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Water Availability and Economic Development: Signs of the Invisible Hand - An Empirical Look at the Falkenmark Index and Macroeconomic Development

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ABSTRACT

It is widely believed that critically low levels of water availability will hinder economic growth and development. To the contrary, we find that countries with available water resources below 500 m^3 actually outperform countries with levels between 500 and 1600 m^3 in terms of growth, per capita Gross Domestic Product, and investment. We show descriptive evidence indicating that much of the reason for this seemingly unintuitive result lies in the natural pressures faced by critically water-scarce countries to move from water intensive agriculture to less water intensive services and industry, with an emphasis on the services sector. We believe governmental policy should focus less on water resource attainment in support of agriculture and more on transitioning to services.

I. INTRODUCTION

Fresh water is an essential element for our survival and development. Water scarcity has been receiving substantial attention in recent years within the media, academia, and governmental and non-governmental organizations. With the shrinking of the water supply due to natural limitations and pollution on the one hand, and increasing demand due to population growth, agricultural irrigation, industrial development, and massive urbanization on the other, we are now living in a "water-short world," facing a "full-scale emergency," entering the

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"age of water scarcity." Therefore we must deal with the "looming water crisis."[1]

A number of countries are coming up against the "water barrier" due to unfavorable climate and increasing population.[2] By 1997, some 80 countries were already suffering from serious water shortages;[3] Cosgrove and Rijsberman report that "water stress will increase significantly in more than 60% of the world, including large areas of Africa, Asia and Latin America."[4] The World Health Organization and UNICEF [2000] estimate that "more than 2 billion people are affected by water shortages in over 40 countries,"[5] and by 2050, Gardner-Outlaw and Engelman estimate that at least one in four people is likely to live in countries affected by chronic or recurring shortages of fresh water.[6] In the worst-case scenario, "nearly 7 billion people in sixty countries will live water-scarce lives by 2050."[7]

Economically, a lack of water is the ultimate constraint for food security, production growth, and economic development in general;[8]

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1. *See, e.g.*, Malin Falkenmark et al., *Water Scarcity as a Key Factor Behind Global Food Insecurity: Round Table Discussion*, 27 AMBIO 148, 148-54 (1998); *UN Warns of Looming Water Crisis*, BBC NEWS, Mar. 22, 2002, http://news.bbc.co.uk/1/hi/world/1887451.stm; Carmen Revenga et al., *Pilot Analysis of Global Ecosystems: Freshwater Systems*, WORLD RESOURCES INSTITUTE REPORT 25-27 (2000), *available at* http://pdf.wri.org/page_freshwater.pdf; Charles I. Vorosmarty et al., *Global Water Resources: Vulnerability from Climate Change and Population Growth*, 289 SCIENCE 284, 284-85 (2000); U.N. Environment Programme, *Time Is Running Out*, *in* GEO-2000: GLOBAL ENVIRONMENTAL OUTLOOK 2000 (1999), http://www.unep.org/geo2000/english/0236.htm; U.N. EDUC., SCI. & CULTURAL ORG., THE U.N. WORLD WATER DEVELOPMENT REPORT: WATER FOR PEOPLE, WATER FOR LIFE 5-19 (2003), http://www.unesco.org/water/wwap/wwdr/table_contents.shtml.

2. *See* Malin Falkenmark, *The Massive Water Scarcity Now Threatening Africa – Why Isn't It Being Addressed?*, 18 AMBIO 112 (1989).

3. U.N. Secretary-General, *Comprehensive Assessment of the Freshwater Resources of the World* ¶ 28, at 8, *delivered to the U.N. Commission on Sustainable Development*, U.N. Doc. E/CN. 17/1997/9 (Feb. 4, 1997), *available at* http://www.un.org/esa/sustdev/documents/docs_csd5.htm.

4. WILLIAM J. COSGROVE & FRANK R. RIJSBERMAN, MAKING WATER EVERYBODY'S BUSINESS, WORLD WATER VISION, at xxi (2000), http://www.worldwatercouncil.org/fileadmin/wwc/Library/WWVision/TableOfContents.pdf.

5. U.N. EDUC., SCI. & CULTURAL ORG., *supra* note 1, at 10 (citing World Health Org./U.N. Children's Fund, *Global Water Supply and Sanitation Assessment 2000 Report* (2000)).

6. Tom Gardner-Outlaw & Robert Engelman, *Sustaining Water, Easing Scarcity: A Second Update*, *in* REVISED DATA FOR THE POPULATION ACTION INTERNATIONAL REPORT, SUSTAINING WATER: POPULATION AND THE FUTURE OF RENEWABLE WATER SUPPLIES 6 (1997), http://www.populationaction.org/resources/publications/water/water97.pdf.

7. U.N. EDUC., SCI. & CULTURAL ORG., *supra* note 1, at 13.

8. *See, e.g.*, Malin Falkenmark, *Rapid Population Growth and Water Scarcity: The Predicament of Tomorrow's Africa*, 16 POPULATION & DEV. REV. 81, 82 (Supp. 1991); U.N. Secretary-General, *supra* note 3, at 8. Falkenmark et al., *supra* note 1, at 148; David Seckler

moreover, water scarcity is a source of social conflict leading to competition between different sectors of the economy, between different groups of a population, and between countries over the shared water resources.[9] The major impact of water availability on growth lies largely in agriculture, which accounts for 70% of water demand. The lack of irrigation water leads to poor yields and fewer types of crops, reducing farmers' income as well as employment opportunities in the agricultural sector. Water scarcity also hurts many non-agricultural industries that use water as an essential raw material. Water insufficiency may also increase the incidence of water-related disease preventing people from taking on productive activities while reducing their welfare through increased medical expenditures. In addition, water competition between different sectors of an economy or different groups of a population can result in political and economic instability, negatively affecting economic growth and development.

Despite the considerable attention paid to the "water crisis," little empirical work has been done to examine the impact of water availability on economic growth and development; water variables are virtually ignored in the cross-country growth literature. In their sensitivity analysis of cross-country growth regressions, Levine and Renelt examined over 50 variables that had been found to be correlated with growth, and water availability is not one of the candidates;[10] nor does it appear in Sala-I-Martin's 59 variables that potentially have an impact on economic growth.[11] Recent empirical work on growth has identified more variables that are partially correlated with the growth rate, yet water availability is rarely taken into consideration. An exception is Barbier, who investigates the claim that increasing water scarcity may constrain economic growth.[12]

Assuming that water is a public good subject to congestion, Barbier tests and confirms the existence of an inverted-U relationship between economic growth and the rate of water utilization across

et al., *Water Scarcity in the Twenty-first Century*, 15 INT'L J. WATER RESOURCES DEV. 29, 29–42 (1999); Mark W. Rosegrant & Ximing Cai, *Water for Food Production*, 2020 VISION FOCUS 9: OVERCOMING WATER SCARCITY AND QUALITY CONSTRAINTS (Ruth S. Meinzen-Dick & Mark W. Rosegrant ed., 2001), http://www.ifpri.org/2020/focus/focus09.htm.

9. *See* HYDROPOLITICS: CONFLICTS OVER WATER AS A DEVELOPMENT CONSTRAINT 1, 1-212 (Leif Ohlsson ed., 1995); Leif Ohlsson, *Water Scarcity and Conflict*, *in* SECURITY CHALLENGES OF THE 21ST CENTURY 211-34 (1999), http://www.padrigu.gu.se/ohlsson/files/Bonn.pdf.

10. Ross Levine & David Renelt, *A Sensitivity Analysis of Cross-Country Growth Regressions*, 82 AM. ECON. REV. 942, 944–60 (1992).

11. Xavier Sala-I-Martin, *I Just Ran Two Million Regressions*, 87 AM. ECON. REV. 178, 180–82 (1997).

12. Edward B. Barbier, *Water and Economic Growth*, 80 ECON. REC. 1, 1-16 (2004).

countries; that is, as the water utilization rate increases, growth first increases and then decreases. His estimation of this relationship also shows that "current rates of fresh water utilisation in the vast majority of countries are not yet constraining economic growth."[13] In addition, he found no evidence of falling income per capita since there are no "severe diminishing returns to allocating more output to provide water."[14] By using dummy variables to represent water scarce countries, however, he could not reject the hypothesis that "the presence of moderate or extreme water scarcity adversely affects economic growth."[15] Barbier's acceptance of a positive water/growth relationship does appeal to our intuition that a lack of water is harmful for growth.

