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Freshwater Resources and the Agricultural Sector

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Abstract

Freshwater is depleted very rapidly, which will adversely affect the world economy. Agriculture will be the sector most affected by future water shortages. Therefore, it is essential to model water utilisation and the agricultural industry. This paper examines the two relationships between water scarcity and agricultural growth. First is a neoclassical model where freshwater is taken as a factor of production in the agricultural sector. The second model is an Environmental Kuznets Curve model, where agrarian output takes freshwater depletion as an environmental degradation. Using EU member countries' data, it was found that water utilisation and agricultural production have a robust inverted U-shaped relationship. The significant proof was that water scarcity followed the EKC trend with agricultural output. For the econometric analysis, panel data regression with endogenous covariates was used.

Keywords: *Water resource · Environment · EKC · Agriculture · Neoclassical Growth model*

Introduction

Water is essential for human existence. We use water daily, and it is an intricate part of a functional economy. We know that the Earth is a blue planet, and about 75% is covered by water. This might make people think that water scarcity should not be a problem. However, of that 75% of Earth's water, only 1% is available for human consumption and production. Freshwater resources are finite; however, water demand is not. The stress on freshwater resources will increase significantly in the near future with the growing population, climate change, and urbanisation (Alcamo et al., 2007; Hoekstra, 2014). Over the last century, water

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use has increased more than double the rate of population increase. Water scarcity today already weakens economic prosperity in many countries. Accounting for population growth alone, 46% of the world population will live in countries with severe water scarcity by 2050 (World Bank, 2016). Climate change will further amplify this problem; renewable water resources will be affected by the projected temperature change, precipitation pattern, and other climate variables (Damania & Roson, 2017). Global water demand is projected to surge by 55% by 2050, making water the most extremely challenging resource on Earth (OECD, 2013). Freshwater resources are finite, but their demand is multiplying with population and economic growth.

The most considerable effect of water scarcity will be on agriculture. Agriculture is the most water-intensive sector. Intensified water constraints could mean a threat to food and nutrition security. Out of all global freshwater withdrawals, agriculture accounts for about 72% (UN-Water, 2021). 3.2 billion people live in arable areas with high water scarcity, of which 1.2 billion live in severe water-scarce agricultural regions. The effect on agriculture is relevant because, in developing countries, agriculture is the dominant part of the countries' gross domestic product (Aksoy & Ng, 2010). Studies show that because developing economies depend on agricultural production, future water shortages will stunt the economies' growth and cause wider global inequality (Aksoy & Ng, 2010). Also, due to globalisation and international trade, a shock to agricultural production will have worldwide consequences. Therefore, understanding future freshwater trends and agricultural growth worldwide is vital for policymaking. There is evidence that water affects agrarian growth. Auffhammer et al. (2006) and Fishman (2016) found that rainfall and temperature affect Kharif-rich production in India. There is also strong evidence of a positive correlation between accumulated rainfall and rice production in Thailand, the Philippines, and Indonesia (Sawano et al., 2008; Koide et al., 2013; Naylor et al., 2007).

There is very little research on the effect of water scarcity on the agricultural sector. This paper will try to answer this question in two different ways. The first way is to find the relationship between agricultural growth and freshwater water utilisation. The model should explain how water utilisation can be modelled into the agricultural output model. The second way is to find empirically if there is an EKC relationship between water utilisation and agricultural growth.

EKC studies showed a possible inverted U-shaped relationship between freshwater utilisation and agricultural growth (Katz, 2015). Water use will increase in the first stage of agrarian growth and decrease after a specific turning point. Studying this relationship can answer some questions about water resource management in agriculture. There can be two significant reasons for restricted water utilisation; the first is that there can be an absolute lack of water. Secondly, as water becomes scarce, public institutions will restrict public water use. So, it can be hypothesised that freshwater use and agricultural output follow an EKC path. The reciprocal linkage between environmental performance and economic development is integral to economic research. Grossman and Krueger (1995) said, "Our lives are affected by the air we breathe, the water we drink, the beauty we observe in nature, and the diversity of species, "which means ecological quality is vital to the human race. Since the Industrial Revolution, there has been a heightened public concern for environmental degradation. For example, global warming is the by-product of the Industrial Revolution, using extensive fossil fuels to power economic growth (Uchiyama, 2016). In the 21st century, we are in an ecological overshoot; the demand for environmental resources is higher than the available supply worldwide (WWF, 2016). Deforestation, erosion, extinction, and renewable water shortages are all due to ecological overshoot.

