator. Hence, it is important – recommended by IWA - that one not only looks at one NRW indicator as this may give only partial information about the

[3] The IBNET database has been growing over time. It started with a small number of utilities in 1996 and has been growing to 1,861 utilities in 2010.

actual performance of a utility. It also supports the conclusion that too much focus on a certain indicator may be at times misleading (Liemberger, 2002).

In Table 3 we present descriptive statistics for utilities with low NRW per cubic meter per day (the best quartile of the sample that on average is about 10 cubic meter per kilometer per day), and those that register high levels of NRW (more than 35 cubic meter per day). Mean comparison tests show that utilities that have low levels of water losses tend to occur in utilities that are smaller in terms of people served, kilometers of network, and towns served. As can be seen in Table 3, bandsize that measures the number of people served by the utilities tend to be lower and the effect is quite significantly (t-value is 28.19). The average network length in utilities with lower water losses is 610 kilometers compared to 1,110 kilometers in utilities that are characterized by higher water losses. In the case of utilities with lower water losses, 81 percent of the better performing utilities serve only one utility compared to 71 percent for the utilities with higher water losses. On average, utilities with higher water losses tend to serve more municipalities (11.40) than those utilities that face lower water losses (8.65). Utilities with low water losses are also faced with lower population densities (i.e., the number of people served per kilometer of water supply network). The average number of people served per kilometer of network is 176 in utilities with low water losses compared to 416 in utilities with high water losses. The population density is made up of two components: connection density and population per connection. The first indicator, the number of connections per kilometer of pipe is essentially a physical factor that is determined by urbanization rates and building patterns. In Singapore, which was mentioned earlier, the number of connections per kilometer of network tends to be very high. The number of people per connection tends to be linked to economic development and urbanization. The higher the level of economic development is, the lower the number of people per connection. The median number of people per connection is more than 9 in low-income countries and less than 3 in high income countries. Pipe breaks which can act as a proxy for age and quality of maintenance are also significantly lower in utilities with lower water losses. Moreover, utilities with lower water losses are less likely to provide both water and wastewater services. The economies of scope associated with delivering both services (Nauges and van den Berg, 2008) tend to also result in more complexity and higher water losses.

Insert Table 3: Non-Revenue Water - Descriptive Statistics for NRW

One interesting feature is that water production per capita in utilities with low water losses is significantly lower than that of utilities with high water losses. In better performing utilities, water production stands at 206 liter per capita per day (lcd) compared to 282 lcd in utilities with higher water losses. This effect is not mirrored in consumption patterns that are not significantly different between utilities with high and low water losses. It is possible that water production reflects actual capacity and that the higher the production capacity, the higher the likelihood of water losses. However, as IBNET does not collect data on water production capacity, we are not able to verify this effect. If utilities are able to provide similar levels of consumption to its customers independent of the size of their water losses, tighter design standards may help to control water losses.

We also looked into a set of indicators that may reflect the management quality of the utility. The staff productivity index which measures the number of staff in the utility per 1,000 people served is higher in utilities with lower water losses. This may be linked to the fact that these utilities tend to be smaller in size and hence do not benefit as much from economies of scale than larger utilities do. The total annual revenues per capita (USD) tend to be significantly higher in utilities with low water losses. This reflects that water is a more valuable commodity in utilities with low water losses. Whether a utility is financially able to cover its basic operation and maintenance costs (as measured by operating cost coverage) – which reflects a higher quality of financial utility management – is 1.24 in utilities with low water losses compared to 1.20 in utilities with high water losses. The difference is very small, but statistically significant. Yet, it is not clear whether the higher operating cost coverage is a result of the lower water losses or that a better financial performance enables utilities to deal more effectively with water losses.

It is often assumed that metering is a prerequisite for reducing NRW. Table 3 shows that utilities with higher water losses tend to have lower levels of water metering than those that show lower water losses. The difference is statistically significant, but it also shows that the difference in levels of water metering is rather small in size. The effect of universal metering tends to be more significant. More than half the utilities with low water losses tend to be fully metered compared to about one-third of the utilities with high water losses. It is also noted that duration of supply is slightly higher in utilities with low water losses. Gonzalez-Gomez et al. (2012) mentioned the presence of private sector participation as a factor in explaining water losses. In utilities with low water losses, the presence of some form of private sector participation is slightly below that of utilities with higher water losses.