The arguments of a positive water/development relationship do not take into account the adaptation mechanism. Water scarcity imposes constraints on food production and industrial development, yet it could also be a powerful driving force for societal change and economic restructuring. This could potentially lead to faster growth and better living standards in the long run. Such a scenario could happen along two dimensions.

The first dimension is the more efficient use of existing water resources through improvements in water resource management such as water pricing and technological advances such as drip irrigation and less unaccounted-for water. The second dimension, which is far more important, lies in economic restructuring. Chile, for example, reallocates water from low-value agricultural production, such as grain, oil-seed, and cattle farming, to more profitable fruit production and vineyard planting. This has made Chile the largest fruit-exporter in the world in 1993.[16] In countries where water resources are extremely limited, water scarcity could act as a potent catalyst pushing an agriculturally dominated economy toward a developed economy. Such economic development occurs via the bypassing of constrained food production and focusing on less water-intensive industrial production and service provision. People caught under such circumstances are more compelled to make the transformation and enjoy increased long-run growth and better living standards.

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13. *Id.* at 2.
14. *Id.*
15. *Id.* at 14.
16. Leif Ohlsson, *Water Scarcity and Conflict*, paper for the "New Faces Conference," Forschungsinstitut der Deutsche Gesellschaft für Auswärtige Politik (Oct. 5-8, 1997), at 18, *available at* http://www.padrigu.gu.se/ohlsson/files/Bonn97.pdf (citing Karin E. Kemper, *The Cost of Free Water: Water Resources Allocation and Use in the Curu Valley, Ceará, Northeast Brazil*, 137 LINKÖPING STUDIES IN ARTS & SCIS. (1996)).

The possible positive effect of extreme water scarcity on economic growth and income per capita may also be implied from the natural resource literature. Sachs and Warner have noted that "[o]ne of the surprising features of economic life is that resource-poor economies often vastly outperform resource-rich economies in economic growth,"[17] and confirmed the adverse effects of resource abundance on growth in a cross-country growth regression framework. The possible explanation of this phenomenon includes Bodin's claim that easy riches lead to sloth,[18] Lane and Tornell's model that resource-rich countries are more vulnerable to rent-seeking behavior than resource-poor countries,[19] and Matsuyama's framework showing that the agricultural sector draws employment from manufacturing, thus lowering economic growth.[20] The question is, under the water resource context, can we expect a similar relationship? That is, can the water-poor countries outperform water-rich countries in economic growth and development? Is extreme water scarcity a blinded blessing?

A variable that one can use to test the impact water scarcity has on growth and development is the Falkenmark index.[21] The Falkenmark index measures per capita water availability in m^3. It is considered that water availability below 500 m^3 per person indicates a country that is beyond the "water barrier" of manageable capability. Availability between 500 and 1,000 m^3 indicates chronic water scarcity, while availability between 1,000 and 1,600 m^3 indicates water stress. It could be considered that below the 500 m^3 level, a country's economy should probably be negatively impacted by the lack of available water, while countries between 500 and 1,600 m^3 can probably still function with no real direct impact on the economy, but these countries could marginally be feeling the burden of a lack of water.

This article finds that, in general, water availability did not have an impact on growth in the 1980s; whereas, in the 1990s, countries with availability between 500 and 1,600 m^3 had lower growth than countries with availability below 500 m^3. In both the 1980s and 1990s, countries

17. Jeffrey D. Sachs & Andrew M. Warner, *Natural Resource Abundance and Economic Growth* 3 (Nat'l Bureau of Econ. Research Working Paper No. 5398, 1995), http://www.nber.org.

18. *Id.* at 4 (citing JEAN BODIN, THE SIX BOOKS OF A COMMONWEALE (Kenneth Douglas McRae ed., Richard Knolles trans., Harvard Univ. Press 1962) (1606)).

19. Philip R. Lane & Aaron Tornell, *Power, Growth and the Voracity Effect*, 1 J. ECON. GROWTH 213 (1996).

20. Kiminori Matsuyama, *Agricultural Productivity, Comparative Advantage, and Economic Growth*, 58 J. ECON. THEORY 317 (1992).

21. Malin Falkenmark & Carol Widstrand, *Population and Water Resources: A Delicate Balance*, 47 POPULATION BULL., Nov. 1992, at 1, 19.

with water resources below 500 m^3 had higher levels of per capita Gross Domestic Product (GDP) than countries with higher levels of the resource. When measuring the resource's impact on investment, we find a similar tale where countries with availability below 500 m^3 have higher levels of investment as a fraction of GDP.

We argue that these seemingly counter-intuitive results have much to do with the "invisible hand" of economic adjustment. This means that countries beyond the "water barrier" show trends out of water intensive agriculture and into less water intensive industry and especially services. In a sense, extreme water scarcity is a driving force behind economic development. While the trend into services could be considered a worldwide phenomenon, the adjustments do appear more robust in these countries than in the countries with availability between 500 and 1,600 m^3.

A policy implication of this article would simply be to try to encourage the countries facing the water barrier to start soon in implementing strategies to make this transition, and to minimize the use of financial resources in alternative water attainment. In this study we did make the unrealistic assumption that water availability as measured by the Falkenmark index was time invariant over both decades. This assumption is clearly false at least over the long run. Eventually, the countries in the 500 to 1,600 m^3 group will migrate into the water barrier to economic growth and probably be naturally guided by the "invisible hand" into less water intensive sectors that produce higher incomes and greater development. But this scenario may take a while. To implement these strategies now would speed the development process and lower poverty levels and increase the well-being of agents in these countries.

In what follows, section II describes the models employed as well as the data used; section III discusses the results of individual decadal regressions as well as the results from a restricted seemingly unrelated regression; while section IV tries to provide a story for the results that has intuitive appeal and is supported by descriptive statistics. Section V provides a conclusion.

II. THE MODELS AND DATA

The empirical models we use to model growth and per capita GDP were derived directly from Mankiw, Romer, and Weil's (MRW) formulation,[22] which in turn was derived from Solow's.[23] Solow's model

22. N. Gregory Mankiw et al., *A Contribution to the Empirics of Economic Growth*, 107 Q. J. ECON. 407, 415-18 (1992).

23. Robert M. Solow, *A Contribution to the Theory of Economic Growth*, 70 Q. J. ECON. 65 (1956).

assumes that production in an economy can be measured by differing degrees of physical capital (plants, machines, equipment, etc.), labor force, and technology. It is common in empirical work to proxy physical capital with measures of *investment* in capital, and to proxy the labor force with measures of population. Technology is typically relegated to some error measurement or residual.

MRW's purpose was to test omitted variable bias with regard to omitting human capital, which is typically proxied by measurements of secondary education in a population. This bias, they hypothesized, would occur if both technology and investment are functions of human capital (*i.e.*, the more educated a nation, the higher the level of technological ability; and a more educated population may be likely to invest more than a nation with low levels of education). Since, by definition, the residuals (technology) of any regression must be independent of the determinants (investment and/or population) of the regression, biased estimators would result if the connection between human capital, technology, and investment is a significant one. To try to address this possible bias, they add human capital (proxied by the percentage of secondary schooling in the population) to their regressions to show that particular parameter estimates fall in line with conventional wisdom. This form is known as the "augmented" Solow model.

The results from the above regression model would therefore allow us to interpret the impact that increasing levels of investment, population, and human capital would have on the output of an economy. In particular, if we assume the simple functional form $Y = a_0 + a_1X + e$, where Y is in our case GDP, X is for example investment, and e are the residuals, then a regression would estimate a_1 as a point estimate for the slope of a line that indicates the "typical" effect of investment on GDP.[24] The MRW model predicts that there should be a positive effect of investment on production, a negative effect (or Malthusian effect) of population on production, and a positive effect of schooling on production. Hence, we would expect that any statistically significant impact of these variables should result in their respective coefficients (the a_1 s) being positive, negative, and positive, respectively.

Some may say that, with regard to the context of our article, it would be sufficient to regress growth and income on the Falkenmark index by itself. However, if water availability is correlated with, for

24. Some would argue that a correlation between X and Y may not mean that there is a causation from X to Y, and in many cases this is true; however, in our case, the existing theory (Solow's theory) indicates that we can interpret correlation as causation.

example, investment in physical capital due to the diversion of resources to compensate for the lack of water, and if investment is correlated with either growth or per capita GDP, excluding it would compromise the property of independence between the residuals and regressors (just like the argument above for the inclusion of schooling); this implies that this theoretically-based model of growth and income may be more suitable than just a simple regression.