Therefore, understanding the mechanism driving environmental degradation is necessary now more than ever. Recent research is trying to push the econometric relationship between GDP and various indicators of environmental quality. Much research postulated an inverted-U relationship between economic growth and ecological damages called the Environmental Kuznets Curve. Most EKC research is on air pollutants and water pollutants, but very few shed light on how the economy will behave when freshwater starts to exhaust. This paper looks into this problem and will check if there is an EKC relationship.

Water significantly impacts economic growth, and the lack of fresh water already constrains economic growth in China and India (Pacific Institute, 2007). Modelling the relationship between water utilisation and agricultural development requires us to define water as a government-provided non-excludable production input. Also, to model water scarcity, water utilisation will be subject to congestion. Using the approach of Barro (1990) and Barro and Sala-I-Martin (1992), a model for agricultural growth, including public good water, can be hypothesised. There are two fundamental ways water scarcity will affect the farm sector. First, when water starts to become scarce in the agricultural industry, the government will intervene to allocate water efficiently to the farms. The second factor is an absolute restriction on water use due to availability. So, in the model, there is a binding factor if the country's agriculture sector has water constraints. Barbier (2004) used water usage and its impact on economic growth. However, his data set was limited, and the economist called for further analysis. Few empirical papers have provided evidence of a robust relationship between water usage and agricultural output.

Using data from 27 EU member countries, I have set up an econometric analysis to understand the relationship between water usage and the agricultural sector. The results showed a robust relationship between the two types of water and agriculture models.

This paper is set as follows. The next section will review some literature on the theoretical and empirical studies of the Environmental Kuznets Curve. The first part of Chapter III will introduce a simple neoclassical growth model for agriculture using agricultural water stress as an input. The second part of this section will show the econometric framework to prove the model. Chapter IV will show the results of the econometric analysis, and this section will also consist of a regression that proves that water scarcity also follows the EKC. Chapter V will discuss some critical problems with the agricultural growth model and critique the EKC. Chapter VI consists of the conclusion and future research recommendations.

Literature Review of the Environmental Kuznets Curve

In the mid-1950s, economist Simon Kuznets hypothesised that income inequality should follow an inverted U-shaped trajectory with economic development. Grossman and Krueger, Shafik and Bandyopadhya, and Panayotou were the first researchers to find an inverted U-shaped connection between environmental evolvement and economic growth. Panayotou was the first to name the U-shaped relationship the Environmental Kuznets Curve (EKC). The Environmental Kuznets Curve is a hypothesised association between environmental degradation and economic growth. Ecological degradation accumulates with economic development at the initial stages, but pollution decreases with an increase beyond a turning point. It means that at the beginning of industrialisation, inequality will rise because of immobile workers and decline as more and more workers join the productive sectors (Kuznets, 1955).

There are a few possible reasons for the shape of the EKC. The first reason is the equity of income distribution. Simon Kuznets first hypothesised the relationship between economic growth and income distribution. Similarly, economic growth can make the average citizen better off. Economic development makes more of the population aware of the environment, preferring less environmentally harmful options. Torras and Boyce (1998) said pollution would be reduced if the power gap between agents who benefit from it and agents burdened by pollution decreases. Therefore, if income inequality decreases, so will environmental degradation. Empowering agents that bear the burden of environmental degradation will improve the environment. Empowering agents can be done through education and equitable income distribution (Bimonte, 2002). Bimonte (2002) uses data from countries in the last phase of economic development to estimate the EKC. He found that the shape and level of the EKC curve depend on the population's participation during the growth process. Education, information access, and income inequality can shift the EKC curve. This is why countries with a similar level of growth can have widely different pollution levels. Magnani (2000) found a significant inverted U-shaped relationship between income inequality and expenditure on environmental protection research in OECD countries. Therefore, the descending slope of the EKC will appear if the economic growth does not increase income inequality. Cantore and Padilia (2010) found a robust correlation between income distribution and pollutant emissions. To find an EKC-shaped relationship, Coondoo and Dinda (2008) used European countries' data on inter-country income inequality and carbon dioxide emissions. However, due to the data structure and availability, it is impossible to significantly say that the citizen's perception of environmental degradation changes with a change in income distribution.

