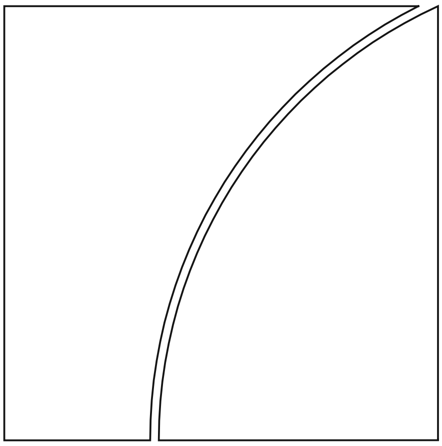

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The economics of water scarcity

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The economics of water scarcity

Jon Frost, Carlos Madeira and Serafín Martínez Jaramillo.[1]

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Abstract

In many countries around the world, water scarcity could become a macroeconomically relevant concern. As a key input into production processes (agriculture, power generation and industrial use) and a common good, water resources risk being overexploited. Regressions with panel data for 169 countries between 1990 and 2020 show that, while water use is positively correlated with output, higher water *scarcity* is associated with lower gross domestic product growth and investment, and higher inflation. In contrast, water use efficiency is associated with higher gross domestic product growth and lower inflation. Climate scenarios show risks of much more severe water shortages in the future, threatening its sustainable use. This could impose higher costs on individual sectors and on the economy, reducing output and pushing up prices. Water availability and use could thus become an area for economists and central banks to monitor in the context of climate change, economic forecasting and monetary policy.

Keywords: water scarcity; efficiency; tragedy of the commons; climate change; natural resources.

JEL classification: L95; Q25; Q50.

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1. Introduction

Fresh water is a necessity for human, animal and plant life and a crucial input into various sectors of economies around the world. Water availability is essential for agriculture, mining, manufacturing and human capital activities (Islam and Hyland, 2019). Economic activity can be disrupted by either extreme rainfall (Kotz et al, 2022), drought or excessive water withdrawal (Zaveri et al, 2023). Already, around 60% of humanity lives in areas with water stress for at least part of the year (Mekonnen and Hoekstra, 2016; He et al, 2021). Over 85% of people affected by dry shocks live in low- or middle-income countries (Damania et al, 2017), with women being particularly affected (Carr et al, 2024). While the overall volume of water on earth is fixed, and water availability remains stable on average in arable lands, rapid changes in freshwater availability are affecting regions with large populations (Carleton et al, 2024). Furthermore, there has been a decline in available water across several areas (Jones et al, 2024; Li et al, 2024) and across several dimensions, including blue water (surface and groundwater), green water (soil moisture) and water quality (Liu et al, 2025).

This paper examines the economics of water scarcity and its macroeconomic implications. We start with a descriptive discussion of water scarcity issues in the Americas – a region with substantial freshwater resources, but substantial heterogeneity in water use and scarcity measures. We then examine the impact of water scarcity on output growth, investment and inflation across a global sample of economies. Finally, we discuss future scenarios based on recent climate projections.

We contribute to the literature by assessing the economic effects of water scarcity – a topic that has received relatively little attention in macroeconomic research. We first document water resources, daily use and scarcity for the Americas. We then propose a simple Cobb-Douglas model for how water use and water scarcity affect production even after accounting for traditional factors such as capital and labour. We estimate a linear version of this model with cross-country panel data. We show that, while water use is correlated positively with output, water scarcity has a negative association with real gross domestic product (GDP) growth and investment and is tied to higher inflation. Furthermore, we show that higher water withdrawal is associated with a lower share of services in the economy and lower growth in water intensive manufacturing industries. Our analysis is relevant for understanding how the scarcity of freshwater resources may affect the economy – a relatively understudied area.

Notably, climate change is exacerbating water scarcity. Aside from raising global temperatures and driving human migration (Albagli et al, 2024), climate change can alter precipitation patterns (Waidelich et al, 2024). Global land area facing extreme droughts could more than double from 3% during 1976–2005 to 7%–8% by the late 21st century, affecting heavily populated regions (Pokhrel et al, 2021). Adapting to rainfall variability can be more challenging than accommodating long-term trends, due to the less predictable duration, magnitude and frequency of climate disasters. But the future risks associated with water scarcity are not exclusive to surface water. Groundwater sources rely on adequate recharge, which will be affected by climate change. In particular, the aridity of soil can be affected if evapotranspiration is larger than precipitation; this can severely impact the recharge of groundwater. Groundwater replenishment can have relevant implications for humans, ecosystems and the economy (Berghuijs et al, 2024, Franke, 2024, Rouhani et al, 2025).

Because water resources are a common good (ie rival but non-excludable or only partially excludable), private actors and local governments may have insufficient incentives to preserve them. Water management can therefore suffer from a "tragedy of the commons" problem, which requires proper institutional arrangements for access and/or adequate pricing (Debaere et al, 2014; Rodella et al, 2023). Several policies are available for governments to improve water management, including the use of contracts that stimulate water savings and efficient water use during droughts (Vicuña et al, 2018), more developed water markets (Debaere et al, 2014; Ricalde et al, 2022; Bruno and Jessoe, 2024), better water management among associations of users (Engler et al, 2021) and more resilient infrastructure (Ricalde et al, 2022; Piemontese et al, 2024).

Freshwater is a key input in agriculture. In turn, international trade in agricultural products helps to satisfy regional demands and limit water consumption in importing regions.[2] Unfortunately, in part caused by climate change and overconsumption, freshwater is becoming a scarcer resource in many key agricultural regions, threatening food security and causing shifts in agricultural activities to places where the water is more available (Graham et al, 2023).

Water also plays a key role in electricity generation. Ecuador's recent electricity crisis due to severe droughts in the country is an important reminder of the economic effects of the lack of access to water. Although the current water crises could be associated with the meteorological impact of "La Niña", the physical impact of climate change could be very similar and possibly worse than the current situation. Ecuador and its neighbour Colombia rely heavily on hydropower. Both countries experienced important water shortages with the associated spillover effects to the rest of the economy. On one hand, hydropower can promote economic development, provide energy security and aid the energy transition. On the other hand, the construction of hydropower dams disrupts river flows and has important socioeconomic and environmental consequences, affecting ecosystems and the riverine communities which depend on the associated ecosystem services.

Finally, from the long list of ecosystem services, water is probably the most important input for many industrial processes. Unfortunately, there is an important knowledge gap in its full economic value. In many countries, the monetary value of water used in industrial processes does not reflect its sustainable use. The full cost of water (reflecting its sustainable value in use) is not paid, imposing important externalities on human health and on other ecosystems (Savenije and van der Zaag, 2002). Additionally, the direct economic impacts of water scarcity to industrial activities (as with agriculture and electricity generation) can be amplified by the transmission of the negative impacts to other economic sectors through the supply chain (Freire-González, 2017a).

The Americas region forms a highly relevant backdrop to investigate these issues. As we will show below, the region has ample renewable water resources, which is one reason that it is so important for agricultural production on a global scale. It also means that water scarcity in the region can have a global impact. The Americas are also very diverse, with drivers of future water scarcity varying substantially across countries (Birnbaum et al, 2022). Finally, the region is already at the forefront of many debates on water use and availability.[3] Therefore, it is important to study where, when and under which circumstances water scarcity could affect economies in the Americas. This helps to ground the discussion, before moving to empirical analysis at the global level.

We seek to assess whether water scarcity can affect macro-outcomes like growth, investment, inflation and electricity production. To inform this, we use a simple Cobb-Douglas model with GDP growth depending on capital, labour, total factor productivity (TFP) and water – as an additional factor of production that is ignored in standard growth models. The effect of water on production is modelled by two parameters, with the first parameter corresponding to water use as a production

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[2] Trade helps to limit water consumption by importing countries and regions, since goods (whether primary goods or manufactures) that require a lot of water for their production can be produced in water abundant countries and then be imported by water scarce countries.

[3] In several US states, notably California, severe droughts have already led to water rationing and some commentators refer to a "water crisis" (Howarth, 2024). Mexico City, home to 22 million people, saw dire warnings of a complete water supply failure, or "Day Zero", in June 2024 (Averbuch, 2024). Finally, the governments of the United States and Mexico have an ongoing conflict about water sharing under the terms of the 1944 Treaty on utilization of waters of the Colorado and Tijuana Rivers and of the Rio Grande (Grant, 2025).

factor and the second parameter corresponding to a decline in production with higher water scarcity (due to decreasing productivity or increased marginal costs of scarce water). This model can be estimated using a simple panel data model with country and year fixed effects and observable variables for water use and its scarcity. We expect that a lack of water can form a constraint on production, particularly when freshwater withdrawal is above a certain threshold. For this reason, we also estimate panel quantile regressions of the same model, using the methodology suggested by Machado and Santos Silva (2019).

Regression analysis with panel data for 169 countries between 1990 and 2020 show that high water scarcity is associated with lower GDP growth and investment, and higher inflation. As expected, water use is positively associated with growth (although it is not always statistically significant). We also find that high water use in absolute terms is associated with stronger physical investment growth if water stress is avoided. Our results are economically sizeable and statistically significant, with a one standard deviation increase in water scarcity being associated with 0.12% to 0.16% lower GDP growth, 0.39% to 0.42% lower investment growth and 2.9% to 3.5% higher annual inflation. Furthermore, we find that higher water withdrawal rates are associated with lower growth of the service sector and the vehicle manufacturing industry.

Going forward, scenarios show that water scarcity could become even more intense. We argue that water scarcity could become a relevant constraint on economic production and a source of inflationary pressure. For instance, water scarcity can impact inflation by its effects on food prices or on energy availability. This could become macroeconomically relevant and thus a key issue for economists and central banks.

Our key contribution to the literature is to bring together empirical evidence on water scarcity and its potential macro impact. This fits into broader literature in environmental economics and macroeconomics, showing the macro relevance of water scarcity issues. While our discussion focuses on the Americas region, this holds insights for countries around the world. Previous literature has documented the effects of rainfall on economic growth (Damania et al, 2020; Kotz et al, 2022; Bareille et al, 2024). However, our paper extends the analysis of water scarcity and output by showing an association of water scarcity with overall GDP growth, investment and inflation. This differs from the rainfall effect estimated in the previous literature, since there are more water resources besides rainfall. Furthermore, our analysis goes beyond finding an effect on economic growth and shows that the negative effects extend to lower investment and higher inflation rates.

Our study also contributes to a better understanding of the effects of water scarcity on different economic sectors. We find strong coefficients for water scarcity in regressions for the services sector and vehicles manufacturing. This result goes beyond previous studies, which only study the effects of water scarcity for the agriculture sector (Booker and Trees, 2020; Carleton et al, 2024).

This paper is organised as follows. Section 2 uses Aquastat data to give an overview of freshwater resources and use in the Americas relative to other continents. Section 3 analyses the link between water usage and output, investment and inflation. Section 4 shows the effects of water withdrawal on different economic sectors. Section 5 discusses the role of water pricing and public infrastructure for conservation efforts. Section 6 shows simulated scenarios for water stress in future years due to climate change. Section 7 concludes.