To further our investigation into the realm of how water scarcity impacts domestic investment, we use a simple model of investment with a standard set of control variables used in Levine and Renelt.[25] We use this formulation because there really is no widely accepted theoretical model of investment from which to form a particular empirical model. Without loss of generality, in all models we assume that the Falkenmark index of water stress originates from the residuals of the model and is essentially a component of technology.

Within these same model structures, the existence of regionally specific fixed effects in the mean can bias the estimators and their respective test statistics.[26] We address this issue by allowing for regionally specific fixed effects delineated as per the Penn World Tables 6.1 (PWT).[27] This delineation allows for 15 possible regions of the world. In addition, we control for heterogeneous aspects of growth, per capita GDP, and investment, with respect to whether a country is either a member of OPEC, or pumping at least an average of 2 million barrels of oil per day over both decades with primary control of the oil revenue given to the government. This added the countries of Mexico, Russia, and China to the list of OPEC countries. The oil countries in the context of our particular data set are Indonesia, Iran, Nigeria, Saudi Arabia, United Arab Emirates, Venezuela, Mexico, Russia, and China. Also, to prevent feedback from the dependent variables to the determinants, we regress the ten-year averages of the dependent variables on the observations of the determinants from the first year of each decade. For

25. Levine & Renelt, *supra* note 10, at 945.

26. *See, e.g.*, Jeffrey Edwards, *The Great Growth Debate: A Statistical Look at Mankiw, Romer, and Weil, versus Islam*, 33 ATL. ECON. J. 71 (2005) [hereinafter Edwards, *The Great Growth Debate*]; Jeff Edwards & Anya McGuirk, *Kuznets Curveball: Missing the Regional Strike Zone*, 1 ECON J. WATCH 222, 226-30 (2004), http://www.econjournalwatch.org/main/archive.php; Barry P. Bosworth & Susan M. Collins, *The Empirics of Growth: An Update*, 2 BROOKINGS PAPERS ON ECON. ACTIVITY 113, 159 (2003); William Easterly & Ross Levine, *It's Not Factor Accumulation: Stylized Facts and Growth Models*, 15 WORLD BANK ECON. REV. 177, 190 (2001); ROBERT J. BARROW & XAVIER SALA-I-MARTIN, ECONOMIC GROWTH 442 (2001).

27. *See* Alan Heston et al., *Penn World Table Version 6.1*, Center for International Comparisons at the University of Pennsylvania (CICUP) (Oct. 2002), http://pwt.econ.upenn.edu/php_site/pwt_index.php (follow "PWT6.1" hyperlink).

instance, the decadal average of growth in GDP for the 1980s would be regressed on the 1980 value of the control variables and the time-invariant value of the Falkenmark index. The econometric forms of our equations are

$$(1)\ Average\,Growth_i = b_{0r} + b_1 \ln(y)_{i0} + b_2 \ln\left(\frac{I}{Y}\right)_{i0} + b_3 \ln(PopulationGrowth)_{i0}$$
$$+ b_4 \ln(schooling)_{i0} + b_5 f(Falkenmark)_i + u_i$$

$$(2)\ \ln(Average\,GDP)_i = a_{0r} + a_1 \ln\left(\frac{I}{Y}\right)_{i0} + a_2 \ln(PopulationGrowth)_{i0}$$
$$+ a_3 \ln(schooling)_{i0} + a_4 f(Falkenmark)_i + e_i$$

$$(3)\ \ln\left(Average\frac{I}{Y}\right)_i = c_{0r} + c_1 \ln(y)_{i0} + c_2 \ln(PopulationGrowth)_{i0} +$$
$$c_3 \ln(schooling)_{i0} + c_4 f(Falkenmark)_i + v_i$$

where Average Growth is the average growth rate in per capita real GDP, Average GDP is the average per capita real GDP, and Average I/Y is the average level of the ratio of domestic investment to GDP.

In each of the models, the subscript r on the constant terms reflects the fact that our models control for heterogeneous aspects of the mean with regard to regions. The 0 subscript reflects an observation that was taken at the beginning of the decade. The variable $\left(\frac{I}{Y}\right)$ is the standard proxy for saving in physical capital, while the variable "schooling" is the typical proxy for saving in human capital. In all regressions, the Falkenmark index simply enters in an additive form. This form will be either continuous or a set of dummy variables.

The Falkenmark index is defined as the ratio of available water resources per capita (in m^3) per year. In our data set, this index ranges from a low of 0.1 for countries such as Jordan, the United Arab Emirates, and Israel, to a high of 605 for Iceland. Because of the large spread in the Index, we take the natural log to normalize the variable in the continuous form. Regarding the dummy variable specification, each dummy variable will take the value one if a country has between 1,000 and 1,600 m^3 of water per capita, 500 to 1,000 m^3 of water per capita, and less than 500 m^3 of water per capita respectively, and zero otherwise; hence, the control group consists of countries with more than 1,600 m^3 of water per capita; the first group we call "Water Stressed," the second "Water Scarce," and the third "Water Extreme."

All of our data, with the exception of the Falkenmark index, comes from the World Banks' World Development Indicators, 2003 version. The data spans the years 1980 to 1999 and encompasses 94 countries. Because the Falkenmark index reflects a cross-section with no

time dimension, we use decadal averages of the dependent variables for each country from 1980-1989 and 1990-1999. Assuming that the measure of the Index did not vary much from 1980-1989, nor from 1990-1999, the most important reason for splitting the data at 1990 is to investigate whether a country's performance is hindered more or less in one decade than in the other. But because our data set spans two decades we ultimately use a seemingly unrelated regression (SUR) estimation technique to test longer-run effects. This regression procedure allows us to test for coefficient constraints and joint tests of significance across decades, and also provides full use of the number of observations over both decades in the constrained form while allowing for serially correlated errors.

Before the SUR technique can be employed, statistically adequate models for both decades must first be specified. If the regressions from each decade are statistically inadequate, any inference drawn from them is likely to be flawed.[28] This, of course, will also lead to invalid inference in the SUR results. In particular, our model is assumed to have a residual structure that follows the normal distribution, residuals that are free of non-linearities in the determinants, residuals that are identically distributed, as well as parameters (the a's and the variance of the errors) that are constant.

We first perform a battery of statistical misspecification tests on the regressions for each decade and then respecify each regression accordingly before implementing the SUR technique with cross-equation parametric restrictions. The misspecification tests we use are the Hansen parametric stability test, the Cook-Weisburg (CW) homoskedasticity test (if the residuals are not identically distributed, they are called hetero-skedastic, which leads to biased tests of statistical significance and invalid inference), the regression specification error test (RESET) for statistically omitted variables (*i.e.*, non-linear determinants in the residuals that would lead to not only biased test statistics, but also biased estimator values), and a standard skewness-kurtosis test for the normality assumption. Since the Hansen parametric stability test must have a coherent ordering to be viable, we order our data by region according to the PWT 6.1. The regions are ordered as West Africa, Central Africa, East Africa, South Africa, North Africa and the Middle East, North America, South America, the Caribbean, Southeast Asia,

28. Edwards, *The Great Growth Debate*, *supra* note 26, at 72; *See also* Jeff Edwards & Anya McGuirk, *Reply to Change and Ram: Statistical Adequacy and the Reliability of Inference*, 1 ECON J. WATCH 244 (2004), http://www.econjournalwatch.org/main/archive.php; ARIS SPANOS, PROBABILITY THEORY AND STATISTICAL INFERENCE: ECONOMETRIC MODELING WITH OBSERVATIONAL DATA 602-35 (1999).

Southwest Asia, Western Europe, and Oceania.[29] Table 1 below lists the initial testing statistics for each decadal regression.