The second reason for the EKC pattern can be variations in consumer preferences due to changes in income. Andreoni and Levinson (1998) used a static partial equilibrium model of consumers' preference between maximising consumption and minimising investment for abating pollution. They found that investment will increase with income so that the EKC shape can arise. An increase in the average income of citizens can change the elasticity of demand for environmental quality. Lopez (1994) used a static general equilibrium model where output and welfare are attributes of the environment quality; he found that non-homothetic utility functions may cause the EKC. If the elasticity of demand for better environmental quality is more significant than unity, increased wealth or income will make consumers move to environmental options (Dinda, 2004). In Sweden, Kander and Lindmark (2004) estimated that after 1970, the population put a higher value on environmental quality and caused policy changes to prevent pollution. However, Martini and Tiezzi (2010) found that the income elasticity of willingness to pay for the quality environment in Italian households was less than or equal to unity. The consumer income–pollution relationship is complicated to analyse on a macroeconomic level because consumer preferences are based on microeconomic foundations (McConnell, 1997).

Technological progress or structural changes are another primary reason behind the inverted U-shaped relationship. Technological advancement includes developing environmentally favourable production technology, which releases fewer pollutants or requires fewer polluting inputs. The structural change consists of changing primary industries in the economy, transferring from polluting industries (manufacturing or mining industries) to less pollution-intensive industries (information or service-based industries). The economic scale effect is that more resources and energy consumption will increase environmental degradation through pollution or depletion when growth occurs. The scale effect causes the upward trend of the EKC curve when an economy shifts from primary to secondary production. At this stage, the economy has the resources to invest in better modes of production or can change to tertiary industries. This shift is termed the composition and technique effect. The composition effect means environmental degradation will increase when an economy shifts from agrarian to manufacturing. However, production initially increases ecological degradation when the economy develops and moves from manufacturing to an information or service-based economy. However, it falls when the economy shifts to a more environmentally friendly industry (Panayotau, 2003). The technological effect occurs when the economy adopts better ecologically friendly technology through research and development (Neumayer, 1998). Technological or composition effects concentrate on production, not consumption so that it may depend on business-cycle fluctuations or market mechanisms (Bouvier, 2004; Smulders et al., 2010). When the composition and technique effect exceeds the scale effect, the economy will be at the turning point of the EKC and will start its downward-sloping path (Dinda, 2004). Jaeger (1998) specifies a general equilibrium model where the choice is between a clean or polluting production method; he concluded that when income level increases, abundant and polluting resources start to get scarce, so agents move to cleaner and more efficient technology over a period of time. John and Pecchenino (1994) used a dynamic overlapping generational model with environmental degradation as an attribute of utility; they found that at low-income levels, no environmental investment is optimal. However, as income increases, capital stock accumulation related to better environmental quality leads to EKC. Jones and Manuelli (1995) also used a dynamic overlapping generational model; pollution is a by-product of capital use and enters the utility function in the model. Producers have a choice between clean methods or pollution-releasing technology. Pollution taxes and standards are also specified in the model. Optimal taxes and standards policy will cause producers to choose environmentally friendly inputs, resulting in the EKC. Stokey (1998) proposed a dynamic infinite horizon model two-country growth model where pollution is an attribute of utility, and environmental degradation is a production waste product. He found a critical value in which the technological effect is the turning point of the inverted U-shaped relationship. Dinda et al. (2000) observed suspended particulate matter and sulphur dioxide levels across regions and time. They found that the pollution level can be attributed to changes in production technology and sectoral composition. Hattige et al. (2000) used industry water pollution data and industry share in total production as an explanatory variable. The relation follows an inverted U-shaped trajectory.

The institutional framework can also be a fundamental reason behind the EKC pattern. The primary theory behind the institutional framework is that as the economy grows, the government is keener and has the budget to impose policies that prevent market failure due to pollution. However, whether such policy changes will decrease environmental degradation is unclear and depends mainly on social institutions and functional markets. Dutt (2009) found an EKC pattern in developed countries with more potent institutions. Bhattarai and Hammig (2001) researched tropical deforestation and found that institutional factors are much more significant in decreasing deforestation than other macroeconomic factors. The last reason economists found was the international trade and pollution haven hypothesis. International trade increases the economy's production capacity through comparative or absolute advantage. Higher production causes pollution. When environmental degradation rises primarily due to higher pollution, stricter anti-pollution legislation will be imposed. These regulations will shift them from now expensive domestic production due to legislation to importing from other countries with fewer regulations. This transition from manufacturing to importing is known as the pollution haven hypothesis because domestic pollution is declining. Suri and Chapman (1998) used a model with the proportion of imports and exports to GDP as another explanatory variable for income. They found strong evidence that trade shifts the EKC for carbon dioxide.