2. Freshwater resource use in the Americas

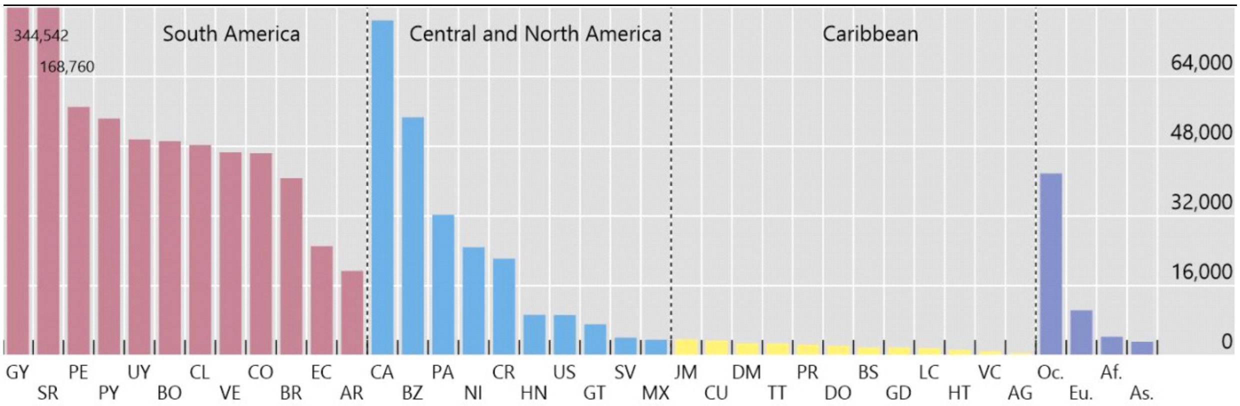
We start with a discussion of water scarcity issues for the Americas region. Countries in the Americas have some of the most abundant freshwater resources in the world. This makes the region an interesting case, because it includes a heterogeneity of water rich and dry areas. Another interesting characteristic of the region is that some of the water rich areas can suffer from scarcity due to high demand or mismanagement. Brazil, for instance, has the largest total renewable water resources of any country in the world (8.6 trillion m^2 per year, or 15.8% of the global total), given the strong rainfall and freshwater flow in the Amazon basin. Canada, the United States, Colombia and Peru also have abundant freshwater resources. Together, North and South America – which have 1/8th of the world's population – have about 39.8% of the world's renewable water resources (World Bank and FAO, 2024). This is one reason why the region plays such an important role in global agricultural production, hydropower generation and more.

At the same time, freshwater resources are not evenly spread across the region – and in several countries, water scarcity is already an issue. In terms of water resources per capita, Graph 1 shows that Guyana, Canada, Suriname and Belize have the most abundant resources in the Americas, while the Caribbean faces the strongest scarcity. Per capita, the Americas have the most abundant water resources of any region, except for Oceania, while Africa and Asia have the lowest water availability.

Total renewable water resources per capita[1]

In cubic meters

Graph 1



[1] Total annual renewable water resources per inhabitant. Data for 2020. AG = Antigua and Barbuda. AR = Argentina. BB = Barbados. BO = Bolivia. BR = Brazil. BS= Bahamas, BZ = Belize. CA = Canada. CL = Chile. CO = Colombia. CR = Costa Rica. CU = Cuba. DM = Dominica. DO = Dominican Republic. EC = Ecuador. GD = Grenada. GT = Guatemala. GY = Guyana. HN = Honduras. HT = Haiti. JM = Jamaica. LC = St. Lucia. MX = Mexico. NI = Nicaragua. PA = Panama. PE = Peru. PR = Puerto Rico. PY = Paraguay. SR = Suriname. SV = El Salvador. TT = Trinidad and Tobago. US = United States. UY = Uruguay. VC = St. Vincent and The Grenadines. VE = Venezuela. Eu = Europe. Oc = Oceania. Af = Africa. As = Asia. Weighted averages values for Africa, Asia, Europe and Oceania.

Sources: FAO; Aquastat: BIS.

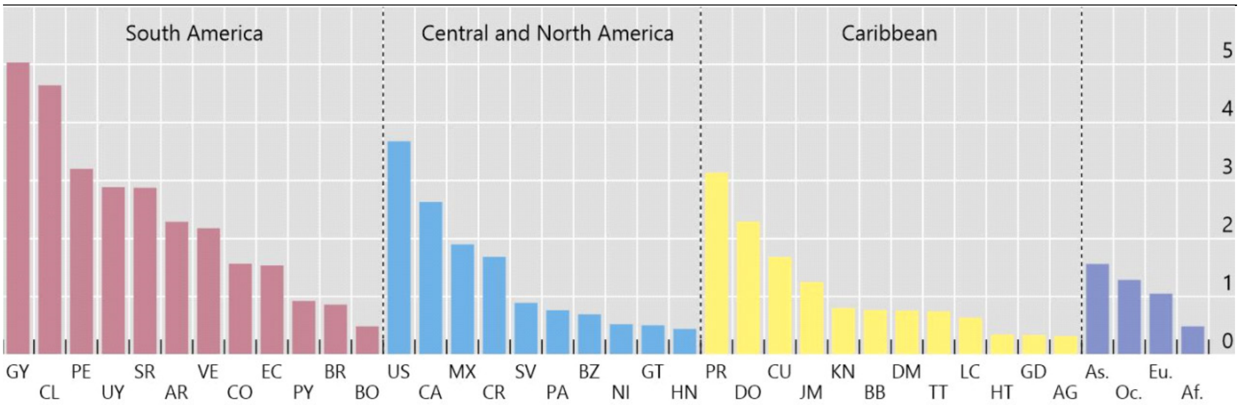
That said, water use per capita is also much higher in the Americas than in other countries. Graph 2 shows that several countries in the Americas have daily water use per capita above 2 cubic meters, which is a level much higher than other continents. Guyana and Chile have daily water use per capita of almost 5 cubic meters, which is almost 3 times the use in Asia and more than 4 times the use in Europe or Oceania. The US, Canada, Peru, Uruguay and Suriname also have water usage per person around 3 daily cubic meters, about three times as much as Europe.

Furthermore, while it is true that water resources on Earth are constant (Carleton et al, 2023), that is not necessarily the case for specific regions and countries. Furthermore, water demand is rising in several countries due to population growth and higher economic activity.

Daily water use per capita[1]

In cubic meters

Graph 2



[1] Total daily amount of water withdrawn per capita. Data for 2020. Same specification as in Graph 1. Weighted averages values for Africa, Asia, Europe and Oceania.

Sources: FAO; Aquastat; BIS.

In this paper we use several measures of water use and water scarcity from the World Bank and from Aquastat, a database of the Food and Agriculture Organization (FAO) of the United Nations:

i) Annual or daily freshwater withdrawal per capita (in cubic meters). This refers to total water withdrawal, not counting evaporation losses from storage basins. Withdrawals also include water from desalination plants in countries where they are a significant source.[4]

ii) Annual freshwater withdrawal as a share of internal renewable resources. Renewable water resources are defined as the maximum theoretical yearly amount of water available for a country at a given moment. Renewable internal freshwater resource flows refer to river flows and groundwater from rainfall in the country, based on estimates of runoff into rivers and recharge of groundwater.[5] This measure considers environmental water requirements. Note that withdrawals can exceed 100% of total renewable resources if extraction from non-renewable aquifers or desalination plants is large or where there is significant water reuse.

iii) Annual freshwater withdrawal as a share of total renewable resources (ie both internal and external resources). This measure does not account for environmental water requirements

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[4] Caution should be used in comparing data on annual freshwater withdrawal, which are subject to variations in collection and estimation methods. In addition, inflows and outflows are estimated at different times and at different levels of quality and precision, particularly for water-short countries, notably in the Middle East and North Africa. The data are based on surveys and estimates provided by governments. The coverage rates are based on information from service users on actual household use rather than from service providers, which may include nonfunctioning systems.

[5] Because the data are collected intermittently, these may hide significant variations in total renewable water resources from year to year. Data for small countries and countries in arid and semiarid zones are less reliable than those for larger countries and countries with greater rainfall.

in water use. It is limited to considering water needed for human activities in front of the overall water availability. Therefore, some countries can drain extra water from ecosystems.

iv) Annual freshwater withdrawal as a share of available freshwater. This is the ratio between total freshwater withdrawn by all major sectors and total renewable freshwater resources, after taking into account environmental water requirements.[6] Renewable water resources (internal and external) include average annual flow of rivers and recharge of aquifers generated from endogenous precipitation, and those water resources that are not generated in the country, such as inflows from upstream countries (groundwater and surface water), and part of the water of border lakes and/or rivers. Non-renewable water includes groundwater bodies (deep aquifers) that have a negligible rate of recharge on a human time scale. This indicator is also known as water stress or water withdrawal intensity. It provides an estimate of pressure by all sectors on the country's renewable freshwater resources. A high level of water stress indicates a situation where the combined withdrawal by all sectors represents a substantial share of the total renewable freshwater resources, with potentially large impacts on the sustainability of the resources, conflicts and competition between users.

In our exercises, we always use two water measures. The first corresponds to water use, ie log total water withdrawal per capita. This variable measures how much water is used in the economy across all final users (whether consumers, workers or firms). It is a measure of water as an input into the production function. The second is for water scarcity, ie freshwater withdrawal as a fraction of a measure of available resources. This can be seen as a proxy for the increasing marginal cost of obtaining additional water or the decreasing marginal benefit of water that is harder to reach. The denominator can be measured by internal renewable resources (domestic sources of streams, groundwater and rainfall), total renewable resources (internal resources and water flowing into the country from upstream sources) or available freshwater (water that can be practically used, given technical limitations, quality or specific agreements or restrictions on water use). As Table A.2 in the appendix shows, water use per capita differs substantially from water scarcity, with a correlation being between 33% and 41%. The measures of water scarcity are highly correlated but still differ somewhat, since their correlation ranges between 85% and 95%.

Of course, water use is strongly correlated with population size and economic activity. Table 1 shows some regressions of water withdrawal according to population and GDP per capita, measured in 2017 USD at purchasing power parity (PPP). These variables are obtained from the World Bank. The results show that total water withdrawal grows with population, but with a coefficient smaller than one. This result implies that there could be economies of scale in water use. Notably, higher GDP per capita is associated with lower total water withdrawal. This could come from greater water use efficiency and a shift from water-intensive sectors like agriculture to services as countries develop. Measures of water scarcity (freshwater withdrawal as a share of internal resources, total renewable resources and available freshwater) also increase with population. GDP growth does not have a statistically significant association.