Insert Table 4 : NRW as measured in cubic meters per kilometer per day by Income Status

Finally, the GDP per capita in utilities with lower water losses is almost double that of GDP per capita in utilities with high water losses. Utilities with lower water losses tend to be more likely to be located in countries where corruption levels are lower. Corruption is likely to have a significant effect on water losses as it tends to impact the investment quality of the infrastructure built, but also affect the operation and maintenance of these systems through lack of proper maintenance, inadequate procurement processes and inappropriate billing practices as outlined by Transparency International (2008). As can be seen in Table 4, water losses show a particular pattern in which it is high in low-income countries, increases further in lower-middle income countries and then decreases once countries hit the upper middle-income status and it declines even more when countries gain high income status. The differences within the four country categories tend to be large, and hence local factors play an important role.

4. Specification of NRW loss models

Following the still limited literature on the drivers of water losses, we will specify the water loss function as

(1) $L = f(P, M, E) + e + u$

This relationship describes the relationship between non-revenue water as measured by water losses (L) on the one hand, and a vector of physical characteristics of the water infrastructure (P), a vector of management characteristics of the utility (M) and a vector of environmental factors (E) that characterize the environment in which the utility is located. As we depend on panel data, that covers the period between 2006 and 2011 and includes utilities from a subset of countries, we include the country effects (e) and an error term (u). Each country has its own characteristics that may influence the water losses. These country effects may refer to among others institutional settings, legal and regulatory framework, environmental, public health and building standards and levels of corruption.

Before including the variables in the above specified model, we first corrected for correlation between variables. Many of the variables are correlated. For instance, low corruption levels and GDP per capita tend to correlate: the higher the GDP per capita, the lower corruption levels. These correlations do not stop there, as utilities evolve so does the performance of utilities. Tariffs tend to be correlated with GNI – the higher the income, the higher tariffs tend to be, and wage rates. Or similarly, the cost of service is correlated to the cost of labor and staff productivity, which tend to increase with GDP.

The estimation of the single loss reduction function provides insight on variables driving water losses. We will specify the water losses and its explaining variables in natural logarithm terms, so that the coefficients will measure the elasticity of water losses, i.e., by how much water losses will change if the values of the different drivers will change to determine the importance of the different drivers.

We will use non-revenue water in cubic meter per kilometer per day as the explaining variable. The reason for selecting this specific indicator is mainly that it is a more objective indicator than NRW per connection. What constitutes a connection is rather differently defined by country. In Latin America, for instance, the number of people per connection tends to be low and linked to household size. In other parts of the world, the number of people per connection tends to be much higher as households share connections with neighbors as is the case in Africa. In Eastern Europe and Central Asia, buildings are usually outfitted with a water connection and hence the number of people can be very large in the case of apartment buildings.

Our first hypothesis is that physical characteristics of the water systems affect the level of water losses. The factors included in the model are the density of water connections (per kilometer of network as measured by LN_CONNDENS). It is assumed that the higher the density of water connections, the higher the water losses will be. A denser network tends to be linked with more pressure required in the system to reach the higher floors of buildings. Pressure is probably the most important factor which influences the level of leakage in distribution systems (Skipworth et al., 1999). As a result of the higher pressure, a very dense network of connections is likely to require more maintenance to preserve the network. High connection density also may increase the complexity of managing the service. Connection density and its management falls mostly outside of the control of utility management as it is shaped by urbanization and land settlement patterns of the localities that are served by the utility. In the IBNET sample, small systems mostly located in small towns showed a mean density of water connections of 55 compared to 134 in utilities in large systems, while the variance between utilities can differ widely.

The length of the water network (LN_LENGTHWAT) is another physical characteristic of the water system. The length of the network should be positively related to water losses, as a larger network is more costly to maintain in order to preserve the functioning of the water network. A larger network will often also transport water over larger distances and hence has to deal with higher costs.