Table 1: Initial Testing Results for Decadal Regressions

Variables	Growth				GDP				Investment			
	1980		1990		1980		1990		1980		1990	
GDP	0.39	0.36	0.21	0.24					0.13	0.12	0.05	0.07
Schooling	0.42	0.39	0.25	0.27	0.41	0.50	0.39	0.46	0.14	0.12	0.05	0.06
Population	0.38	0.34	0.96	0.92	0.18	0.08	0.10	0.05	0.10	0.06	0.11	0.14
Investment	0.38	0.36	0.30	0.31	0.26	0.32	0.31	0.36				
Oil Dummy	0.20	0.19	0.38	0.40	0.09	0.05	0.08	0.05	0.08	0.14	0.17	0.09
Falkenmark	0.19		0.26		0.59		0.62		0.18		0.04	
Water Stress		0.30		0.21		0.12		0.10		0.45		0.12
Water Scarce		0.02		0.03		0.02		0.03		0.02		0.02
Water Extreme		0.08		0.18		0.02		0.05		0.02		0.03
Constant	0.40	0.38	0.29	0.30	0.25	0.30	0.28	0.34	0.09	0.08	0.06	0.07
Variance	0.19	0.19	0.25	0.12	0.09	0.11	0.37	0.37	0.96	1.02	0.68	0.64
CW	0.50	0.63	0.45	0.49	0.21	0.01	0.05	0.00	0.00	0.00	0.45	0.24
RESET	0.00	0.00	0.81	0.50	0.00	0.02	0.00	0.00	0.60	0.70	0.00	0.01
Normality	0.39	0.37	0.37	0.67	0.74	0.09	0.21	0.10	0.02	0.00	0.27	0.15

The top row of statistics that relate to each variable are Hansen parametric stability test statistics. If the statistic is above 0.50 for a particular parameter, then that parameter is considered unstable. The second row of statistics are p-values pertaining to the Cook-Weisburg homoskedasticity test, the Regression Specification Error Test for correct functional form, and a skewness-kurtosis test for normality respectively. The underlined values indicate that the models fail the respective null hypotheses at the 5% level of significance. Water Stressed, Water Scarce, and Water Extreme are dummy variables relating to countries with 1,000-1,600, 500-1,000, and less than 500 m^3 of water per capita respectively. The control group is countries with more than 1,600 m^3 of water per capita.

Table 1 tells us that every decadal regression fails at least one misspecification test. The 1980s growth regression was corrected simply by adding two regional effects to the specification. It is common that regional effects can influence the RESET test even though the RESET test does not specifically test for fixed effect heterogeneity in the mean. The 1990s growth regression was corrected by including interactions of the

29. *See* Edwards, *The Great Growth Debate*, *supra* note 26.

population growth variable with the regions of Western Europe, Southeast Asia, and Southwest Asia. The 1980 and 1990 GDP regressions using the continuous Falkenmark index were corrected both with the inclusion of 10 and 8 regional dummy variables respectively and interactions between the Falkenmark index and North Africa and the Middle East, South America, and Southeast Asia. The same decadal regressions but using the dummy variable Falkenmark index were corrected by adding 11 regional dummies for both regressions, but the 1990's regression additionally required a quadratic schooling variable. The investment regressions were easily corrected with either 1 or 2 regional dummies in the mean, but required a feasible generalized least squares (FGLS) procedure to correct for regional heterogeneity in the conditional variance.[30] The respecified regressions are below.

III. THE RESULTS

The results from regressions (1), (2), and (3) are shown respectively in Tables 2, 3, and 4 below. The results are from separate decadal regressions testing the two specifications of the Falkenmark index. In the first column of each decade the natural log of the Falkenmark index is entered in its continuous form; in the second column of each decade, the Falkenmark is broken down into dummy variables. The variable "Water Stressed" takes the value one if a country has between 1,000 and 1,600 m^3 of water per capita and zero otherwise; "Water Scarce" and "Water Extreme" take the value one for countries with 500 to 1,000 m^3 of water per capita and less than 500 m^3 of water per capita respectively, and zero otherwise.

Concerning the standard control variables in Table 2, we find that when significant the coefficients enter with the expected signs. For instance, we do find the typical Malthusian effect of population growth on growth in GDP where, ceteris paribus, increases in population growth lowers growth in per capita GDP. This effect is more pronounced in the 1990s than it is in the 1980s for most regions with the combined effect for the regions of West Europe, Southeast Asia, and Southwest Asia being negligible. The p-values for the joint significance of the standard population growth variable and the population growth variable with the regional interactions are 0.650, 0.429, 0.458 for the continuous Falkenmark regression in the 1990s, and 0.808, 0.625, and 0.782 for the dummy variable Falkenmark regressions. In addition to the sign of the

30. *Id.* at 76, 85; Jeffrey Edwards et al., *Accounting for Regional Variance Heterogeneity of Growth* (2005) (working paper, Dep't of Econ., Texas Tech University) (on file with author).

population growth variable, the investment variable also enters with the expected positive relationship to economic growth.

Table 2: OLS Regression of Growth in Per Capita GDP				
Dependent variable is growth in real per capita GDP				
Variables	1980s Regressions		1990s Regressions	
GDP	0.218 (0.395)	0.220 (0.413)	-0.133 (0.500)	-0.163 (0.388)
Schooling	-0.516 (0.232)	-0.498 (0.276)	0.691 * (0.084)	0.373 (0.338)
Population	-0.711 ** (0.014)	-0.708 ** (0.028)	-1.076 ** (0.004)	-1.358 ** (0.001)
Investment	1.246 * (0.066)	1.265 * (0.067)	1.175 ** (0.032)	1.029 ** (0.048)
Oil Dummy	-2.986 ** (0.000)	-2.952 ** (0.001)	-0.973 (0.117)	-1.208 ** (0.042)
Population*WEuro			1.288 * (0.050)	1.465 ** (0.018)
Population*SeAsia			1.886 * (0.061)	1.837 * (0.054)
Population*SwAsia			1.935 * (0.076)	1.661 (0.109)
Falkenmark	-0.022 (0.857)		0.027 (0.785)	
Water Stressed		-0.158 (0.867)		-1.096 * (0.097)
Water Scarce		0.597 (0.658)		-2.802 ** (0.004)
Water Extreme		-0.002 (0.998)		0.653 (0.313)
Constant	-3.027 (0.157)	-3.218 (0.164)	-3.226 * (0.085)	-1.037 (0.585)
Adjusted R^2	0.281	0.266	0.320	0.390
Number of Regions	2	2	0	0

P-values in parentheses. * implies significance at 10%, ** implies significance at 5%. Number of Regions pertains to the number of regionally-specific fixed effects used in the regression. WEuro, SeAsia, and SwAsia stand for West Europe, Southeast Asia, and Southwest Asia respectively. Water Stressed, Water Scarce, and Water Extreme are dummy variables relating to countries with 1,000-1,600, 500-1,000, and less than 500 m^3 of water per capita respectively. The control group is countries with more than 1,600 m^3 of water per capita.

In the 1980s, it seems as though levels of water availability had no impact on economic growth. In the 1990s, countries with between 500 and 1,600 m^3 of water resources conditionally had on average about two percentage points lower growth than countries with below 500 m^3 of available water. Perhaps more surprising is the fact that countries with 500 to 1,000 m^3 of water resources had growth rates that were nearly three times lower than countries with 1,000 to 1,600 m^3. This result is probably due to several factors such as transition costs from water intensive sectors to non-water intensive sectors, as well as the possibility

that countries in this group may still be in the pre-transition stage where a large amount of resources are being used to find alternative sources of water for existing water intensive sectors.

Table 3: OLS Regression of Per Capita GDP				
Dependent variable is the natural log of real per capita GDP				
Variables	1980s Regressions		1990s Regressions	
Schooling	0.636 **	0.770 **	-1.197	-1.478
	(0.000)	(0.000)	(0.179)	(0.138)
Population	-0.073	0.007	0.0002	0.162
	(0.546)	(0.953)	(0.998)	(0.283)
Investment	0.260	0.161	-0.151	-0.155
	(0.263)	(0.504)	(0.493)	(0.527)
Oil Dummy	0.308	0.335	0.202	0.211
	(0.282)	(0.248)	(0.445)	(0.435)
Schooling Squared			0.345 **	0.379 **
			(0.011)	(0.012)
Falkenmark	0.004		0.014	
	(0.957)		(0.806)	
Falkenmark*NAME	-0.756 **		-0.636 **	
	(0.003)		(0.007)	
Falkenmark*SAmer	-0.458 **		-0.331 **	
	(0.000)		(0.000)	
Falkenmark*SeAsia	-0.452 **		-0.498 **	
	(0.032)		(0.001)	
Water Stressed		0.298		-0.177
		(0.415)		(0.579)
Water Scarce		0.358		-0.471
		(0.524)		(0.365)
Water Extreme		1.680 **		1.144 **
		(0.001)		(0.016)
Constant	6.151 **	5.917 **	8.629 **	9.459 **
	(0.000)	(0.000)	(0.000)	(0.000)
Adjusted R^2	0.805	0.784	0.844	0.825
Number of Regions	10	11	8	11
P-values in parentheses. * implies significance at 10%, ** implies significance at 5%. Number of Regions pertains to the number of regionally-specific fixed effects used in the regression. NAME, SAmer, and SeAsia stand for North Africa and the Middle East, South America, and Southeast Asia respectively. Water Stressed, Water Scarce, and Water Extreme are dummy variables relating to countries with 1,000-1,600, 500-1,000, and less than 500 m^3 of water per capita respectively. The control group is countries with more than 1,600 m^3 of water per capita.				