Finally, Table 1 projects water withdrawal statistics for the different countries and the world for 2050, assuming the median population projections of the United Nations and a constant 2% growth in GDP per capita. The results show a substantial heterogeneity in water withdrawal across countries. For some countries, water withdrawal is expected to fall significantly relative to 2020, due to both a fall in population and increased GDP per capita. However, for the world as a whole it is projected

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[6] Knowledge of environmental water requirements enables a better understanding of the amount of water available for withdrawal in a sustainable way and encourages consideration of ecosystem health.

that water withdrawal in 2050 will be 230% of the current level. This is a significantly higher level of water use in 2050, especially for countries with a growing population. Other measures of freshwater withdrawal (in % of internal resources, total renewable resources and available freshwater) for 2050 are several times higher than current levels. Obviously, this is a very simple exercise and forecast for 2050, but it does show that the water scarcity problem may be substantially worse in the future.[7]

Regressions of water withdrawal per country and projections for 2050

Table 1

	$\ln(\text{total water withdrawal}_{c,t})$	Freshwater $\text{withdrawal}_{c,t}$ (% of internal resources)	Freshwater $\text{withdrawal}_{c,t}$ (% of total renewable resources)	Freshwater $\text{withdrawal}_{c,t}$ (% of available freshwater)
Controls				
$\ln(\text{Population}_{c,t-1})$	0.696***	5.346***	2.508**	3.990***
	(0.0744)	(1.765)	(0.978)	(1.219)
$\ln(GDP_{c,t-1}^{PPP,pc})$	-0.113**	-0.991	0.0192	0.208
	(0.0498)	(0.966)	(0.651)	(0.958)
Observations	4,429	4,371	4,419	4,399
R-squared (total)	0.994	0.984	0.988	0.983

Expected water withdrawal in 2050 as a ratio of water withdrawal in 2020 (in %)

Assumption 1: Population in 2050 for each country is given by the median forecast of the UN (World Population Prospects 2024).

Assumption 2: GDP pc for each country grows at 2% per year.

	Total water withdrawal	Freshwater withdrawal (% of internal resources)	Freshwater withdrawal (% of total renewable resources)	Freshwater withdrawal (% of available freshwater)
Country percentiles				
10	16.6%	24.1%	28.2%	33.8%
25	31.7%	73.4%	88.6%	78.8%
50	98.9%	256.8%	421.6%	267.9%
75	328.4%	1219.3%	1347.2%	837.4%
90	1189.8%	2908.0%	4359.0%	2233.0%
World	230.4%	2231.4%	2318.7%	898.8%

Robust standard errors in ( ). Clusters by country. ***, **, * denote 1%, 5%, 10% statistical significance. All regressions include fixed effects by country (omitted).

Sources: World Bank; BIS

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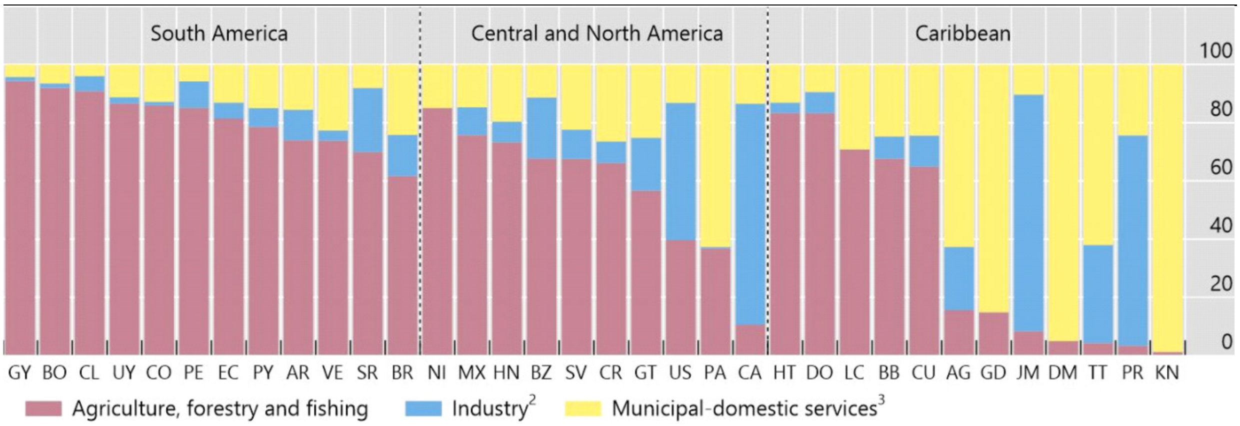
[7] The regression models in Table 1 are not meant to be an accurate forecasting model of water demand. The regressions merely show that even just with country fixed effects and two control variables (growth in GDP per capita and population growth), one obtains heterogeneous values for future water demand. In this simple model, around 25% of the countries keep values of water demand that are similar to today or even lower, while 25% of the countries increase their water demand by 8 times or more. It is likely that models with higher complexity, such as additional control variables, would have even higher disparity in water demand forecasts. Therefore, our model could be seen as a lower bound for the heterogeneity in country experiences for the future water demand, since additional controls very likely increase the heterogeneity in the estimates.

Agriculture tends to be the largest user of water in most countries. Graph 3 shows the share of water withdrawal used in the Americas by agriculture, forestry and fishing (primary sector), industry (secondary sector, which includes mining, quarrying, manufacturing, construction and energy (electricity and gas) industries) and municipal-domestic services (tertiary sector, which includes the water collection, treatment and supply industry). Agriculture, forestry and fishing is the sector with the largest usage of water, representing more than 60% of the total water withdrawal across most countries in the Americas. In the US, Canada, Puerto Rico and Jamaica, there is also significant water usage by industry. In Canada, Jamaica and Puerto Rico, industry represents more than 70% of the water withdrawal. The US dedicates more than 40% of its water to industrial use. Some countries have strong water use by municipal services, but it is difficult to separate water consumed by households through utilities versus firms.

Share of the total water withdrawal (in %) across economic sectors[1]

In per cent

Graph 3



[1] Economic sector water withdrawal as a percentage of total water withdrawal. Data for 2020. [2] Includes mining, quarrying, manufacturing, construction and energy (electricity and gas) industries. [3] Includes the water collection, treatment and supply industry.

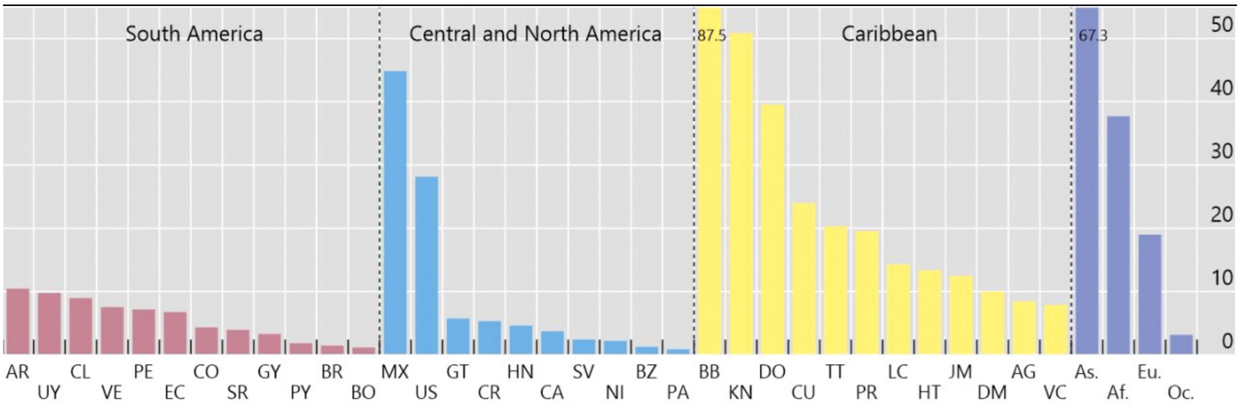
Sources: FAO; Aquastat; BIS. ISO2 country abbreviations used.

In terms of freshwater withdrawal as a share of available resources, Graph 4 shows that countries in South America are among the lowest water spenders in the world. However, Mexico, Barbados and St. Kitts and Nevis spend 40% or more of their water resources, which is more than twice the European rate and many times more than Oceania.

Freshwater withdrawal[1]

In per cent of available freshwater resources

Graph 4



[1] Ratio between total freshwater withdrawn by all major sectors and total renewable freshwater resources, after considering environmental water requirements. Data for 2020. Same specification as in Graph 1. Weighted averages values for Africa, Asia, Europe and Oceania.

Sources: FAO; Aquastat: BIS.

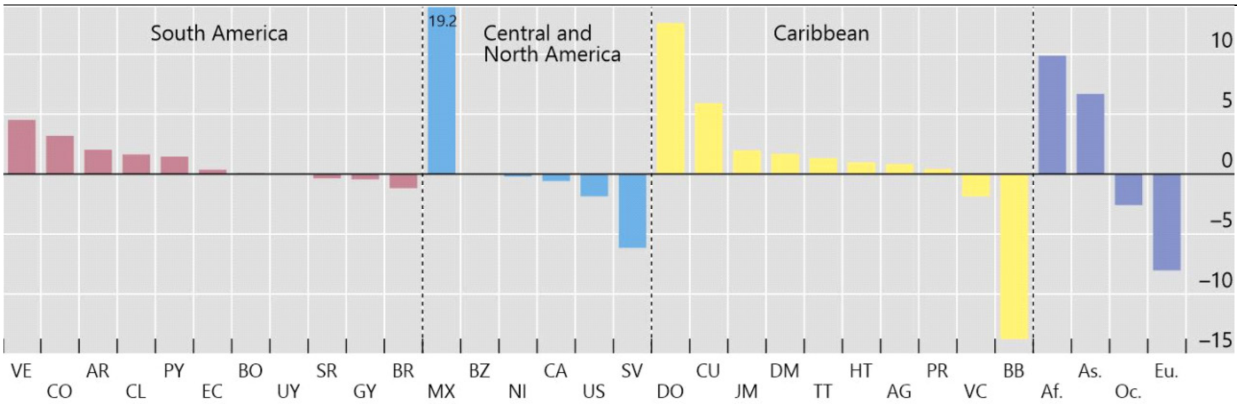
Furthermore, water withdrawal in most countries in the Americas has increased substantially since 2000, as shown in Graph 5. Freshwater withdrawal increased substantially in Mexico and the Dominican Republic. Mexico is a particularly serious case, because in the last 20 years has spent almost 20% more of its water resources, with spending having almost doubled since 2000. The Dominican Republic is spending around 12% more of its available freshwater resources than in 2000, a growth of almost 50% more. This huge growth in freshwater withdrawal in Mexico and the Dominican Republic may point to serious institutional flaws in terms of water efficiency.

Water management improved slightly in the US, Canada, Brazil, El Salvador, Guyana, Suriname and Barbados. However, these improvements in water management in some countries in the Americas were far below those of Europe and Oceania. Europe reduced its freshwater withdrawal rate by about 8% of the available resources, a very significant water saving effort.

Change between 2000 and 2020 in freshwater withdrawal as a proportion of available resources[1]

In percentage points

Graph 5



[1] Data for 2020. Same specification as in Graph 1. Weighted averages values for Africa, Asia, Europe and Oceania. Weighted averages values for Africa, Asia, Europe and Oceania.