The share of energy costs as part of total operation and maintenance costs (LN_ENERGY_SHARE) is used as a proxy for the type of adduction of the distribution system. The more pumping a system needs the higher the share of energy in the total costs will be. We assume that the more pumping is needed in a system, the higher the likelihood that water losses are higher.

The presence of a dummy variable measuring universal water coverage (WATCOVDUMMY) is used to explain the physical characteristics of the water losses. It is assumed that universal coverage has a negative effect on water losses. Universal coverage has a positive effect on using more of the existing production capacity. Water systems tend to be designed with a horizon of several decades in mind and hence tend to have significant excess capacity in less mature water systems; the level of excess capacity will depend on the water supply design standards applied in the country. Hence, once access to water supply services improves (in terms of people and consumption), and with capacity mostly fixed, excess capacity tends to decline over time. It should therefore not come as a surprise that in mature, developed systems water losses should be relatively lower, whereas systems that have been built more recently and hence have significant excess capacity are likely to have relatively higher water losses as managing a system with large overcapacity tends to be complicated.

We also included a dummy for sewerage coverage. In general, utilities follow a pattern in which they first tend to provide water supply services to be followed by access to sewer services. In first instance, wastewater is collected. Afterwards, it will be treated to increasingly exacting standards. These increasing higher levels of sewer services tend to be linked to economic development. It is assumed that access to sewer services tend to complicate utility management as it increases the scope of services. The more complex the services are that are provided by the utility, the higher water losses will tend to be.

The second hypothesis is that utility management quality affects water losses. It is assumed that the better the quality of utility management, the lower water losses. The first variable that reflects management quality is the level of staff productivity (the number of staff per 1,000 people served as measured by LN_STAFFPROD). We assume that the higher the number of people of staff per 1,000 people served, or the lower the staff productivity, the higher the water losses.

Metering is often seen as key to reducing commercial water losses. Metering increases customer metering accuracy, improve meter reading and billing and assist in the detection of illegal water connections and water theft. We introduce a dummy for the presence of universal metering (FULLMETER). The assumption is that utilities with universal metering will show lower water losses than those that have not yet achieved that level of metering.

A third variable is the total revenues per capita per year (in US dollars) (LN_TOTREVPCAPUSD). The relationship is between the total revenues per capita per year (the result of household consumption volumes and tariffs charged) and NRW is more ambiguous. It is possible that high total revenues per capita per year result in more financial ability of the utility to pay for reduction in water losses. Yet, high total revenues per capita per year may also provide the utility with sufficient financial ability to deal with the water losses and hence not provide utilities with an incentive to reduce them. As total revenues per capita are useful to determine whether utilities have some financial ability, the actual available financial space is determined by the difference between revenues and costs. It is quite well possible that the total revenues per capita are very high but so are the costs per capita and hence the margin available to deal with water losses are limited. We hence included a dummy variable (OCCRDUMMY) that measures a positive or negative difference between total revenues and total operation and maintenance costs[4] per capita per year. We expect this variable to be showing an inverse relationship with water losses. When total revenues exceed total operation and maintenance cost will result in more financial ability and hence lower water losses and vice versa.

Finally, we include a variable that according to Garcia and Thomas (2001) reflects the opportunity cost of water losses as measured by the cost of increasing production reflected in higher energy costs (in most systems resource cost of drinking water are negligible). These authors point out, that reductions in NRW are constrained by high repair costs. In their paper they note that utilities have two options when they both produce and distribute water – which is the case in most utilities. The first option is to keep production constant while reducing NRW through more frequent repair and maintenance. The second option is to increase production while keeping the water network rate of return constant. In case the labor and maintenance cost involved in repair and maintenance is higher than the cost associated with increased production (energy and resource costs), the second option will be the preferred one. When using the IBNET sample, we find that the cost of repair is significantly higher than that of energy costs in most utilities. We assume that the higher the opportunity cost of water losses (LN_WATERLOSS), the lower water losses will be. This variable is somewhat similar to that used of Saez-Fernandez et al. (2011) and the opportunity cost of water losses.