Much empirical research proves the existence of the EKC and the relationship between carbon dioxide emissions. Carson et al. (1997) used 1990 cross-sectional data in the US states and found a significant inverted U-shaped relationship between carbon emission and economic growth. Roberts and Grimes (1997) used data from low-medium-high-income countries and other social-political factors as parameters. They found that wealthy countries followed the EKC trend, but low- and medium-income countries did not show any inverted U-relationship with GDP and carbon dioxide emissions. Galeotti et al. (2006) find evidence of EKC for OECD countries but not for non-OECD countries. Coondoo and Dinda (2008) used panel data from 1960-2000 from 88 countries and inter-country income inequality as an explanatory variable. They found that only European countries follow the EKC trajectory of income and emissions.

Villanueva (2012) examined the impact of structural and government institutional quality on the environment and supported the EKC hypothesis. Lee et al. (2009) incorporated the pollution haven hypothesis in their econometric model. They used panel data from 1960- 2000 from 88 countries. The panel found an N-shaped relationship between carbon dioxide emissions and per capita income and an inverted U-shaped relationship between middle-income, American, and European countries. Dutt (2009) took 1960- 2002 panel data from 124 countries. He used other parameters like the political institution, socio-economic conditions and education. From 1960- to 1980, data showed a positive relationship between economic growth and emissions, but from 1984 to 2002, the association was an inverted U-shaped. Taguchi (2012) found that sulphur emissions follow the expected EKC shape, but carbon dioxide emissions correlate positively with economic growth. Perman and Stern (2003) used cointegration and unit root tests and found that sulphur emissions follow an inverted U-shaped relationship in the long run. Osabuhien et al. (2013) found that social and institutional quality, international trade, and economic growth can jointly provide evidence for EKC in the long run in Africa.

Some empirical evidence found inconclusive relationships or a positive relationship between environmental degradation. Azomahou and Van Phu (2001) researched panel data on 100 countries from 1960- 1996 and found a positive relationship between economic growth and carbon dioxide emissions. De Bruyn et al. (1998) used data from the Netherlands, West Germany, the UK and the USA and used other parameters like population, technology, and structural changes. The time series regression results gave a robust positive relationship between income per capita and emissions. Egli (2002) used time-series data from 1966- 1998 in Germany and found an inconclusive relationship between income and carbon dioxide emissions. Halicioglu (2009) used time-series data from Turkey and used energy consumption and foreign trade as the other explanatory; he found a robust positive relationship. Few pieces of research were devoted to fixing the econometric issues. Roberts and Grimes (1997), Moomaw and Unrug (1997), Cole et al. (1997), and List and Gallet (1999) found that changing the data structure changes the results of EKC research. For example, if cross-sectional data is substituted with time-series data and regional data with country-specific data, the turning point of the EKC changes. In some cases, there is no inverted U-shaped relationship.

There is extensive literature on pollution and economic growth, mainly the relationship between carbon dioxide emissions and economic development. There are also a few pieces of research on water pollution and economic growth. Most studies based on water pollution and economic growth showed an ambiguous inverted U-relationship. Farzin and Grogan (2012) used data from California State to find the relationship between income and water pollution. They also included main socio-economic factors, like agricultural intensity, land use, educational attainment, ethnic composition, and population density. Phosphorous and suspended solids are robust determinants of water quality. However, they found no proof of the EKC relationship. Shen and Hashimoto (2004) found an EKC relationship between most water pollutants in China. However, the relationship is N-shaped for dust fall and industrial waste stock. Barua and Hubacek (2008) performed GLS and GMM estimation on 20 (1981-2001) years of panel data from India. They did not find substantial evidence of an inverted U-shaped relationship between per capita income and water quality. They found that reducing water pollution during economic growth is short-lived; the pollution rises further with economic growth. Paudel et al. (2005) performed parametric and semiparametric regression models on watershed-level data of the Lousiana state. They found an N-shaped relationship between pollution (nitrogen, phosphorous and dissolved oxygen concentrations) and GDP per capita. Lee et al. (2009) performed a GMM analysis to find the EKC relationship between real income and biological oxygen demand emissions. They have an inverted U-shaped relationship in America and Europe, but no evidence of EKC exists in Asia, Africa, or Oceania. Although most of the research was between water pollution and economic growth, there is little research on the relationship between renewable water resources and agriculture. Section IV will use the ideas and econometric methods of the EKC literature to find if agricultural growth and renewable water resources follow the inverted U-shaped relationship.