With regard to Table 3, at first sight the significance of the estimates of the control variables may seem a puzzle; in fact, only schooling accounted for any difference in per capita GDP. Digging deeper, it soon becomes clear that it is likely that the large number of regionally specific fixed effects must be capturing the cross-country differences in per capita GDP in a more significant fashion than do the standard controls. Perhaps the most exciting results exist in the interpretation of the Falkenmark coefficients.

The coefficient estimates for the regional interactions with the continuous Falkenmark index indicate that the impact of water resources on levels of income is negative for North Africa and the Middle East, South America, and Southeast Asia, with the impact being almost double in North Africa and the Middle East than in the other two regions; water resource availability has no statistically significant impact in the rest of the world. The estimates indicate that within each of the above-mentioned regions countries with relatively high levels of water resources actually have lower levels of income per capita. With regard to the coefficient estimates of the dummy variable form of the Falkenmark index, we find that countries with below 500 m³ of available resources conditionally had on average four times higher income per person in the 1980s and 1990s than countries in the 500 to 1,600 m³ group. (We see this in the decadal regression for the 1980s by comparing the coefficient on the water extreme variable (1.68) with that of water scarce variable (0.358); the 1990s interpretation is based on absolute values.) The results of the investment regressions depict even more seemingly puzzling results.

Table 4: FGLS Regression of the Investment to GDP Ratio

Dependent variable is the natural log of the investment to GDP ratio

Variables	1980s Regressions		1990s Regressions	
GDP	0.015	-0.015	-0.063 **	-0.070 **
	(0.543)	(0.504)	(0.002)	(0.010)
Schooling	0.137 **	0.159 **	0.222 **	0.170 **
	(0.007)	(0.001)	(0.000)	(0.006)
Population	0.042	0.021	0.028	0.030
	(0.160)	(0.449)	(0.349)	(0.444)
Oil Dummy	0.024	0.051	0.091	0.066
	(0.793)	(0.501)	(0.182)	(0.475)
Falkenmark	-0.016		0.0006	
	(0.278)		(0.958)	
Water Stressed		0.177		-0.048
		(0.220)		(0.621)
Water Scarce		0.100		-0.323 **
		(0.439)		(0.025)
Water Extreme		0.280 **		0.031
		(0.000)		(0.730)
Constant	2.416 **	2.522 **	2.655 **	3.215 **
	(0.000)	(0.000)	(0.000)	(0.000)
F-statistic	299.79	211.86	553.75	60.39
Number of Regions	1	1	2	1

P-values in parentheses. * implies significance at 10%, ** implies significance at 5%. Number of Regions pertains to the number of regionally-specific fixed effects used in the regression. An FGLS regression was performed to account for regionally-specific heterogeneity in the conditional variance [see Edwards, 2005]. Water Stressed, Water Scarce, and Water Extreme are dummy variables relating to countries with 1,000-1,600, 500-1,000, and less than 500 m³ of water per capita respectively. The control group is countries with more than 1,600 m³ of water per capita.

With regard to the estimates of the Falkenmark coefficients, the results and potential interpretations are arguably more puzzling than in the prior regressions. In the 1980s, extremely water constrained countries, *i.e.*, those below 500 m^3 of water resources, had higher levels of investment (comparing 0.280 for water extreme with 0.100 and 0.177 for water scarce and water stressed countries respectively), but in the 1990s there exists no relationship for the countries in this category. In addition, countries with water resources between 500 and 1,000 m^3 had statistically significant lower levels of investment than did countries in any other grouping during the 1990s. Contrary to these seemingly arbitrary and non-intuitive results, all of the results in Tables 2–4 taken together tell a surprisingly succinct and intuitive story. But, to assure that our results in those three tables are statistically adequate, Table 5 below lists the same tests as in Table 1 but after respecification.

Table 5: Respecified Testing Results

Variables	Growth				GDP				Investment			
	1980		1990		1980		1990		1980		1990	
GDP	0.08	0.08	0.14	0.14					0.05	0.28	0.05	0.06
Schooling	0.10	0.11	0.13	0.14	0.41	0.50	0.37	0.46	0.05	0.23	0.05	0.06
Population	0.03	0.02	0.26	0.27	0.11	0.08	0.06	0.05	0.03	0.03	0.07	0.07
Investment	0.08	0.09	0.13	0.13	0.32	0.32	0.28	0.36				
Oil Dummy	0.05	0.05	0.24	0.25	0.08	0.05	0.07	0.05	0.07	0.05	0.06	0.17
Falkenmark	0.19		0.18		0.35		0.32		0.16		0.04	
F-Stress		0.36		0.18		0.12		0.10		0.42		0.11
F-Scarce		0.01		0.03		0.02		0.03		0.03		0.02
F-Bad		0.01		0.18		0.02		0.05		0.02		0.01
Constant	0.09	0.09	0.13	0.14	0.29	0.30	0.24	0.34	0.06	0.21	0.06	0.06
Variance	0.51	0.51	0.18	0.16	0.07	0.11	0.33	0.37	0.50	0.11	0.38	0.35
CW	0.45	0.44	0.30	0.94	0.50	0.16	0.62	0.31	0.91	0.71	0.06	0.75
RESET	0.49	0.51	0.67	0.44	0.27	0.16	0.09	0.05	0.51	0.21	0.75	0.41
Normality	0.26	0.23	0.82	0.76	0.57	0.73	0.18	0.09	0.05	0.09	0.74	0.08

The top row of statistics that relate to each variable are Hansen parametric stability tests. The second row of statistics are p-values pertaining to the Cook-Weisburg homoskedasticity test, the Regression Specification Error Test for correct functional form, and a skewness-kurtosis test for normality respectively. The underlined values are null hypotheses the fail at the 5% level of significance.

As the reader can see, now all models pass each misspecification testing criteria to at least the 5% level of significance. Given this result,

we are now justified in testing cross-country restrictions and performing SUR regressions in order to utilize the full potential of the data across both decades.

Table 6: SUR Regressions with Restricted Coefficients When Justified

Dep. Variables	Growth in Real Per Capita GDP		Real Per Capita GDP		Investment to GDP Ratio	
Ind. Variables	1980s	1990s	1980s	1990s	1980s	1990s
Falkenmark	0.013 (0.854)	0.013 (0.854)	0.033 (0.527)	0.033 (0.527)	-0.005 (0.615)	-0.005 (0.615)
Falkenmark*NAME			-0.807** (0.000)	-0.807** (0.000)		
Falkenmark*SAmer			-0.417** (0.000)	-0.417** (0.000)		
Falkenmark*SeAsia			-0.674** (0.000)	-0.674** (0.000)		
Water Stressed	-0.756 (0.147)	-0.756 (0.147)	-0.103 (0.736)	-0.293 (0.315)	0.029 (0.693)	0.029 (0.693)
Water Scarce	-1.272 (0.298)	-3.147** (0.000)	-0.434 (0.338)	-0.434 (0.338)	0.032 (0.785)	-0.325** (0.013)
Water Extreme	0.388 (0.423)	0.388 (0.423)	1.535 ** (0.000)	1.535 ** (0.000)	0.191 ** (0.002)	0.191 ** (0.002)

P-values in parentheses. * implies significance at 10%, ** implies significance at 5%. The control variables from the previous regressions are included in these regressions, but their coefficients are not listed for clarity. Only coefficients that passed tests of restrictions across decades were restricted. All of the Falkenmark coefficients as well as the coefficients for Water Extreme were restricted across both decades in each case, while only Water Scarce was restricted across decades in the per capita GDP regression, and Water Stressed was restricted across decades for the Growth and Investment regressions.