The last hypothesis states that the "environment" in which the utility operates affects the level of water losses. We do not have much access to environmental data at the utility level. Data on GNI or corruption are only available at the national level and hence captured in the fixed effects of the

[4] No data is available on the total costs (including depreciation and financial costs) and hence we had to limit ourselves to operation and maintenance costs.

model. Yet, we include two "environmental" variables based on the data available. The first variable is the wage rate per employee in USD as a proxy for GNI at utility level as reflected in LN_WAGERATE. Another variable we use is the population served per connection (LN_POP_CONN). In general, the population per connection differs widely by region and is linked to urbanization and utilities' connection policies. In Africa, for instance, population per connection is very high due to the high cost of connection and the accepted practice of sharing connections. In Eastern Europe and Central Asia, it is still rather commonplace that apartments building are outfitted with only one connection instead of individual household connections – although this pattern is changing. In Latin America and the Caribbean, the number of population per connection is mostly linked to household size. It is assumed that the relationship between population served per connection and water losses is positive as more people served per connection essentially increases the stress on the water system.

5. Estimation Results

The analysis was conducted using cross-sectional data from utilities covering 69 countries. This sample is smaller than the available sample, as we cleaned the data set for outliers taken out the 1 percent at either tail of the distribution. Given the nature of the dependent variable, we used a model with fixed effects in which the water losses as measured by LN_NRW_KM and controlled for heteroskedasticity. Table 5 shows the results of the panel data regression with fixed effects. Estimated coefficients are almost all significant and have the expected sign as can be seen in Table 5. It also shows that the fixed effects variable captured by the country effects is very significant. The overall fit of the model is satisfactory, with a R square adjusted of 0.61. The errors in the model are not correlated with the regressors in the fixed effects model. About 40 percent of the variance in the model is due to differences across panels (or countries), showing that the characteristics of the country have a major effect on water losses – and hence the environment in which the utility operates plays key role in explaining water losses.

Insert Table 5: Estimation Results of Fixed Effects Model

We found that the higher the number of connections per kilometer of network, the higher the water losses as a denser network tends to be linked with more pressure required in the system. As a result of the higher pressure, a very dense network of connections is likely to require more maintenance to preserve the network. The effect of this variable is very significant, with a t-value of more than 38. The coefficient is also large showing that a 10 percent increase in connection density increases the water losses by more than 12 percent.

Population per connection is also a highly significant variable. The higher the number of people served per connection, the higher water losses will be. More people using the same connection will put more pressure on the system. The coefficient of this variable is large - a 10 percent increase in people per connection increases the water losses by 12 percent.

LN_LENGTHWAT is also positively related with water losses. A larger water supply network results in higher water losses. An increase in the network with 10 percent results in a 1.1 percent increase in water losses. An increase in LN_ENERGY_SHARE is resulting in higher water losses. The effect is very significant; a 10 percent increase in the energy share, results in a 11 percent increase in warer losses. NRW is lower in a mature water supply network with universal access to its customers (measured by WATCOVDUMMY) but the effect is small. SEWCOV_DUMMY's effect is positive and significant.

We now turn to the role of managerial factors in explaining water losses. LN_STAFFPROD turns out to be a significant variable. The higher the number of staff per 1,000 people served (or the lower the staff productivity) is, the higher water losses will be: an increase of 10 percent in staff productivity will result in an almost 4 percent decline in water losses. Total revenues per capita per year (in US dollars) (LN_TOTREVPCAPUSD) has a positive relationship with water losses: the higher the total annual revenues per capita are the higher the water losses; an increase in the utilities' revenue base of 10 percent, increases water losses by almost 7 percent. The higher total revenues per capita per year will provide the utility with sufficient financial ability to deal with the water losses and hence does not provide utilities with incentives to reduce them. The OCCRDUMMY which measures either a positive or negative value of the difference between total revenues and total operation and maintenance costs per capita per year shows a negative relationship as an operating cost coverage ratio that covers more than operation and maintenance costs results in lower water losses. Switching from a negative to a positive operating cost coverage margin has a significant impact on water loss reduction. Utilities with universal metering have lower water losses than those that do not. Universal metering results in lower water losses. Finally, the opportunity cost of water losses as measured by the energy cost of the service (as measured by LN_WATERLOSS) are negatively related to water losses. An increase in the opportunity cost of water losses (i.e., energy cost of water) results in lower water losses: a 10 percent increase in the opportunity cost of water losses results in an almost 11 percent decline in water losses.