Methodology for Modelling Agricultural Growth and Water Utilisation

I. Neoclassical Model of Renewable water use and Agricultural output

Using concepts from Barro (1990) and Barro and Salam-I-Martin (1992), we can set up a neoclassical growth model to model an economy's renewable water use and agricultural growth.

Given the constraints, the model will be a social planner's problem maximising the utility of a unit-mass continuum of identical utility-maximising households. The social planner will find an optimal path by choosing the present and future allocation of agricultural consumption and using freshwater resources to maximise social welfare. The identical preferences over an infinite time horizon are $U = \int_{t=0}^{\infty} \beta^t \, u\,(\,c_t\,)$

β is the time constant discount factor, with $\beta \in (\,0, 1\,)$

$u\,(\,c_t\,)$ for this model is assumed to be Constant Relative Risk Aversion, so

$$u\,(\,c_t\,) = \frac{c_t^{1-\theta}}{1-\theta}$$

θ is the parameter that measures the degree of relative risk aversion implicit in the utility function. If we find the marginal rate of substitution between time period t and t+1

$$\frac{c_t}{c_{t+1}} = (\frac{u'(c_t)}{u'(c_{t+1})})^{1/\theta}$$

For the CRRA utility function, the elasticity of substitution is constant, $1/\theta$. The CRRA's other properties are $u'(c_t) > 0$ and $u''(c_t) < 0$. Which means the utility function is concave. Also, to guarantee stable agricultural growth in the neoclassical growth model, the utility function needs to satisfy the Inada conditions, and CRRA does satisfy it

$$\lim_{c_t \to 0+} u'(c_t) = \infty \qquad and \qquad \lim_{c_t \to \infty} u'(c_t) = 0$$

Water for agriculture and irrigation is modelled as a nonexcludable public good subject to overcrowding. Producer y_i can produce

$$y_i = Akf(\frac{w}{Y})$$

Where $A > 0$ is the parameter that reflects agricultural technology (this includes irrigation technology, fertilisers, land efficiency, etc.). k to simplify the model includes both human and physical capital stock used in agricultural output. Y is the total agricultural production, and as all the producers are identical, $Y = \sum_{i=1}^{N} y_i$ (N is the total number of producers). f is the production function and should have these properties $f' > 0 \; and \; f'' < 0$, so the production function is concave. Also, the production function should satisfy the Inada conditions for the stability of the model

$$\lim_{c_t \to 0+} f' = \infty \qquad and \qquad \lim_{c_t \to \infty} f' = 0$$

In the model, the production function depends on the ratio $\frac{w}{Y}$ because agricultural water utilisation must increase compared to agricultural output Y to increase individual agricultural output. Similarly, a relatively higher increase in total agricultural output per capita than total water utilisation will reduce production. This production function captures the non-excludable and overcrowding aspect of water utilisation among producers. To supply water, there are costs to build pipes, dams, pumping stations, etc. So, we can model the water utilisation of agriculture as a share of total agricultural output. $0 < \alpha < 1$ can be the share of agricultural output devoted to water supply. So renewable water utilisation is equal to $w = \alpha Y$. $\phi = \frac{w}{W}$ is the rate of water utilisation relative to total renewable water resources. So, $w = \alpha(\phi)Y$ and we can impose the constraint $w = \alpha(\phi)Y \leq W$.

$$\alpha(\phi)Y < W \; if \; 0 \leq \phi < 1$$

$$\alpha(\phi)Y = W \; if \; \phi = 1$$

$\alpha'(\phi) > 0$ and $\alpha''(\phi) > 0$, the proportion of agricultural output used to fund the water supply is assumed to be an increasing function concerning the $\frac{w}{W}$. α is an increasing function of ϕ because it is assumed that as water scarcity increases, so will the cost of appropriation of freshwater. Also, when aggregate agriculture rises, so will water utilisation; $\phi \to 1$, and α will reach its upper bound γ.