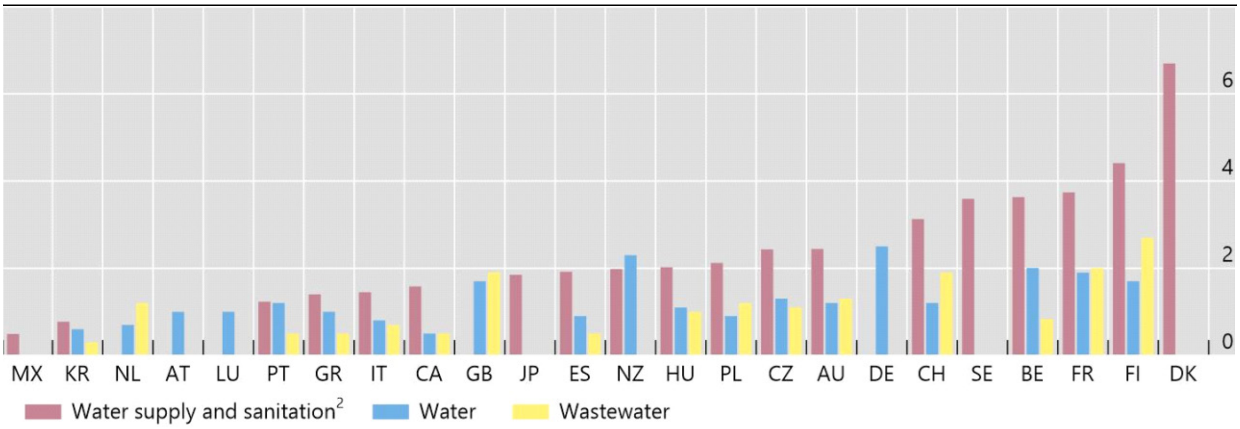
Sources: FAO; Aquastat; BIS.

A crucial factor in managing the use of water is the price mechanism. Adequate pricing can set incentives for water preservation and careful use. Generally, water prices are hard to obtain and compare across countries. But the OECD compiled cubic meter prices in USD for their water supply and sanitation services in the year 2008, which were self-reported by national authorities (OECD 2010). Water supply and sanitation services can also be decomposed into two different categories, specifically water consumption and wastewater services. The results, summarized in Graph 6, show that Mexico charges the lowest water prices in the OECD, less than 0.5 USD per cubic meter. This is less than one-tenth the level of Denmark. Canada, meanwhile, charges 1.58 USD per cubic meter of water – less than half of the prices charged in other advanced economies, such as Sweden, Belgium, France, Finland and Denmark. Furthermore, it is noticeable that across many countries the cost of removing wastewater is as high as the cost of supplying freshwater.

Unit price of water services[1]

USD per cubic meter

Graph 6



[1] Financial costs associated with supplying water services and use to users without considering either externalities of water consumption or alternate uses of water consumption. [2] Estimations based on national averages communicated by the countries. The sum of the unit values may not match the total unit price of water supply and sanitation.

AT = Austria. AU = Australia. BE = Belgium. CA = Canada. CH = Switzerland. CZ = Czechia. DE = Germany. DK = Denmark. ES = Spain. FI = Finland. FR = France. GB = Great Britain (UK). GR = Greece. HU = Hungary. IT = Italy. JP = Japan. KR = South Korea. LU = Luxembourg. MX = Mexico. NL = Netherlands. PL = Poland. PT = Portugal. SE = Sweden.

Source : OECD (2010).

The implicit economic value of water use can also be extremely low across several countries, especially in the agriculture sector. A popular measure of water use efficiency is the ratio of value-added (in current USD) to the volume of water withdrawal used (Ozcelik et al, 2021). This is shown in Graph A.1 in the appendix. This measure is similar to the World Bank's concept of "water productivity", which is measured in terms of value-added in constant 2015 USD per cubic meter of total freshwater withdrawal. Water use efficiency in Europe and Oceania is very high, with a value-added above 80 USD per cubic meter. This is about twice as much as the 40 USD ratio in the US, Canada and Panama. Except for a few Caribbean nations, all the other countries in South America and Central America have a water use efficiency that is lower than 20 USD per cubic meter.

Water use efficiency differs remarkably across economic sectors, even within the same country. As shown in Graph A.2 in the appendix, the agriculture, forestry and fishing sector has an implicit value of water that is below 2.5 USD per cubic meter across any country in the world. Industry, in turn, is the sector with the strongest heterogeneity of water value, with some countries showing extremely high value for industrial water use.

The value of water in industry is more than 50 USD per cubic meter in continents other than the Americas. In some countries like Panama, Nicaragua and Bermuda, the value-added of industrial water is around 2,000 USD per cubic meter or higher. Other countries such as Bolivia, Colombia, Uruguay and Guyana also have a value of industrial water above 100 USD per cubic meter.

The value of water tends to be highest in the service sector. The water value by municipal services is above 250 USD per cubic meter in countries like the US and Oceania. The services value-added per cubic meter also reaches above 180 USD in Canada and Europe, and more than 100 USD per cubic meter in Uruguay, Chile, Barbados, Antigua and Barbuda.

3. Economic implications of water scarcity

Water scarcity could affect the economy through several channels. Since water is a key factor of production, water scarcity can limit agricultural production, power generation, industrial use and – in some circumstances – human consumption. These could limit economic production (thus weighing on growth) and push up prices (thus putting pressure on inflation). This section discusses these in turn, based on statistical associations between water and economic outcomes.[8]

Water has a wide range of channels of impacts on output and prices, especially in agriculture through irrigation and in energy through hydroelectricity production (Harou et al, 2009; Damania et al, 2017; Damania et al, 2020; Russ 2020). The effect of water on the productivity of other natural resources is also widely documented in the literature due to its effect on ecosystems (Fenichel et al, 2016; Thia et al, 2024), agriculture (Damania et al, 2017; Damania et al, 2020) and mining (Morgan and Dobson, 2020; Meißner et al, 2021).

Some studies have found a strong impact of rainfall, water availability and water infrastructures on capital productivity (Dillon and Fishman, 2019; Islam and Hyland, 2019) and complementary factors such as hydropower energy (Harou et al, 2009; Dillon and Fishman, 2019; Russ, 2020). Water could impact inflation through energy availability or food price channels.

Finally, the effects of water on human welfare and health (Howard and Bartram, 2003; Damania et al, 2017) have strong effects on labour supply and employment (United Nations, 2016). For instance, one area in which water availability affects labour productivity is through its effects on the yields of different seeds, which can lead farmers to select more labour-intensive crops (Booker and Scott Trees, 2020). Water quality and availability are known to affect urban health (Rui et al, 2018).

We can think of the effects of water scarcity on real GDP and investment growth (measured by the gross fixed capital formation), using a larger model with other production factors. The effects of water availability on the output of country *c* at time *t* can be understood through a modified Cobb-Douglas aggregate production function in which capital ($K_{c,t}p$), labour ($L_{c,t}$), total factor productivity ($TFP_{c,t}$) and water ($W_{c,t}$) are inputs:

$$1)\quad Y_{c,t} = TFP_{c,t}\left(g\left(W_{c,t}, WS_{c,t}\right)\right)^{1-\alpha-\theta}\left(K_{c,t}p\left(W_{c,t}\right)\right)^{\alpha}\left(L_{c,t}h\left(W_{c,t}\right)\right)^{\theta}.$$

Besides water ($W_{c,t}$) being an input, production also depends on water scarcity ($WS_{c,t}$). This can be explained due to an increasing marginal cost of obtaining water as it becomes scarcer, or due to a declining marginal productivity of water as it is available only in less convenient places for production. Thus, we can parameterize the function g(.) to have a declining value of water production with higher values of water scarcity as:

$$2)\quad g\left(W_{c,t}, WS_{c,t}\right) = W_{c,t}/\left(1 + WS_{c,t}\right).$$

Applying the logarithm to both sides of equation 1), we obtain a linear expression of the log-output in terms of TFP, capital, labour, water use and a negative output effect for water scarcity. Since water is a complementary production factor with TFP, capital and labour, restrictive levels of water scarcity should have a negative impact on the growth rate. In this sense, (fresh)water is a production factor than is unaccounted for in the standard growth regressions. Furthermore, applying a derivative relative to capital gives us the traditional marginal product of capital. The marginal product of capital is also a function of capital, labour, TFP and water resources. By setting

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[8] We are careful to note that these are associations, and that – in the absence of a clear instrumental variable or other strong identification approach – we cannot claim causality.

the marginal product of capital equal to interest rates, we obtain an investment function which also depends on water scarcity and the other production factors (capital, labour and TFP).

We can first estimate the effects of water scarcity through simple linear panel data regressions. The dependent variables are GDP growth, investment, inflation, sectoral output and hydro power:

$$3)\quad Y_{c,t} = \beta X_{c,t} + \alpha_c + \alpha_t + \varepsilon_{c,t},$$

with $X_{c,t}$ denoting the water availability measures, α_c and α_t being country and year fixed effects. The unobserved residual is given by $\varepsilon_{c,t}$. The X vector includes variables such as freshwater withdrawal as a fraction of either total renewable resources, internal resources or available freshwater (which are measures of the binding restrictions on water availability); the total water withdrawal per capita; and GDP per capita (a proxy for the development and the quality of the institutions of each country over time). All water availability variables in the X vector are winsorised at the top percentile. Table A.1 in the appendix gives the sample of countries used in the empirical exercises of this section and the appendix.

Table 2 gives descriptive statistics of the variables. Across the sample, the average growth rate of GDP is 4%, annual fixed investment is 6% and the growth of consumer price index (CPI) inflation is 25%. Note that the median freshwater withdrawal is low, just between 7% and 12% (according to whether it is measured as a ratio of internal resources, total renewable resources and available freshwater), but the average freshwater withdrawal ratios are much higher, at around 21% to 28%. The standard deviation of the freshwater withdrawal ratios is between 29% and 33%, far above the mean, which again implies a distribution of water use with a big upper tail of country users. This implies that heterogeneity is large and there is a significant tail of countries with very high freshwater withdrawal ratios, with some countries using 100% of their available water.

Statistics of water use and macroeconomic variables (1965-2020, 169 countries)

Table 2

	Minimum	Maximum	Median	Mean	Standard-deviation
Annual GDP growth (%)	-64	150	4	4	6
Annual fixed investment (%)	-294	2,358	4	6	37
Annual CPI inflation rates (%)	-18	23,773	5	25	344
Freshwater withdrawal as % of:					
internal resources	0	100	10	26	33
total renewable resources	0	100	7	21	29
available freshwater	0	100	12	28	33
Variables in logarithm:					
Total water withdrawal per capita	2	7.8	5.8	5.6	1.2
Water Productivity (2015 USD per m3)	-1.7	6.6	2.9	2.9	1.6
Water Use Efficiency (USD per m3)	-2.1	5.8	2.5	2.4	1.6
GDP-PPP in 2017 USD	6.1	11.7	9.2	9.1	1.2

Finally, we include a large fraction of the countries in the world. Therefore, the yearly GDP per capita in the sample is diverse going from a minimum of USD 445 to a maximum of USD 120,571.