Essentially, Table 6 reflects the same results as Tables 2–4 with some slight adjustments due to the statistical ability to constrain particular coefficients across decades. In essence, water extreme countries have both higher per capita GDP and higher investment in both decades while water scarce countries have statistically significant lower levels of growth and investment in the 1990s. Water availability does not appear to be an economic issue in other countries except for countries in North Africa and the Middle East, South America, and Southeast Asia where increased availability also lowers per capita GDP.

IV. THE STORY BEHIND THE RESULTS

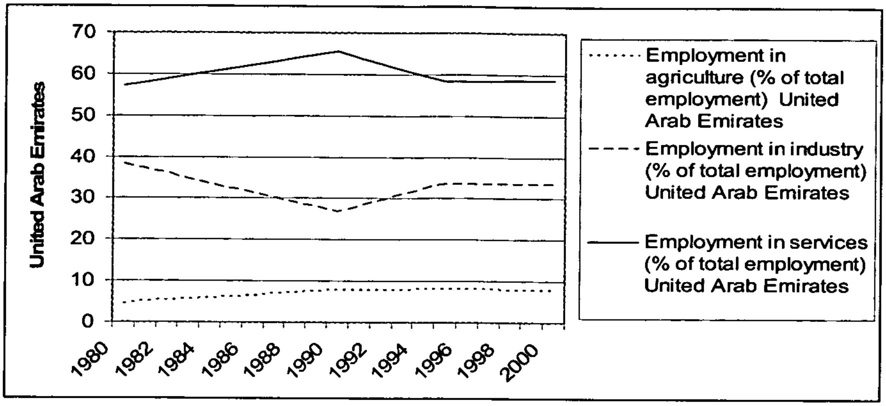
It is at this point that we would like to give our story of what could possibly generate the results we have seen above. Nevertheless, at this point we would also like to supply a caveat regarding the subsequent story. We realize that the story we give can in no way be comprehensive, but we do believe that at least a large portion of the reasoning behind the aforementioned results can be inferred from what follows.

The fact that the empirical results attained suggest that countries with water resources below 500 m^3 per year are not only wealthier (even after controlling for oil reserves), but have higher levels of investment, may seem a puzzle. On the other hand, a possible explanation could reside in the fact that many of the extreme countries show significant employment trends out of agriculture, a relatively water intensive industry, and into the service sector, which is far less water intensive. Contrasting this trend is the fact that, in general, the countries with water resources between 500 and 1,600 m^3 show at most a negligible movement out of agriculture while in most cases maintaining a modest to weak increase in the service sector.

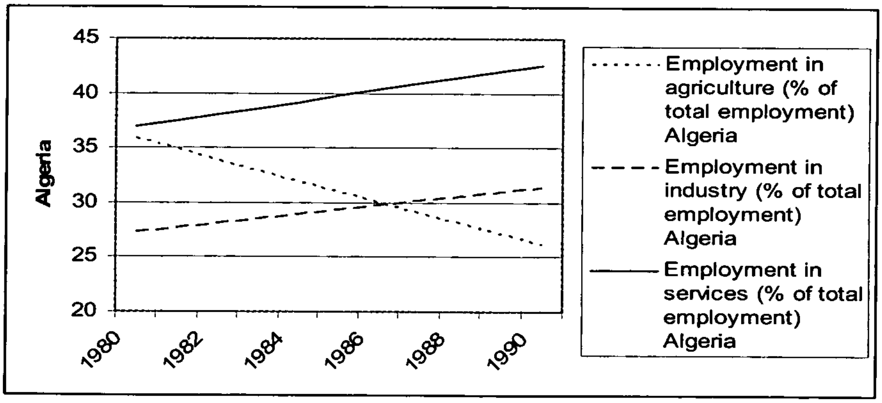
All of the data for the figures below were obtained from the World Bank's World Development Indicators. No observations were available before 1980 for any country; to fill in the decadal gaps we used moving averages. In addition, data for several entire countries were missing, resulting in the deletion of those countries from the analyses. Nevertheless, very informative general trends do appear. Figure 1 below plots employment in the agriculture, services, and industrial sectors as a percentage of total employment for the countries with water resources below 500 m^3.