Last, we need the dynamics of k

$$\Delta k_t = y_t - c_t - w - (n + \tau)k_t$$

Δk_t is the change in capital stock per capita. n and τ are the population growth and depreciation of capital, respectively. $\Delta k_t = 0$ when consumption equals the difference between the agricultural output and investments.

The Lagrangian can be set up to find the values of c and ϕ that maximise the utility function given the water utilisation and the consumer's budget constraints.

$$\mathcal{L} = \int_{t=0}^{\infty} \frac{c_t^{1-\theta}}{1-\theta} - \lambda_t [\, y_t - c_t - w - (n+\tau)k_t \,] - \mu_t [\, W - w \,]$$

$$\Rightarrow \mathcal{L} = \int_{t=0}^{\infty} \frac{c_t^{1-\theta}}{1-\theta} - \lambda_t \left[\, Akf(\frac{W}{Y}) - c_t - w - (n+\tau)k_t \,\right] - \mu_t [\, W - w \,]$$

f can be written as a function of $\alpha(\phi)$ so the Lagrangian can be written as

$$\mathcal{L} = \int_{t=0}^{\infty} \frac{c_t^{1-\theta}}{1-\theta} - \lambda_t [\, Akf(\,\alpha(\phi)\,) - c_t - \alpha(\phi) Akf(\,\alpha(\phi)\,) - (n+\tau)k_t \,] \\ - \mu_t [-W + \alpha(\phi) Akf(\,\alpha(\phi)\,)\,]$$

So, the first-order conditions are

1: $c_t^{-\theta} = \lambda_t$. This is the standard condition that the marginal utility of consumption is equal to the Lagrange multiplier

2: $\lambda_t [\,(1-\alpha) Akf'\alpha'\,] - \lambda_t Akf\alpha' = \mu_t [\alpha' Akf + \ \alpha Akf'\alpha'\,]$ this equation determines the optimal water utilisation decision.

$\mu_t \geq 0 \; or \; W - \alpha(\phi) Akf\big(\alpha(\phi)\big) \geq 0 \; and \; \mu_t \big[W - \alpha(\phi) Akf\big(\alpha(\phi)\big)\big] = 0$ this is the complementary slackness conditions (Kuhn-Tucker condition) imposed by the water scarcity constraint.

3:

$$\beta \lambda_{t+1} = \lambda_t [\,(1-\alpha)Af - (n+\tau)\,] + \mu_t \alpha Af$$

$$\Rightarrow \ \beta c_{t+1}^{-\theta} = c_t^{-\theta} [\,(1-\alpha)Af - (n+\tau)\,] + \mu_t \alpha Af$$

This equation shows the consumption trajectory given the agricultural capital stock.

4: $\lim_{t \to \infty} \beta \lambda_t k_t = 0$ is the transversality condition that stops over-saving.

From these equations above, we can find the growth rate of consumption

$$g = \frac{\Delta c}{c} = \frac{1}{\beta\theta} [(1-\alpha)Af - (n+\tau)] - \mu \frac{\alpha Af}{c^{-\theta}}$$

The growth rate depends on whether the water scarcity constraint is binding. First, let us see what happens when the water scarcity is not binding, so $\mu = 0$.

$$g = \frac{1}{\beta\theta}[(1-\alpha)Af - (n+\tau)]$$

We can see that water scarcity is not affecting growth. If water scarcity constraint is not binding, the equation 2 becomes $[(1-\alpha)Akf'\alpha'] = \lambda_t Akf\alpha'$. There is no water scarcity, but water resources still affect growth through $\alpha(\phi)$. Water utilisation is negatively related to growth to $\alpha,$ which means more agricultural output is used to supply the water. Growth is positively related to the contribution of water utilisation to marginal productivity. The optimising rate of water utilisation relative to total water resources is θ^*. This should solve the equation 2; $[(1-\alpha(\theta^*))f'\alpha(\theta^*)'] = f\alpha(\theta^*)'$. When $\theta < \theta^*$, then $\partial g\partial\theta$>0, agricultural growth will increase with the increase in water utilisation. When $\theta > \theta^*$, then $\partial g\partial\theta$<0, agricultural growth will diminish with water utilisation. From here, we can see an inverted U-shaped relationship between renewable water use and agricultural growth, even when there is no water scarcity problem.