LN_WAGE_RATE as measured at the utility level shows that the relationship with water losses is positive. The higher the wage rate at utility level, the higher water losses will be. This is as expected as higher wage rates are likely to be linked with higher repair and maintenance costs that are associated with water loss reduction.

6. Concluding Remarks

Many authors mention the large benefits that reduction of water losses will generate (Kingdom et al., 2006; Frauendorfer and Liemberger, 2010; McKinsey, 2013). Nevertheless in the past six years, improvements in reducing water losses have been limited looking at the different indicators that are being used to measure water losses. So the question arises why utilities are making only limited progress in reducing water losses. The main empirical finding of this paper is that the key drivers of water losses (using a large sample of utilities located in 68 countries) are for a large part outside the control of the utilities. Connection density, population served per connection and the size of the water supply network are important drivers of NRW and are mainly the results of urbanization and land settlement patterns. The type of distribution networks (pumped or gravity as proxied by the share of energy costs in total operation and maintenance costs) is determined by geography. In utilities located in highly urbanized and dense settlements (especially those where water distribution depends on pumping water), NRW will be higher. Urbanization is accelerating in many parts of the world; between 1990 and 2012, the urban population increased from 2.3 to

3.7 billion people. Most rapid urbanization is taking place in low- and middle-income countries. In the IBNET database, the typical utility already has a density of about 66 connections per kilometer of network (compared to only 31 for the utilities in high-income countries). In addition, in many countries the actual connection density can be much higher than that what the typical utility faces. In Singapore, for instance, the connection density was no less than 240 connections per kilometer of network. The trend of higher connection density is partially neutralized by what is a decrease in population per connections once economic development takes off. In many utilities in low-income countries, the typical number of people per connection is high, but that tends to decrease over time driven by economic development and urbanization. A typical utility in a low income country served more than 9 people per connection, but that drops to less than 3 once a country moves to high-income status. The size and scope of the system which is mostly effected by government policies and urbanization policies is equally mostly beyond the control of utilities as larger systems tend to generate higher water losses. Moreover, wage rate levels affect water losses. This is mainly because as mentioned earlier by Garcia and Thomas (2001) the cost of reducing water losses shows up mainly in the form of labor and maintenance costs needed to repair the network to reduce losses. The higher the costs of labor are, the higher the cost of repairing water losses, and hence the less incentives for utilities to reduce water losses. Finally, the opportunity cost of water losses[5] also plays an important role. Careful planning of water and wastewater services upfront may help to alleviate some of the above-mentioned pressures.

Yet, even though some of the key drivers of NRW are beyond the control of utilities, utilities have room to manoeuver in reducing water losses through improving the efficiency with which they operate their water supply systems, and the opportunity cost of water losses[6]. Staff productivity as measured by the number of staff per 1,000 people served (the higher the number of staff per people served, the lower the staff productivity) is directly linked to water losses through the labor

[5] In our sample we find that the best performing utilities in terms of NRW have significantly higher opportunity cost for water losses than poor performing utilities. The utility of Phnom Penh, Cambodia (Biswas and Tortajada, 2005) has a rather uncommon cost structure where the opportunity costs for water losses are relatively high.

[6] In principle, utilities can manage their energy costs, but the costs of water resources and energy prices are beyond the control of utilities. Moreover, energy costs are also driven by amongst others the outlay of the water supply network (pumping in the network drives energy costs), the location of the water source and topography.

costs needed to repair and maintain the water supply network. Utilities that at least cover their operation and maintenance expenses through revenues face lower levels of NRW. Metering has an impact on water losses, but gradually increasing the number of metered connections tends to have a very limited effect on water losses. Yet, once a utility has achieved universal metering, the effects of metering become evident and will dampen water losses.