Our analysis will focus on 169 countries from all inhabited continents over the period 1965–2020. Note that 2020 is the last year with Aquastat data available. Naturally, given the large number of countries (some of which only gained independence in the sample period), this is an unbalanced panel.

Table 3 shows the regression results for real GDP growth. Total water use (log water withdrawal per capita) has a positive coefficient on growth, but it is not statistically significant. Meanwhile, water scarcity has a negative and statistically significant association with growth. Notably, there is a statistically significant negative coefficient for freshwater withdrawal as a share of total internal resources, of total renewable resources or of available freshwater. Each percentage point of water scarcity is associated with 0.08 to 0.10 percentage points (pp) lower economic growth. For Mexico, which increased its freshwater withdrawal as a share of resources by 0.9% per year since 2000, this change would imply a fall by 0.09% in the rate of annual GDP growth.[9]

Regression of annual GDP growth on water usage

Table 3

	(1)	(2)	(3)
Water use			
ln(Total water withdrawal per capita$_{c,t}$)	0.937	0.786	1.252
	(0.958)	(0.872)	(0.914)
Water scarcity			
Freshwater withdrawal$_{\mathrm{c,t}}$	–0.0803*		
(% of internal resources)	(0.0415)		
Freshwater withdrawal$_{c,t}$		–0.0988**	
(% of renewable resources)		(0.0483)	
Freshwater withdrawal$_{\mathrm{c,t}}$			–0.102***
(% of available freshwater)			(0.0388)
Controls			
$\ln\left(\mathrm{GDP}_{c,t}^{PPP,pc}\right)$	1.884	2.023	2.114
	(1.689)	(1.700)	(1.707)
Observations	4,555	4,583	4,583
R-squared (total)	0.218	0.217	0.219

Robust standard errors in ( ). Clusters by country. ***, **, * denote 1%, 5%, 10% statistical significance. All regressions include fixed effects by country and year (omitted).

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[9] Anecdotally, international firms note that water scarcity is a key constraint on their ability to increase industrial production in Monterrey and other cities in Northern Mexico, where water scarcity has been an issue for some time. This may limit the ability to benefit from the recent nearshoring phenomenon (realignment of global value chains to countries that are geographically closer). Similarly, a lack of water could constrain key agriculture sectors such as dairy farming, avocados and others.

Table 4 shows the regressions for the real growth of gross fixed capital formation (GFCF). Here, the results show a significantly positive coefficient of total water withdrawal per capita, while water scarcity measures have a negative coefficient, with both effects being statistically significant. Freshwater withdrawal (whether as a share of internal resources, renewable resources or available freshwater) has a detrimental effect on investment. Investment growth falls by 0.27% to 0.29% for each % point of water scarcity. An additional one standard deviation in water scarcity decreases investment growth by 0.39% to 0.42%, depending on which measure is used.

Regression of annual real fixed investment (GFCF) growth on water usage

Table 4

	(1)	(2)	(3)
Water use			
ln(Total water withdrawal per capita$_{c,t}$)	7.879*	6.686*	7.816*
	(4.135)	(3.813)	(4.058)
Water scarcity			
Freshwater withdrawal$_{\mathrm{c,t}}$	-0.293***		
(% of internal resources)	(0.109)		
Freshwater withdrawal$_{c,t}$		-0283**	
(% of renewable resources)		(0.135)	
Freshwater withdrawal$_{\mathrm{c,t}}$			-0.266***
(% of available freshwater)			(0.100)
Controls			
ln (GDP$_{c,t}^{PPP,pc}$)	-6.584	-6.184	-5.653
	(5.067)	(5.085)	(5.031)
Observations	3,513	3,513	3,513
R-squared (total)	0.048	0.048	0.048

Robust standard errors in ( ). Clusters by country. ***, **, * denote 1%, 5%, 10% statistical significance. All regressions include fixed effects by country and year (omitted).

Finally, the link between water availability and inflation is shown in Table 5. Water scarcity could impact inflation through its effects on food prices or on energy availability. While water use does not have a statistically significant coefficient, water scarcity is associated with higher inflation, when measured relative to renewable resources and available freshwater.[10] The coefficient for freshwater withdrawal relative to internal resources is positive but not significant. Each extra pp of freshwater withdrawal (as a share of renewable resources or available freshwater) is associated with inflation rates that are between 2.1% to 2.2% higher.

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[10] Anecdotally, water scarcity in Chile, Colombia and Peru has been associated with higher agricultural and food prices and thus higher headline inflation rates.

Regressions of annual CPI inflation rates on water usage

Table 5

	(1)	(2)	(3)
Water use			
ln(Total water	9.035	15.86	5.501
withdrawal per capita$_{c,t}$)	(18.83)	(19.49)	(18.98)
Water scarcity			
Freshwater withdrawal$_{\mathrm{c,t}}$	2.115		
(% of internal resources)	(1.471)		
Freshwater withdrawal$_{c,t}$		2.090*	
(% of renewable resources)		(1.109)	
Freshwater withdrawal$_{\mathrm{c,t}}$			2.198*
(% of available freshwater)			(1.220)
Controls			
ln (GDP$_{c,t}^{PPP,pc}$)	-14.24	-15.88	-18.45
	(21.91)	(21.86)	(21.57)
Observations	4,249	4,277	4,277
R-squared (total)	0.145	0.143	0.145

Robust standard errors in ( ). Clusters by country. ***, **, * denote 1%, 5%, 10% statistical significance. All regressions include fixed effects by country and year (omitted).

To make interpretation easier, we report in Table 6 the impact of a standard-deviation increase in each control variable. A one standard-deviation increase in the intensity of water scarcity reduces output growth by 0.12%-0.16%, of fixed investment by 0.39%-0.42%, and of CPI inflation by 2.9% to 3.5%, depending on the measure.

Effect of a one standard-deviation in the (demeaned) control variable

Table 6

	GDP growth	Fixed investment	CPI inflation
Freshwater withdrawal as % of internal resources	-0.115	-0.421	3.042
Freshwater withdrawal as % of total renewable resources	-0.137	-0.394	2.907
Freshwater withdrawal as % of available freshwater	-0.162	-0.424	3.499

Robust standard errors in ( ). Clusters by country. ***, **, * denote 1%, 5%, 10% statistical significance. All regressions include fixed effects by country and year (omitted).

In summary, our results show that water scarcity (freshwater withdrawal as a share of internal resources, total renewable resources or available freshwater) is negatively associated with GDP growth and investment growth. The same measures are positively associated with CPI inflation rates. Overall, our results suggest that water availability could impact output growth and inflation rates.

Finally, we repeat the same regressions of equation 2 as panel quantile regressions with country fixed effects, using the estimator proposed by Machado and Santos Silva (2019). The results for GDP growth are shown in Table A.4 in the appendix and are fairly similar to the ordinary panel regression results in Table 3. Freshwater withdrawal as a share of internal resources has a statistically significant negative coefficient for GDP growth across all quantiles (quantiles 25, 50 and 75). Furthermore, freshwater withdrawal as a share of available freshwater is statistically significant for quantile 25. Note also that all the coefficients for the effect of freshwater withdrawal (whether as a share of internal resources, total renewable resources or available freshwater) on GDP growth have their strongest negative impact on quantile 25 and the smallest effect on quantile 75. This points out that freshwater withdrawal is most relevant when growth is at its weakest point.

We show the panel quantile regressions for investment growth in Table A.5 and for inflation in Table A.6. The estimated coefficients are quite similar to the ordinary panel model estimates in Tables 4 and 5. However, for the quantile regressions none of the coefficients are statistically significant.

4. Effects of water withdrawal across economic sectors

We now analyse the link between water use and scarcity and the growth of different economic sectors. Table 7 shows how water withdrawal and different measures of water scarcity are associated with the share of different economic sectors in terms of GDP. The results show that freshwater withdrawal (as a share of internal resources) is positively associated with a higher fraction of GDP in agriculture, forestry and fishing. This makes sense, because in many countries freshwater withdrawal for agriculture is charged a very low implicit price (see Graph A.2 in the appendix). Industrial activity as a share of GDP is not statistically affected by water withdrawal. However, services as a share of GDP fall significantly with higher levels of total water withdrawal per capita. This could be due to the higher implicit prices for water use charged by public utilities to households and service companies across several countries (Graph 6 in section 2 and Graph A.2 in the appendix).

Industry is a highly heterogeneous sector. For this reason, we now focus specifically on the manufacturing sector. We use annual frequency data for 22 industries from the United Nations Industrial Development Organization (UNIDO). The two digit ISIC (International Standard Industrial Classification of All Economic Activities) categories include 22 manufacturing industries: Food and beverages; Tobacco products; Textiles; Wearing apparel, fur; Leather, leather products and footwear; Wood products (excl. furniture); Paper and paper products; Printing and publishing; Coke, refined petroleum products, nuclear fuel; Chemicals and chemical products; Rubber and plastics products; Non-metallic mineral products; Basic metals; Fabricated metal products; Machinery and equipment n.e.c.; Office, accounting and computing machinery; Electrical machinery and apparatus; Radio, television and communication equipment; Medical, precision and optical instruments; Motor vehicles, trailers, semi-trailers; Other transport equipment; Furniture; manufacturing n.e.c.

Regressions for water and the share of each economic sector in national GDP

Table 7

	Agriculture, forestry, fishing (% of GDP)			Industry (% of GDP)[1]			Services (% of GDP)		
Water use									
$\ln(\text{Total water withrawal pc}_{c,t})$	-0.453	-0.260	-0.214	1.073	1.385	0.770	-1.709	-2.085**	-1.764*
	(0.715)	(0.686)	(0.713)	(1.115)	(1.069)	(1.137)	(1.061)	(0.984)	(1.025)
Water scarcity									
$\text{Freshwater withdrawal}_{\text{c,t}}$	0.0738**			-0.00263			0.00309		
(% of internal resources)	(0.0305)			(0.0904)			(0.0819)		
$\text{Freshwater withdrawal}_{\text{c,t}}$		0.0795**			-0.0520			0.0623	
(% of renewable resources)		(0.0388)			(0.142)			(0.114)	
$\text{Freshwater withdrawal}_{\text{c,t}}$			0.0432			0.0273			0.00693
(% of available freshwater)			(0.0358)			(0.0927)			(0.0786)
Controls									
$\ln\,(GDP^{pc}_{c,t-1})$	-6.406***	-6.451***	-6.489***	6.155***	6.253***	6.208***	0.599	0.468	0.478
	(1.298)	(1.278)	(1.291)	(1.941)	(1.919)	(1.917)	(1.820)	(1.804)	(1.809)
Observations	4,389	4,415	4,415	4,365	4,376	4,376	4,325	4,336	4,336
R-squared (total)	0.928	0.929	0.928	0.861	0.863	0.863	0.858	0.857	0.857

Robust standard errors in ( ). Clusters by country. ***, **, * denote 1%, 5%, 10% statistical significance. All regressions include fixed effects by country and year (omitted).