Figure 1: Countries with Less Than 500 m³ in Water Resources

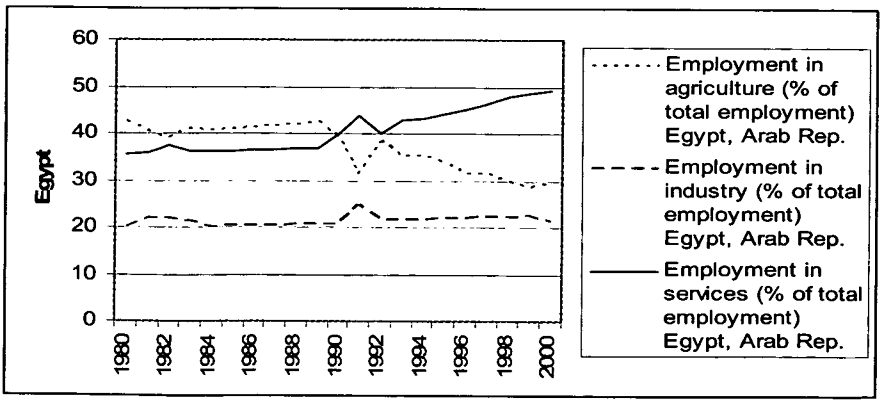
United Arab Emirates



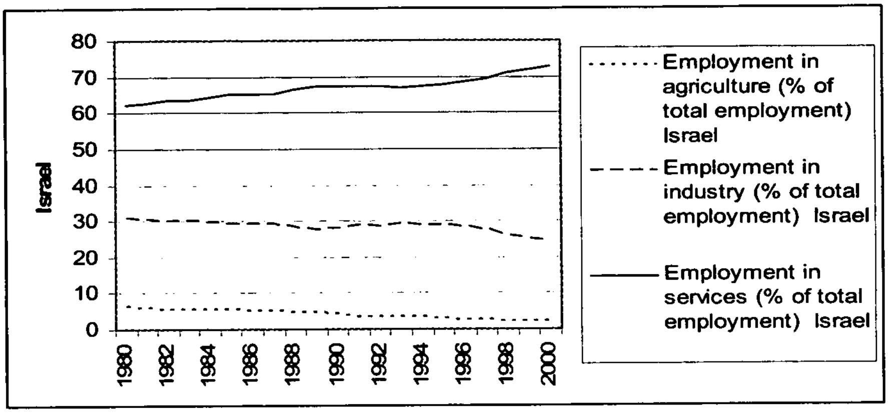
Algeria



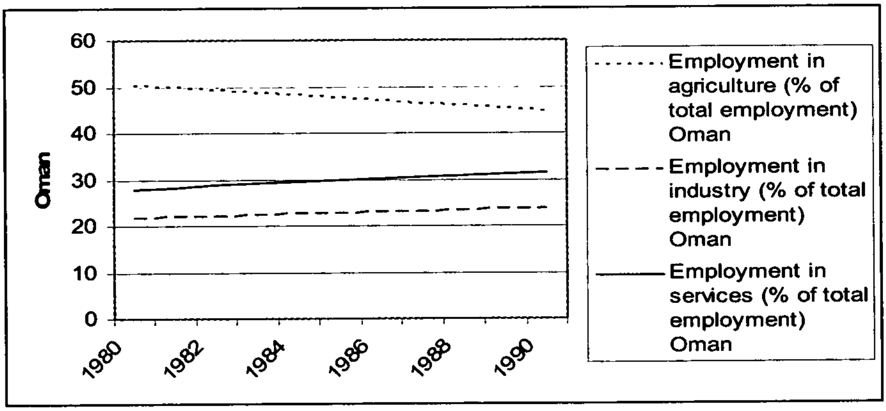
Egypt



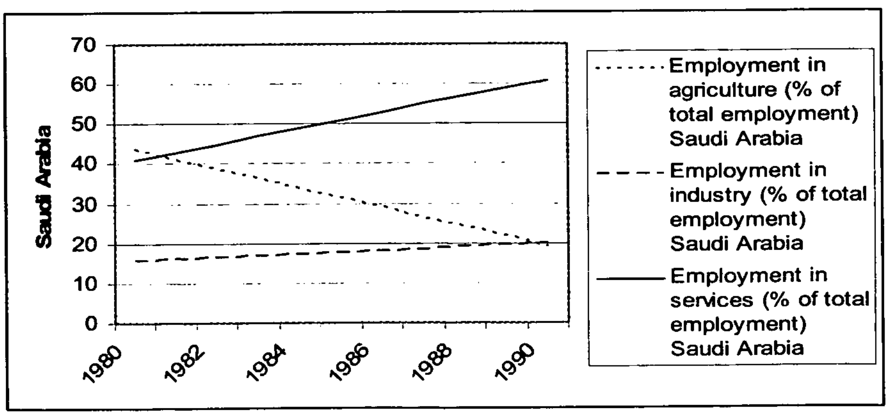
Israel



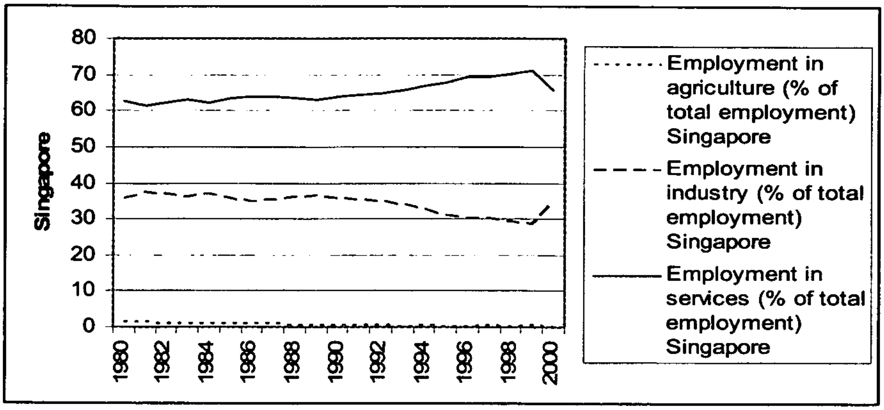
Oman



Saudi Arabia



Singapore

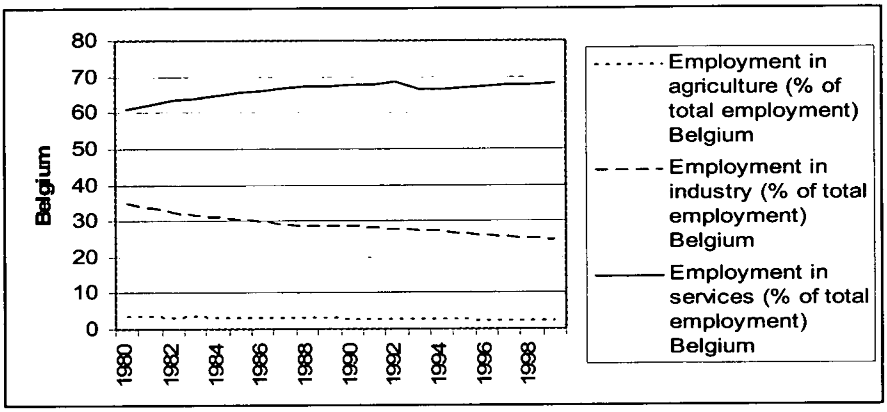


It becomes obvious that significant downward trending in agriculture appears over the entire available time period for all countries except for the United Arab Emirates and Singapore (the change in Singapore is slight due to the fact that it is primarily a city-state with very little agricultural production). From 1980 to 1990, Algeria cut its employment in agriculture by about 30%, with an over 25% reduction for Egypt in the 1990s, a nearly 50% cut in Israel over both decades, and over a 50% cut in Saudi Arabia in the 1980s. A more modest cut occurred in Oman (about 10%). Movement out of employment in agriculture, however, does not necessarily imply movement into less water intensive sectors, but examining the dynamics in industry and service may give us a clue.

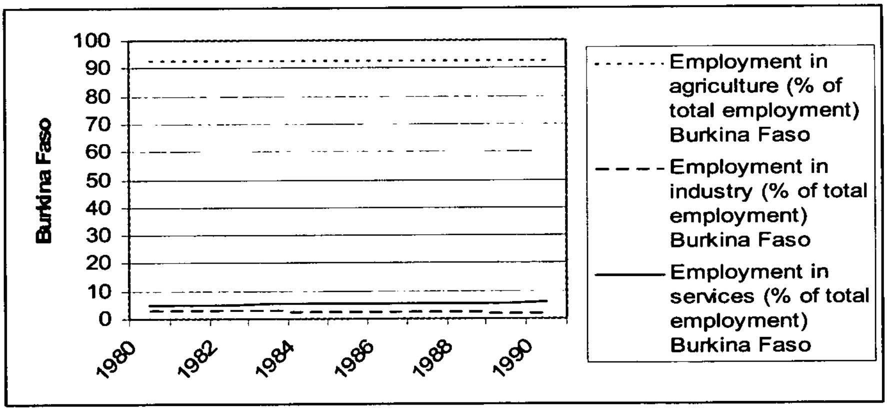
For the United Arab Emirates and Singapore, it appears as though movement between sectors is isolated to movements between the services and industrial sectors with little or no movement in agriculture. For Algeria, Egypt, Israel, Oman, and Saudi Arabia, most of the movement seems to be directly from the agricultural sector into the industrial and service sectors with an emphasis on the service sector. This emphasis on services is particularly pronounced in Egypt, Algeria, Oman, and Saudi Arabia where employment in the industrial sector grows only modestly with significant decreases in agriculture. In fact, in these countries the positive trend in services almost mirrors the negative trend in agriculture; but, do these trends necessarily show the possibility of a redirection of resources from water intensive uses to non-intensive uses relative to the stressed and scarce countries? Or are these trends simply reflecting a global trend from agriculture to industry? An examination of trends in countries with water resources between 500 and 1,600 m^3 should provide some answers to these questions.