A third conclusion is that country effects in the model are very important with almost 40 percent of the variance due to differences across panels (i.e., countries). Hence, the national environment in which a utility operates has a major effect on its effectiveness in controlling water losses. Country effects relate to labor and energy policies, urbanization and land settlement and engineering design standards and norms among others.

A final conclusion is the sometimes paradoxical nature of improving water utility performance and the impact of these improvements on water losses. Water loss reduction is seen as a key ingredient to improving utility performance, but the analysis shows that often proposed tools of utility performance and water loss reduction do not always go hand in hand. For instance, energy efficiency programs can improve the utility's bottom line, but a more energy efficient utility will reduce the opportunity cost of water losses and hence may increase water losses. Similarly, increasing total revenues per capita per year will help to improve the financial viability of the utility, but will also provide more financial buffer to deal with water losses, and hence provide utilities with fewer incentives to reduce water losses. The effect of economies of scale and water loss reduction suggest that the larger the utility, the larger the water losses. This finding seems to deflect the importance of economies of scale. Yet, this finding is consistent with results on economies of scale found by among others Nauges and van den Berg (2008) and Gonzalez-Gomez et al. (2012) that economies of scale are more evident in smaller companies and tend to decrease in relation to the size of the operation. This may be linked to the effect that a larger sized operation may have to deal with longer distances of water being transported and hence the likelihood of water losses increases.

Future Directions of Research

In view of the unobserved characteristics that we found, future research may focus on getting more insight in the variables that might be important but for which we did not have data available, such as topography, age of system[7], soil conditions and the production capacity of the water supply system, whereas more data on energy volumes and prices and abstraction fees would be useful to get more detailed insight in the opportunity cost of water losses. It is especially important that a variable as production capacity is included in the data to be collected. As water consumption does not differ significantly between good and poor NRW performers; the same is not true for water production per capita where poor performers have a much higher per capita water production than good performers. Utilities tend to have an incentive to increase water production when the costs of repair exceed that of the cost of water production. Yet, in systems with large overcapacity, it is much easier to increase production at marginal costs than in systems where there is little overcapacity. Further research is also warranted on how engineering design standards affect water losses. Another element of research is linked to how different development stages affect the drivers of water losses. Water and wastewater services are provided according to a certain trajectory (starting with provision of water supply services and then increasingly higher quality forms of wastewater collection, treatment and disposal), while at the same time income increases affecting consumption patterns and tariffs. Hence, one may assume that this affects the significance of the different drivers of NRW over time.

[7] We had access to pipe breaks per km as a proxy for age of system, but this variable was not collected in many countries and hence the number of observations would have been reduced significantly when this indicator was included in the model. Yet, in a model run with pipe breaks, this variable turned out to be significant.

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Table 1: Non-Revenue Water (as percentage of water production)

Indicator	2006	2007	2008	2009	2010	2011 prelim
Median Non-revenue water	26	31	29	29	28	27
Average Non-revenue water	33	32	31	31	31	30
Standard deviation	26	31	29	29	28	27
Number of utilities reporting	1,242	1,448	1,349	1,403	1,488	1,253

Source: IBNET database
Note: The 2011 data collection cycle are not yet complete.

Table 2: Non-Revenue Water (in cubic meters per km per day)

Indicator	2006	2007	2008	2009	2010	2011 prelim
Median Non-revenue water	20	21	18	19	15	17
Average Non-revenue water		35	34	35	29	29
Standard deviation	280	54	96	85	65	45
Number of utilities reporting	1,274	1,479	1,332	1,419	1,443	1,313
Highest performing quartile	9	7	7	6	5	6
Lowest performing quartile	46	44	40	40	35	36

Source: IBNET database
Note: The 2011 data collection cycle are not yet complete.