[1] Industry comprises value-added in mining, manufacturing, construction, electricity, water and gas.

Sources: World Bank; BIS

Industrial growth is measured by the log increase in the Index of Real Industrial Production (IIP), which accounts for sector-specific prices. Real industrial growth is then multiplied by 100 to be similar to the national growth rates in World Bank and IMF data, which are also reported in percentage points. Again, the data are an unbalanced panel, with some countries-industries reporting missing data in several years. We then interact the variables with the share of global industrial water use of each industry. This interaction variable helps to account for some manufacturing industries using more water than other industries. Since this measure is difficult to obtain for the industries of each country, we use global industrial water shares of each ISIC industry for the year 2020. This variable is obtained from the Worldmetrics.org Report for 2024. We note that we employ the global water use of each industry, because these data are hard to obtain for each country. Basker et al (2019) reports that reliable data for water use at the industry level has not been obtained since 1982.

Table 8 shows that real manufacturing growth falls with the variable for the interaction of water use per industry with total manufacturing water per capita. The coefficient is statistically significant at the 5% level across all three regressions, with further controls for freshwater withdrawal (as a share of total internal resources or total renewable resources or available freshwater). However, it is also found that freshwater withdrawal as a share of total renewable resources is associated with higher industrial growth. One possible interpretation of the negative association of water use with industrial growth is that manufacturing industries must compete with other alternative users of water, and therefore its growth falls with the total water used in the economy.

Regressions for water and real growth of manufacturing industries

Table 8

	Real manufacturing growth$_{(i,c,t)}$			Motor vehicles, trailers, semi−trailers real growth$_{(c,t)}$		
Water use[1]						
$\mathrm{GIWU_i} \times \ln(\text{total water withdrawal pc}_{c,t})$	-3.659**	-3.889**	-3.332**	-111.8***	-123.9***	-121.9***
	(1.754)	(1.727)	(1.691)	(35.94)	(33.89)	(37.14)
Water scarcity						
$\mathrm{GIWU_i} \times \text{FW withdrawal}_{c,t}$	0.113			3.022**		
(% of internal resources)	(0.107)			(1.254)		
$\mathrm{GIWU_i} \times \text{FW withdrawal}_{c,t}$		0.213*			5.267***	
(% of renewable resources)		(0.120)			(1.896)	
$\mathrm{GIWU_i} \times \text{FW withdrawal}_{c,t}$			0.0833			3.059**
(% of available freshwater)			(0.0584)			(1.369)
Controls						
$\ln(\mathrm{GDP}^{pc}_{c,t-1})$	-2.673***	-2.849***	-2.851***	-3.774	-4.297*	-4.269*
	(0.873)	(0.853)	(0.855)	(2.335)	(2.364)	(2.406)
$\text{Real GDP growth}_{c,t}$	1.188***	1.166***	1.166***	2.536***	2.500***	2.497***
	(0.0369)	(0.0369)	(0.0369)	(0.221)	(0.216)	(0.216)
Observations	44,002	44,377	44,377	1,889	1,908	1,908
R-squared (total)	0.198	0.195	0.195	0.253	0.247	0.246

Robust standard errors in ( ). Clusters by country. ***, **, * denote 1%, 5%, 10% statistical significance. All regressions include fixed effects by country-industry and year (omitted).

[1] Water withdrawal measures are weighted by the Global industrial water use (GIWU, Worldmetrics.org) share of each industry.

Repeating these regressions for each of the 22 industries, we find statistically significant results only for the automotive industry. There are several reasons for finding reliable results only for the automotive industry. One reason is due to measurement error in the UNIDO data, with information collected from small manufacturing industries in each country. Measurement error tends to reduce the statistical significance of the regressions (Hausman 2001). Therefore, it is more likely that statistically significant results are only obtained for industries with large companies such as the auto industry, which should report accurate economic activity statistics across all countries. It is also the case that the automotive industry is a large user of water, representing 7% of the global industrial water use in 2020 (according to the Worldmetrics.org Report for 2024). The auto industry uses an average of 39,000 gallons (148,000 litres) of water to produce one vehicle.

Table 8 shows that the real growth of the motor vehicles, trailers and semi-trailers manufacturing industry is sharply lower when total water withdrawal rises. This result is statistically significant at the 1% level across all regressions. Furthermore, freshwater withdrawal (whether as a share of total internal resources or total renewable resources or available freshwater) is associated with higher real growth in the automotive industry. This indicates that the major reason for the negative impact of water use on industrial growth is that the auto industry must compete with other users of water, such as agriculture, services and other industries.

Finally, Table A.7 in the appendix shows that total freshwater withdrawal in the economy is associated with lower hydroelectricity production, which can be a channel in which water scarcity affects industry and services.

5. The role of water pricing and infrastructure for conservation

Water infrastructure is considered by some scholars to be the first task that required a role for governments, such as in the ancient states of Mesopotamia (Allen et al, 2023, Joseph et al, 2024). Since around 3,000 BC there have been several approaches to funding water services, including use fees, public taxes and contributions from the wealthy. One way of improving water supply and services is by increasing public investment (around 98% of the water sector's funding). Around 113 low-income countries will have to almost triple their investment to achieve the Sustainable Development Goals (SDGs) 6.1 and 6.2 in safe water access (Joseph et al, 2024).

To achieve safely managed sanitation at the world level (including capital expenses and operational and maintenance costs) requires 0.3% of annual GDP (Hutton and Varughese, 2020). For advanced economies current water expenditures are just 0.1% of GDP, and an additional 0.1% of GDP is required to achieve the SDGs (Joseph et al, 2024). For Latin America and the Caribbean, current water expenditures are 0.2% of annual GDP, with an estimated increase of 0.26% of GDP being required to achieve the SDG goals. In Sub-Saharan Africa, public expenditures for safe sanitation can require 2.4% of annual GDP, with a funding gap of 4.6% of GDP needed to achieve the SDG goals.

Water losses and more efficient monitoring are two reasons for higher public investment in infrastructure. Leakage in water infrastructure often leads to losses of water of 30% or more before delivery to the final users, with median technical efficiency across water utilities worldwide being just 63% (Joseph et al. 2024)..[11] Water efficiency is estimated to be getting worse over time, with TFP in water public services declining by 6% between 2009 and 2020 (Joseph et al. 2024). Average efficiency loss constitutes 16% of the operating costs of water utilities (Joseph et al. 2024).

A lack of pricing is one cause for efficiency losses of water utilities, as there are few incentives to improve operational management and maintenance. Most countries prefer prescriptive regulations for reducing water use, although empirical evidence suggests that pricing is more cost effective and easier to monitor (Olmstead and Stavins, 2009). There is a substantial amount of innovation in water services such as smart metering, remote sensing, improved water treatment and automated leakage prevention (Viola 2020). However, low prices disincentivize investment and innovation.

Note that, to achieve more efficient overall pricing, it is not necessary to charge high prices to households (for domestic use), nor particularly to low-income households. Water utilities can implement customized pricing, for instance with a low fee up to a certain threshold, and higher fees above this. This can help to incentivize savings among households and firms that find it easier to reduce water spending (Kahn and Krishnamachari, 2023). Moreover, trading markets can transfer water from areas with high abundance to regions experiencing drought (Rafey, 2023). Finally, trade in agricultural products can increase water use efficiency (Carleton et al, 2023).

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[11] Leakage is defined as water that is not accounted for revenue, either due to real losses (broken pipes, transmission mains leaks), inaccuracies in metering or theft.

We test the empirical relationship between water scarcity and prices, using country level data for 2008 (OECD, 2010). Table A.2 in the appendix shows that freshwater withdrawal (whether as a fraction of internal resources, total renewable resources or available freshwater) is negatively correlated with country prices for water supply and sanitation services. This empirical relationship remains even after controlling for GDP per capita, as shown in the linear regressions results in Table A.3 in the appendix. However, the coefficients are not statistically significant due to the small number of observations, as water prices are only observed for 2008 and the sample is limited to 20 countries.

6. Simulated water stress scenarios for the 21st century

In the face of climate change and biodiversity loss, water risks could change dramatically in the future. Climate change is one of the most important drivers of changes in rain precipitation and wind patterns, whereas biodiversity loss has direct implications for the way in which water flows into water basins and its quality (one form of so-called ecosystem services). Therefore, to study water scarcity under climate change, some research has resorted to scenario analysis and scenario discovery. For this, integrated assessment models (IAMs) which include energy, climate, water and land use changes are a suitable tool to explore the risks and alternative scenarios.

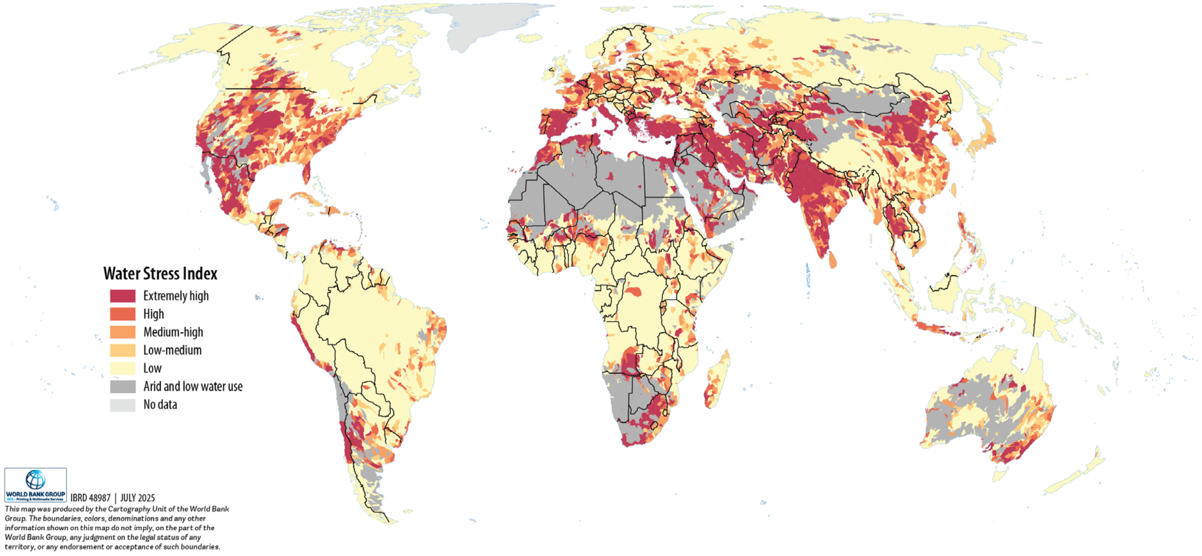
Scenario analysis and exploration are tools which can be well suited to study future possibilities of water scarcity, as has been done by Freire-González et al (2017b), Wu et al (2020) Birnbaum et al (2022) and Graham et al (2023). For instance, Wu et al (2020) study groundwater storage under a business-as-usual scenario (RCP 8.5) and find that the reductions in groundwater storage are associated with over-extraction and climate change. Moreover, over-extraction can considerably exceed replenishment.