Figure 2: Countries with between 500 and 1,600 m³ in Water Resources

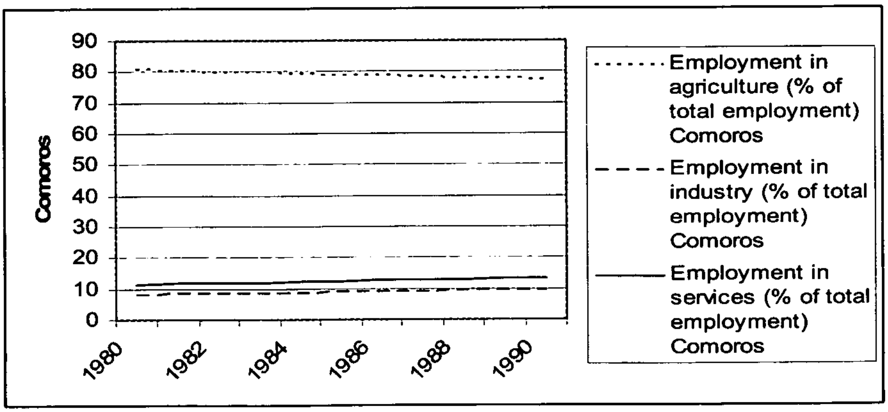
Belgium



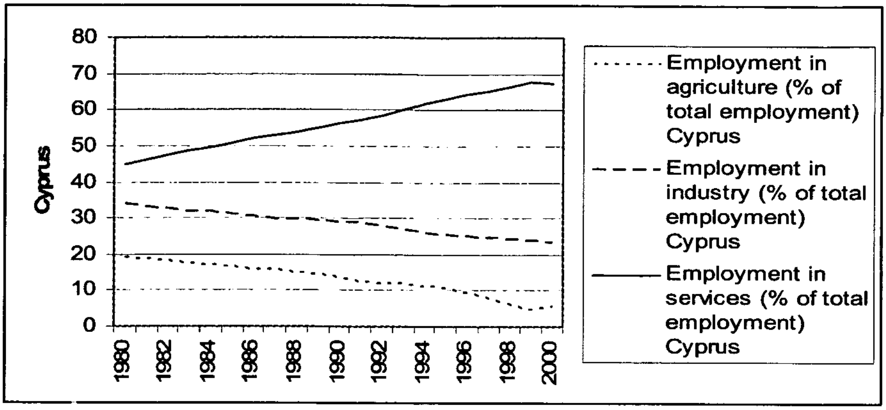
Burkina Faso



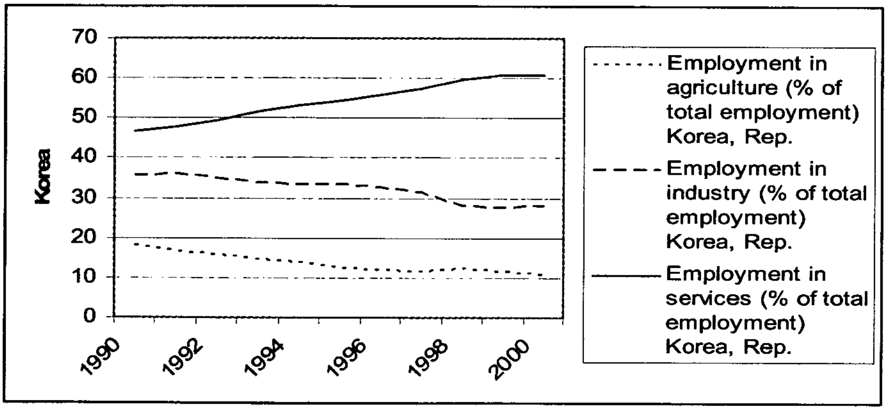
Comoros



Cyprus



Korea



Morocco

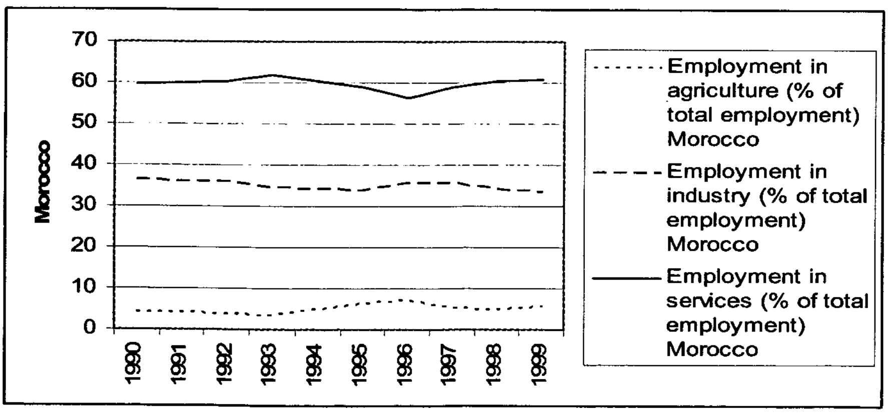
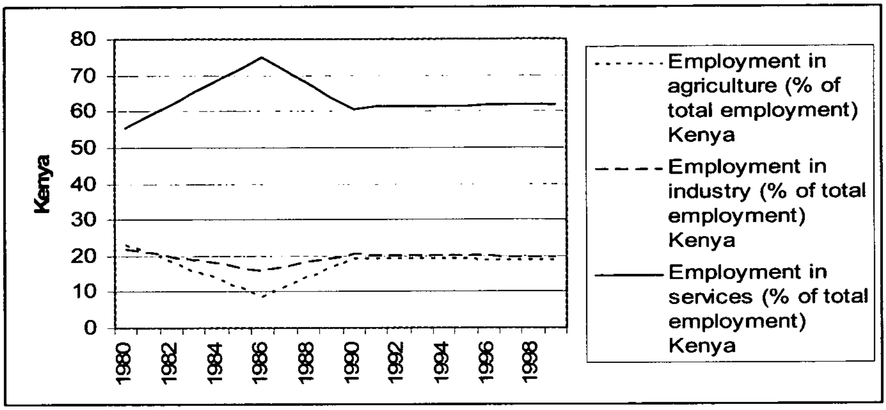
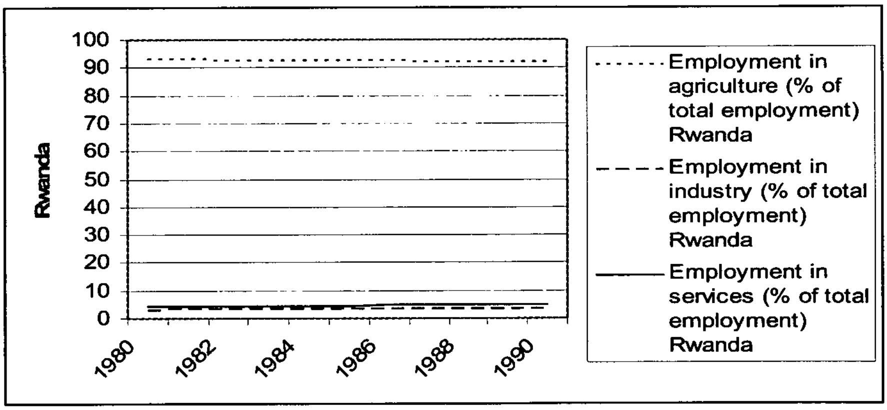


Figure 3: Water Scarce Countries

Kenya



Rwanda



Unlike the plots of the countries in Figure 1, it becomes apparent in Figure 2 that only Cyprus and Korea have significant downward trends in agriculture (about 30% for Cyprus and 40% for Korea) with closely reflecting upward trends in services. The trends in agriculture in the remaining countries appear remarkably stable. To this end, the contrast between Figures 1 and 2 seems to suggest that there does appear to be a general movement out of water intensive agriculture and into less water intensive services when a particular country experiences extremely low levels of water availability. If the service sector is more productive and offers higher wages than the agricultural sector, then estimates as we saw in Table 6 take on a reasonable light.

V. CONCLUSION

It is a widely held belief that many arid and semiarid countries are currently at a point where the quantity and quality of freshwater resources are forming physical constraints that limit the present use of the resource, hindering economic growth and development. This is why these countries are now facing the challenge of reforming their existing water management policies and short-term and long-term strategies as well as the social and political institutions that implement them.

Although water resources should be a central issue in the discussion of economic growth and development, there are very few studies that attempt to estimate this relationship. This article utilizes a cross-country data set from 94 countries to estimate the impact of water scarcity (measured by the Falkenmark Index) on per capita real GDP, growth in per capita real GDP, and investment during a time period that spans from 1980 until 1999. We find that, in general, water availability did not have an impact on growth in real output during the 1980s in a statistically significant fashion. Countries with per capita water availability ranging between 500 m^3 and 1,000 m^3, however, did experience lower growth than countries with per capita water availability below 500 m^3 in the 1990s. Moreover, we find that increased water availability in most developing countries is consistent with lower per capita GDP than countries with water availability below 500 m^3. When measuring the resource's impact on investment, we also find that countries with availability below 500 m^3 had higher levels of investment; this was true across both decades with a large negative impact on investment for countries with 500 to 1,000 m^3 in the 1990s.

Our results suggest that countries suffering most from water scarcity have outperformed countries with less water scarcity. This conclusion seems illogical when one considers water as a factor input in production. The prudent explanation to this phenomenon hinges on the notion that water scarcity is triggering innovative approaches to water management in countries that suffer its adverse effects the most. In other words, countries with less than 500 m^3 per capita water availability have engaged in a serious reallocation of their limited water supply away from low-valued uses and into uses generating greater *value marginal product* within and across sectors. This is not suggesting that countries with greater water availability are wasting their valuable resource. In fact, many of the countries in the 500 to 1,600 m^3 range have instituted water policy reforms of some type—many of which are sponsored by non-profit organizations and international agencies. But this does suggest that countries near, but still above the water barrier are at this

time not motivated to take part in the transition from more to less water-intensive sectors of the economy.

To repeat the policy adjustment put forth in the Introduction, a policy implication of this article would simply be to try to encourage the countries facing the water barrier to start soon in implementing strategies to make this transition and to minimize the use of financial resources in alternative water attainment. In this study we did make the unrealistic assumption that water availability as measured by the Falkenmark index was time invariant over both decades. This assumption is clearly false at least over the long run. Eventually, the countries in the 500 to 1,600 m^3 group will migrate into the water barrier to economic growth and probably be naturally guided by the "invisible hand" into less water intensive sectors that produce higher incomes and greater development. But this scenario may take a while. To implement these strategies now would speed the development process and lower poverty levels and increase the well-being of agents in these countries.

APPENDIX 1: COUNTRIES LISTED BY WATER CONSTRAINTS ACCORDING TO FALKENMARK INDEX

Water Extreme	Water Stressed	Water Scarce
United Arab Emirates	Belgium	Burundi
Bahrain	Burkina Faso	Kenya
Algeria	Comoros	Rwanda
Egypt, Arab Rep.	Cyprus	
Israel	Haiti	
Jordan	Korea, Rep.	
Oman	Morocco	
Saudi Arabia	Zimbabwe	
Singapore		
Tunisia		