Table 3: Non-Revenue Water - Descriptive Statistics for NRW

Variable	Utilities with low NRW losses	Utilities with high NRW losses	t-value
NRW in percent	16.8	34.8	43.76*
NRW in km per day (in cum)	3.3	37.8	40.41*
NRW per connection per day (in cum)	0.13	0.53	25.29*
Physical Factors			
Connection Density (number of connections per km of network)	46.23	82.38	5.69*
Population per Connection	5.64	10.76	2.75*
Pipe Breaks per kilometer of network	0.026	0.046	2.83*
Length of Network	610	1,111	5.36*
Full Water Coverage (dummy)	0.34	0.26	-4.20*
Sewerage Coverage (dummy)	0.65	0.70	3.97*
Service Area is urban (dummy)	0.58	0.65	4.51*
Size of Utility in People Served (1= smallest, 6 = largest)	2.27	3.34	28.19*
Towns served with water	8.65	11.40	1.91**
Water Production per capita per day (lcd)	206	282	19.66*
Water Consumption per capita per day (lcd)	174	177	1.23
Management Factors			
Staff Productivity (staff per 1,000 people served)	1.45	1.32	-4.04*
Total Revenues per Capita (in USD) per Year	103.64	54.64	-18.07*
Operating Cost Coverage Ratio	1.24	1.20	-2.43*
Presence of PSP (dummy)	0.208	0.229	1.59***
Universal metering (dummy)	0.505	0.335	-11.23*
Metering level	0.88	0.82	-7.32*
Hours of Supply	22.34	21.95	-2.59*
Energy Cost per cum of water produced	0.09	0.16	-28.94*
Other Factors			
Wage rate levels in utility (USD)	3,172	3,224	0.08
GDP per capita +	12,299	6,377	-12.03*
Level of Corruption ++ (1 = highest, 10 = lowest)	4.42	3.46	-27.66*
Level of ease to get Construction Permits (0=most difficult, 100 =easiest)	55	59	-8.97*

\+ *GDP per capita and level of corruption is based on country level data*

++ *Level of corruption: the higher the value of the variable, the lower corruption (1= highest level of corruption, 10 = lowest level of corruption)*

* *Significant at 1 percent level*

** *Significant at 5 percent level*

*** *Significant at 10 percent level*

Table 4: NRW as measured in cubic meters per kilometer per day by Income Status

Indicator	10th percentile	25th percentile	50th percentile	75th percentile	90th percentile
Low Income Countries	4.82	9.77	18.51	35.43	70.84
Lower Middle-Income Countries	5.95	12.36	25.49	52.30	101.08
Upper Middle-Income Countries	2.91	7.15	18.90	40.53	66.69
High Income Countries	1.59	2.95	4.92	9.67	16.48

Source: IBNET database

Note: The 2011 data collection cycle are not yet complete.

Table 5: Results of the Panel Data Fixed Effects Regression

Variable	Coefficient	Standard Error	T-value	P-value
LN_CONNDENS	1.170743	0.032446	36.08	0.000
LN_POP_CONN	1.164996	0.0343911	33.87	0.000
LN_LENGTHWAT	0.106682	0.0100910	10.57	0.000
LN_ENERGY_SHARE	1.115983	0.1275154	8.75	0.000
WATCOVDUMMY	-0.075393	0.0414967	-1.82	0.074
SEWCOV_DUMMY	0.2566574	0.0255452	10.05	0.000
LN_STAFFPROD	0.3825044	0.0393743	9.71	0.000
LN_TOTREVPCAPUSD	0.6917163	0.0486540	14.22	0.000
OCCRDUMMY	-0.5611854	0.0695321	-8.07	0.000
FULLMETER	-0.0888838	0.0322734	-2.75	0.008
LN_WATERLOSS	-1.097441	0.1053194	-10.42	0.000
LN_WAGE_RATE	0.2047241	0.0574633	3.56	0.001
Constant	-9.426953	0.8036175	-11.75	0.000
Number of observations	4,386			
Number of groups	68			
R square	0.6067			
F test	541.66			
Prob > F	0.0000			
Rho	0.3927			