Projections for the future show that several regions of the United States, Mexico, Peru, northern and central Chile and northern Argentina will face acute water stress due to climate change in 2080, as shown in Graph 7. India, the Middle East, Europe and large parts of China and Africa will also face acute water stress, unless appropriate policies are taken.

Water stress projections for 2080[1]

Index

Graph 7



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[1] Indicator of competition for water resources defined informally as the ratio of demand for water by human society divided by available water. Projections for 2080.

Sources: Kuzma et al. (2023); Lehner and Grill (2013); Aqueduct; Cartography Unit, World Bank.

7. Conclusion

Given the important economic implications of water scarcity (current and future), careful water management is crucial to increase the resilience of access to this extremely valuable ecosystem service.

Overall, our results show a strong association of water use and scarcity with output growth and inflation rates. Our results show that freshwater withdrawal (as a fraction of internal resources, total renewable resources or available freshwater) is negatively associated with GDP growth and investment growth, and higher CPI inflation rates. These relationships are statistically significant and economically sizeable. For each percentage point of water scarcity there is a fall of 0.08% to 0.10% in economic growth and a reduction in investment growth between 0.28% and 0.29%. An additional one standard deviation in water scarcity (freshwater withdrawal as a share of some measure of available resources) reduces GDP growth between 0.12% and 0.16% and investment growth between 0.39% and 0.42%.

However, the strongest effects of water scarcity are observed on CPI inflation. Each extra percentage point of freshwater withdrawal (whether as a share of internal resources, renewable resources or available freshwater) increases inflation rates between 2.1% to 2.2%. An additional one standard-deviation in water scarcity increases inflation by 2.91% to 3.50%. These findings are consistent with strong movements in food inflation in several countries of the Americas in response to climate shocks, as seen recently in the El Niño phenomenon.

Future research should therefore further investigate the effects of water availability on the economy, the channels in which these negative effects operate and possible policy mitigation alternatives. One possibility is that most countries could consider some forms of pricing for the use of water. In this sense, public authorities may need to consider a “social cost of water use” alongside a social cost of carbon to preserve ecosystems and encourage better economic and ecosystem outcomes.

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Appendix

Country sample used in the empirical analysis

Table A1

Region	Country list
Advanced economies	Antigua and Barbuda (AG), Australia (AU), Austria (AT), Belgium (BE), Canada (CA), Cyprus (CY), Czechia (CZ), Denmark (DK), Estonia (EE), Finland (FI), France (FR), Germany (DE), Greece (GR), Iceland (IS), Ireland (IE), Israel (IL), Italy (IT), Japan (JP), Latvia (LV), Lithuania (LT), Luxembourg (LU), Malta (MT), Monaco (MC), Netherlands (NL), New Zealand (NZ), Norway (NO), Portugal (PT), Puerto Rico (PR), Republic of Korea (KR), Singapore (SG), Slovak Republic (SK), Slovenia (SI), Spain (ES), St. Kitts and Nevis (KN), Sweden (SE), Switzerland (CH), United States (US), United Kingdom (GB).
Emerging market and developing economies	Afghanistan (AF), Albania (AL), Algeria (DZ), Angola (AO), Argentina (AR), Armenia (AM), Azerbaijan (AZ), Bahrain (BH), Bangladesh (BD), Barbados (BB), Belarus (BY), Belize (BZ), Benin (BJ), Bhutan (BT), Bolivia (BO), Bosnia (BA), Botswana (BW), Brazil (BR), Brunei Darussalam (BN), Bulgaria (BG), Burkina Faso (BF), Burundi (BI), Cabo Verde (CV), Cambodia (KH), Cameroon (CM), Central African Republic (CF), Chad (TD), Chile (CL), China (CN), Colombia (CO), Comoros (KM), Congo, Dem. Rep. (CD), Congo, Rep. (CG), Costa Rica (CR), Côte d'Ivoire (CI), Croatia (HR), Cuba (CU), Djibouti (DJ), Dominica (DM), Dominican Republic (DO), Ecuador (EC), Arab Republic of Egypt (EG), El Salvador (SV), Equatorial Guinea (GQ), Eritrea (ER), Eswatini (SZ), Ethiopia (ET), Fiji (FJ), Gabon (GA), The Gambia (GM), Georgia (GE), Ghana (GH), Grenada (GD), Guatemala (GT), Guinea (GN), Guinea-Bissau (GW), Guyana (GY), Haiti (HT), Honduras (HN), Hungary (HU), India (IN), Indonesia (ID), Islamic Republic of Iran (IR), Iraq (IQ), Jamaica (JM), Jordan (JO), Kazakhstan (KZ), Kenya (KE), Kuwait (KW), Kyrgyzstan (KG), Lao People's Democratic Republic (LA), Lebanon (LB), Lesotho (LS), Liberia (LR), Libya (LY), Madagascar (MG), Malawi (MW), Malaysia (MY), Maldives (MV), Mali (ML), Mauritania (MR), Mauritius (MU), Mexico (MX), Moldova (MD), Mongolia (MN), Montenegro (ME), Morocco (MA), Mozambique (MZ), Myanmar (MM), Namibia (NA), Nepal (NP), Nicaragua (NI), Niger (NE), Nigeria (NG), North Macedonia (MK), Oman (OM), Pakistan (PK), West Bank and Gaza (PS), Panama (PA), Papua New Guinea (PG), Paraguay (PY), Peru (PE), Philippines (PH), Poland (PL), Qatar (QA), Romania (RO), Russian Federation (RU), Rwanda (RW), Saudi Arabia (SA), Senegal (SN), Serbia (RS), Seychelles (SC), Sierra Leone (SL), Somalia (SO), South Africa (ZA), South Sudan (SS), Sri Lanka (LK), St. Lucia (LC), St. Vincent and the Grenadines (VC), Sudan (SD), Suriname (SR), Syrian Arab Republic (SY), São Tomé and Príncipe (ST), Tajikistan (TJ), Tanzania (TZ), Thailand (TH), Timor-Leste (TL), Togo (TG), Trinidad and Tobago (TT), Tunisia (TN), Türkiye (TR), Turkmenistan (TM), Uganda (UG), Ukraine (UA), United Arab Emirates (AE), Uruguay (UY), Uzbekistan (UZ), República Bolivariana de Venezuela (VE), Viet Nam (VN), Republic of Yemen (YE), Zambia (ZM), Zimbabwe (ZW)

Source: authors' elaboration.

Correlation matrix (in %) for total water and freshwater withdrawal[1] and water supply and sanitation service prices[2]

Table A.2

		FW (% of internal resources)	FW (% of total renewable resources)	FW (% of available freshwater)	Water SS prices
Ln(total water withdrawal per capita (in annual cubic meters))	1				
Freshwater withdrawal (% of total internal resources)	0.37	1			
Freshwater withdrawal (% of total renewable resources)	0.34	0.89	1		
Freshwater (% of available freshwater)	0.41	0.85	0.95	1	
Water supply and sanitation prices	–0.69	–0.23	–0.26	–0.20	1

Sample includes AT, BE, CA, CH, CZ, DK, ES, FI, FR, GB, GR, HU, IT, JP, KR, MX, NZ, PL, PT and SE.

[1] Average per country over the period 2008-2020. [2] USD per m^3 of water supply and sanitation services in 2008.

Source: BIS

Regressions of freshwater withdrawal (FW)[1] with water supply and sanitation (SS) service prices[2]

Table A.3

	FW[1] (% of internal resources)		FW[1] (% of total renewable sources)		FW[1] (% of available freshwater)	
Water SS price	–3.016	0.953	–1.863	–1.000	–3.129	–1.252
	(2.938)	(3.453)	(1.643)	(2.097)	(3.227)	(4.106)
$\ln(GDP^{PPP,pc}_{c,t=2008})$		–33.400		–7.266		–15.800
		(17.61)		(10.69)		(20.94)
Constant	26.48***	369.2*	17.82***	92.38	32.80***	194.9
	(8.661)	(180.9)	(4.842)	(109.8)	(9.512)	(215.1)
Observations	20	20	20	20	20	20
R-squared	0.055	0.220	0.067	0.091	0.050	0.080

Sample includes AT, BE, CA, CH, CZ, DK, ES, FI, FR, GB, GR, HU, IT, JP, KR, MX, NZ, PL, PT and SE.

Standard errors in ().***,**,* denote 1%,5% and 10% statistical significance.

[1] Average per country over the period 2008-2020. [2] USD per m^3 of water supply and sanitation services in 2008.

Source: BIS

Panel quantile regressions for water use and real GDP growth

Table A.4

	Quantile 25			Quantile 50			Quantile 75		
Water use									
ln(total water withdrawal$^{\mathrm{pc}}_{\mathrm{c,t}}$)	2.745*	2.722	3.331**	2.940***	2.759	3.312	3.099***	2.788	3.298
	(1.625)	(2.122)	(1.554)	(0.848)	(5.260)	(3.543)	(0.564)	(7.874)	(5.305)
Water scarcity									
Freshwater withdrawal$_{\mathrm{c,t}}$	-0.133**			-0.115***			-0.0999***		
(% of internal resources)	(0.0680)			(0.0355)			(0.0236)		
Freshwater withdrawal$_{\mathrm{c,t}}$		-0.180			-0.132			-0.0942	
(% of total renewable resources)		(0.158)			(0.393)			(0.588)	
Freshwater withdrawal$_{\mathrm{c,t}}$			-0.168**			-0.134			-0.106
(% of available freshwater)			(0.0825)			(0.188)			(0.282)
Controls									
ln($\mathrm{GDP}^{\mathrm{pc}}_{\mathrm{t-1}}$)	1.877	1.992	2.203	0.282	0.324	0.527	-1.013	-1.011	-0.827
	(2.537)	(3.580)	(2.475)	(1.326)	(8.867)	(5.636)	(0.883)	(13.28)	(8.440)
Observations	4,555	4,583	4,583	4,555	4,583	4,583	4,555	4,583	4,583

Robust standard errors in ( ). Clusters by country. ***, **, * denote 1%, 5%, 10% statistical significance. All regressions include fixed effects by country (omitted). Panel quantile regressions are inconsistent with ancillary parameters such as year dummies (Machado and Santos Silva 2019). Coefficients are insignificant with year dummies.

Sources: World Bank; BIS

Panel quantile regressions for water use and real GFCF growth

Table A.5

	Quantile 25			Quantile 50			Quantile 75		
Water use									
	5.476	5.318	6.901	9.592	8.376	9.619	13.87	11.61	12.52
	(48.29)	(12.69)	(34.38)	(30.27)	(12.57)	(28.52)	(25.81)	(18.84)	(38.38)
Water scarcity									
Freshwater withdrawal$_{c,t}$	-0.245			-0.328			-0.414		
(% of internal resources)	(1.471)			(0.922)			(0.786)		
Freshwater withdrawal$_{c,t}$		-0.352			-0.327			-0.300	
(% of total renewable resources)		(0.638)			(0.632)			(0.947)	
Freshwater withdrawal$_{c,t}$			-0.348			-0.303			-0.255
(% of available freshwater)			(1.206)			(1.000)			(1.346)
Controls									
$\ln(\text{GDP}^{\text{pc}}_{\text{c,t}-1})$	1.294	1.643	2.410	-5.123	-4.998	-4.380	-11.80	-12.03	-11.61
	(45.34)	(12.72)	(32.57)	(28.43)	(12.61)	(27.02)	(24.24)	(18.89)	(36.35)
	3,513	3,513	3,513	3,513	3,513	3,513	3,513	3,513	3,513

Robust standard errors in ( ). Clusters by country. ***, **, * denote 1%, 5%, 10% statistical significance. All regressions include fixed effects by country (omitted). Panel quantile regressions are inconsistent with ancillary parameters such as year dummies (Machado and Santos Silva 2019). Coefficients are insignificant with year dummies.

Sources: World Bank; BIS

Panel quantile regressions for the impact of water usage on the CPI inflation rate

Table A.6

	Quantile 25			Quantile 50			Quantile 75		
Water use									
ln(total water withdrawal$^{\mathrm{pc}}_{\mathrm{c,t}}$)	12.36	14.22	11.27	13.59	17.19	11.50	18.20	27.70	12.29
	(6,328)	(173.3)	(1,145)	(5,581)	(159.6)	(970.7)	(6,942)	(268.5)	(526.7)
Water scarcity									
Freshwater withdrawal$_{c,t}$	0.609			1.170			3.272		
(% of internal resources)	(389.3)			(343.4)			(427.1)		
Freshwater withdrawal$_{c,t}$		0.602			1.142			3.050	
(% of total renewable resources)		(9.339)			(8.601)			(14.46)	
Freshwater withdrawal$_{c,t}$			0.622			1.220			3.318
(% of available freshwater)			(56.85)			(48.20)			(26.15)
ln(GDP$^{\mathrm{pc}}_{\mathrm{t-1}}$)	-23.21	-22.96	-23.75	-35.53	-35.33	-37.34	-81.66	-79.04	-85.00
	(6,884)	(185.2)	(1,264)	(6,072)	(170.5)	(1,072)	(7,552)	(286.7)	(581.5)
Observations	4,249	4,277	4,277	4,249	4,277	4,277	4,249	4,277	4,277

Robust standard errors in ( ). Clusters by country. ***, **, * denote 1%, 5%, 10% statistical significance. All regressions include fixed effects by country (omitted). Panel quantile regressions are inconsistent with ancillary parameters such as year dummies (Machado and Santos Silva 2019). Coefficients are insignificant with year dummies.

Sources: World Bank; BIS

Regressions for water use and hydroelectricity production

Table A.7

	Electricity form hydro sources (% of electricity production)		
Water use			
ln(total water withdrawal$^{pc}_{c,t}$)	-5.694**	-5.387**	-4.187*
	(2.286)	(2.219)	(2.296)
Water scarcity			
Freshwater withdrawal$_{c,t}$	-0.00911		
(% of internal resources)	(0.0697)		
Freshwater withdrawal$_{c,t}$		-0.0511	
(% of total renewable resources)		(0.0881)	
Freshwater withdrawal$_{c,t}$			-0.127
(% of available freshwater)			(0.101)
Controls			
$\ln(\mathrm{GDP}^{\mathrm{pc}}_{\mathrm{c,t-1}})$	2.820	2.733	2.936
	(3.993)	(3.957)	(3.975)
Observations	2,893	2,916	2,916
R-squared (total)	0.958	0.958	0.959

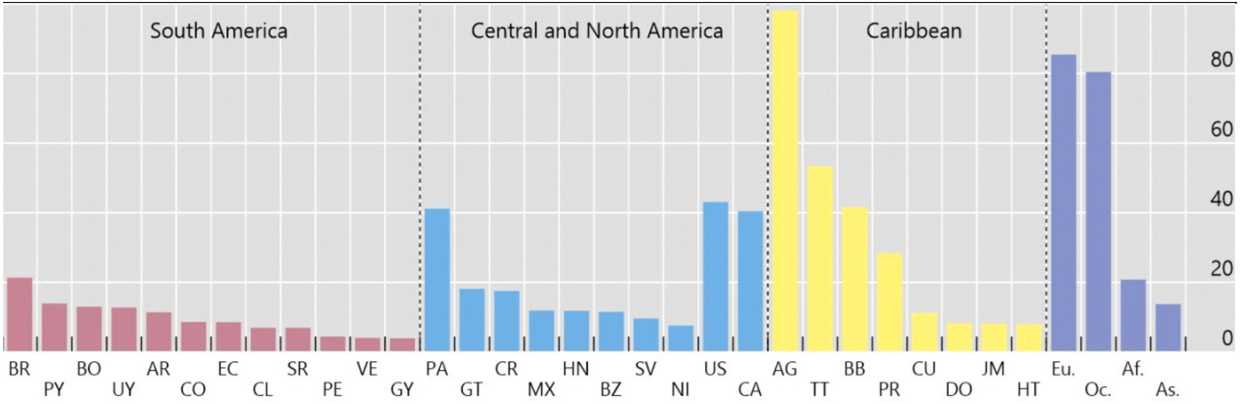
Robust standard errors in ( ). Clusters by country. ***, **, * denote 1%, 5%, 10% statistical significance. All regressions include fixed effects by country (omitted).

Sources: World Bank; BIS

Ratio of dollar value added to the volume of water used[1]

Dollar value to cubic meter

Graph A.1



[1] Water use efficiency measured as the ratio of dollar value added to the volume of water used. It considers water use by all economic activities. Same specification as in Graph 1. Weighted averages values for Africa, Asia, Europe, and Oceania.

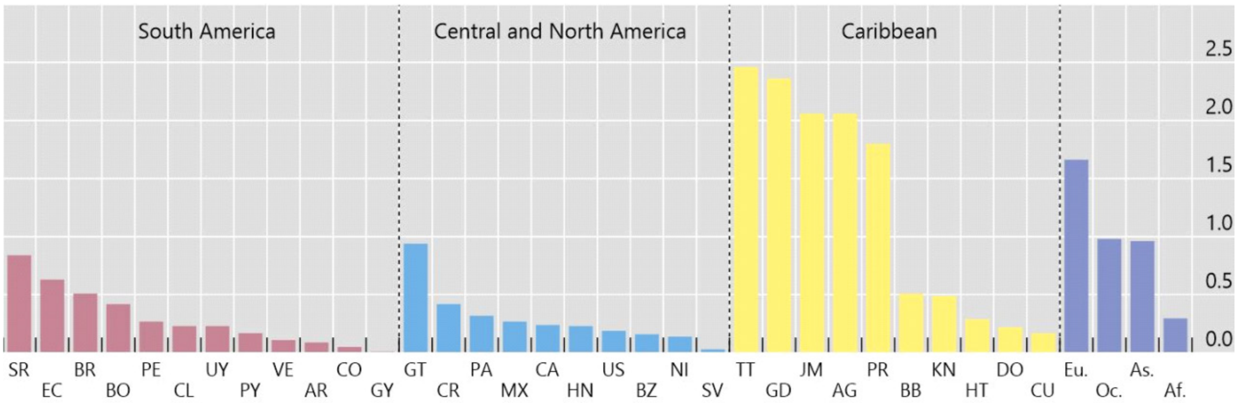
Sources: FAO; Aquastat; BIS.

Ratio of dollar value added to the volume of water used by economic sector[1]

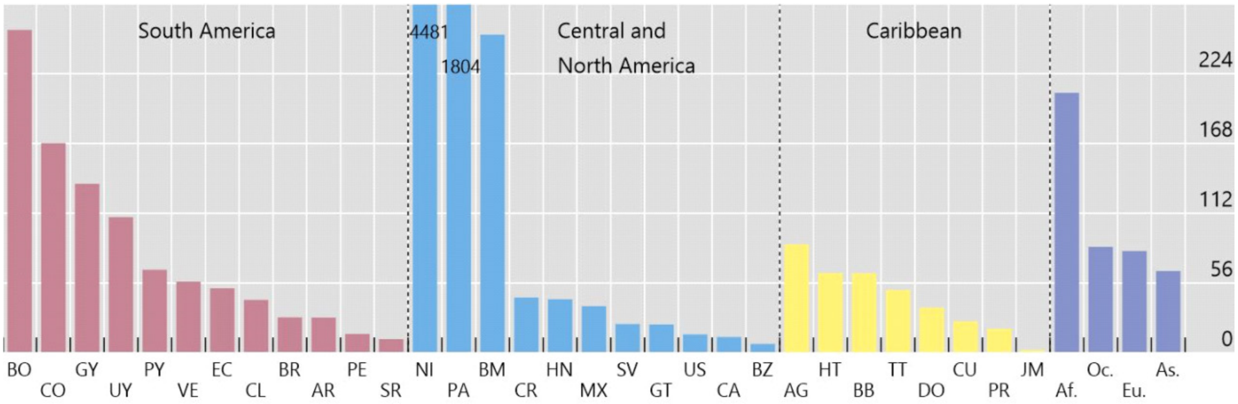
Dollar value to cubic meter

Graph A.2

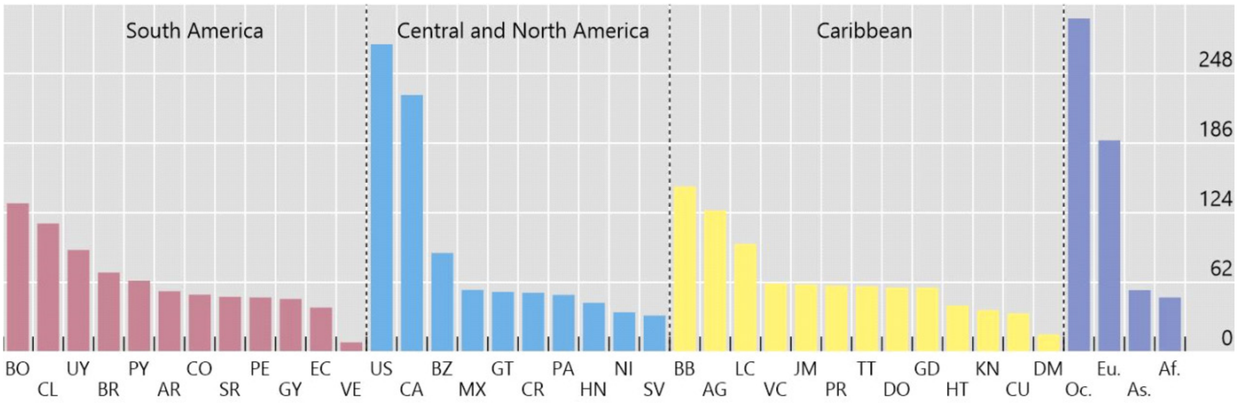
Agriculture, forestry, and fishing



Industry



Services



[1] Data for 2020. Weighted averages values for Africa, Asia, Europe, and Oceania.

Sources : FAO; Aquastat; BIS.

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