Now, when the water scarcity constraint is binding, $\mu_t > 0$. Complementary slackness requires $w = W$. So, the share of agricultural output appropriated for supply will reach its upper bound $\alpha(1) = \gamma$. The growth rate for water constraint production

$$g = \frac{1}{\beta\theta}[(1-\gamma)Af(\gamma) - (n+\tau) - \mu\frac{\gamma Af(\gamma)}{\lambda}]$$

Growth is negatively affected by the share of agricultural output used to supply water and negatively affected by the water scarcity constraint. Growth is positively related to water use in productivity. Equation 2 becomes $\mu=\lambda[\ f'\gamma f\gamma+\gamma f'\gamma-1\ ]$, and by the complementary slackness condition $\lambda\left[\frac{f'(\gamma)}{f(\gamma)+\gamma f'(\gamma)} - 1\right] > 1$. So, the growth equation for

$$g = \frac{1}{\beta\theta}[(1-\gamma)Af(\gamma) - (n+\tau) - \gamma Af(\gamma)\left[\frac{f'(\gamma)}{f(\gamma)+\gamma f'(\gamma)} - 1\right]]$$

So, if $Af(\gamma) - (n+\tau) > Af(\gamma)[\frac{f'(\gamma)}{f(\gamma)+\gamma f'(\gamma)}]$, $g > 0$ and vice versa. During the water constraint situation, it is optimal to use the maximum rate of appropriation γ . Growth will only occur if the net marginal productivity of resources exceeds the negative effects of water scarcity. When there is a water constraint, we can see that water resources and agricultural growth can follow an inverted U-shaped relationship. Water is always important, so the marginal benefit of using water is always greater than the marginal cost of extracting water. Therefore, allocating the maximum amount of output to water extraction is optimal. However, whether this will lead to agricultural growth depends on the net marginal productivity of resources.

II. Econometric model

From the theoretical model above, we can assume that agricultural growth and freshwater relationship follows an inverted U-shaped relationship. We have to use data to back up the economic model theorised above. When water utilisation increases in the beginning, so will agricultural growth, then it will reach its maximum and decrease if water utilisation increases. From the theoretical framework above, we can reduce it to the postulated inverted-U quadratic functional form relationship between water utilisation and agricultural growth. Other exogenous shift variables can be incorporated, such as population, agricultural raw materials import, country-specific variables, etc.

$$Y_t = f(W_t, X_t)$$

Where W_t is the water utilisation rate of the agricultural economy (water withdrawal used in agriculture divided by the net water resources in the country). Y_t is the total agricultural output of the economy. X_t comprises the other exogenous factors affecting agrarian output. There can be two functional forms; one is the inverted relationship on levels, and the other one could be a quadratic relationship in logarithms. These equations are

$Y_{it} = \beta_1 + \alpha_i + \beta_2 W_{it} + \beta_3 W_{it}^2 + X_{it} + u_{it}$ relationship on levels

$lnY_{it} = \beta_1 + \alpha_i + \beta_2 lnW_{it} + \beta_3 \ln(W_{it})^2 + X_{it} + u_{it}$ relationship in logarithms

W_{it} denotes the water utilisation indicator for a country i in the year t. Y_{it} is the agricultural output indicator for a country i in the year t.

For this paper, I have used data from the EU member countries. There are 27 member countries in the EU. The data was taken from 1972 to 2017, with five-year gaps. The five-year gap is taken because the data available on water withdrawal are five-year averages. From AQUASTAT (2021), I found five-year averages of water stress data; this is the total water withdrawal as a proportion of available freshwater resources. I also extracted the percentage of water withdrawal used in agriculture. Using water stress and portion of water withdrawal used in agriculture data, I calculated the water stress for agriculture; this is W_{it} in our econometric analysis. Y_{it} is the agricultural growth data of the countries the World Bank (2021) found. Y_{it} using total agriculture output will also be used in the analysis. I $am\ using\ population, use\ of\ fertilizer\ in\ agriculture, the\ workforce\ in\ agriculture, etc,$ as shifter explanatory variables. The summary statistics of these data can be found in the table below.

Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
agriuse	189	6.645	9.366	.007	47.962
agri w use	189	24.616	27.624	.208	98.283
agri GDP	176	3.627	3.165	.245	20.477
agri growth	170	1.16	10.688	-27.069	47.821
agri raw imports	219	2.59	1.648	.251	9.053
population	270	15659454	20533390	302450	82657002
irrigated	48	8.459	9.806	.034	33.981
water stress	210	25.089	22.898	1.067	109.663
employ agri	179	591.276	814.545	1.807	4577.547
fertiliser	234	216.826	184.475	30.75	1349.008

agriuse = $\frac{\text{Argri\_w\_use}}{100} \times \text{water\_stress}$ = proportion of water used in agriculture and freshwater resources
agriuse = agriuse × agriuse
argri_w_use = proportion of withdrawal used in agriculture
agri_growth = agriculture, fishing, forestry value-added annual growth
agri_growth2 = agri_growth × agri_growth
agri_GDP = agriculture, fishing, forestry value-added current US$ in billions
agri_raw_imports = agricultural raw materials import percentage of merchandise imports
population = total population
irrigated = agriculture irrigated land percentage of total agricultural land
water_stress = freshwater withdrawal as a proportion of available freshwater resources
employ_agri = Total workforce employed in the agricultural sector in thousands
fertiliser = kilograms of fertiliser consumption per hectare of arable land.

α_i is the time-invariant country-specific error term that can be estimated. α_i is uncorrelated with the idiosyncratic shock u_{it}.

The hypothesised relationship is the relationship between W_{it}/lnW_{it} with Y_{it}/Y_{it}; if there is an inverted U-shaped relationship that is then regression results should be $\beta_2 > 0$ and $\beta_3 < 0$. The water utilisation level where the turning point occurs is $-\frac{\beta_2}{2\beta_3}$. If the regression is in logarithms, the turning point is $\exp\left(-\frac{\beta_2}{2\beta_3}\right)$.

Results

I. Econometric Analysis of the Water Utilisation – Agricultural Growth Model

Agricultural production consists of crop production and animal production. First, I wanted to see if the inverted U-shaped relationship holds for a few water-intensive agricultural products: cereal, wheat, barley, cattle meat, and sheep meat. The regression results of the crops and meat output on water utilisation and water utilisation squared.

	(1) cereal_pro	(2) wheat_pro	(3) barley_pro	(4) cattle_meat	(5) sheep_meat
agriuse	-14065.916	-7499.48	10788.463	47.286	-92.608
	(63474.599)	(32677.13)	(19043.009)	(1449.338)	(241.514)
agriuse2	1670.566	1163.18	-176.517	-68.323	-1.771
	(1797.755)	(1128.859)	(497.258)	(64.31)	(8.303)
_cons	10527171***	4483542***	2289016.2 ***	376202.6 ***	35157.328 ***
	(248755.74)	(145789.74)	(66191.658)	(5927.939)	(877.059)
Observations	163	160	160	160	160
R-squared	.019	.025	.005	.038	.009

Standard errors are in parentheses

**** p<.01, ** p<.05, * p<.1*

For the regressions above, Schaffer's (2010) Stata code xtivreg2 was used to determine whether the agriuse is endogenous. If it was, the endogenous instrumental variable was supposed to be used. The endogeneity test showed that this regression agriuse is unrelated to the idiosyncratic shock. Another test was done to check if the error term is homoscedastic or heteroscedastic across country groups. The null hypothesis is that $var(u_i) = var(u)$, where i is the country group. Modified Wald test for group wise heteroskedasticity was done, and it showed that there is groupwise heteroskedasticity. The reason for clustering is that each country in the EU can have different background characteristics due to each country's agricultural policies. Due to heteroskedasticity, cluster robust standard errors were used for inference. The regression table above shows that all the coefficients on agriuse and agriuse2 are statistically insignificant. This means that we cannot find any robust inverted U-shaped relationship. There could be a few reasons behind the absence of such a relationship. First, if there is water stress crop and animal meat, output productivity decreases (Osakabe, 2014), meaning that output will only decrease with increased water stress. Another reason is that there needs to be innovation in productivity when water becomes scarce to have an inverted U-shaped relationship. However, during the last few decades, there were few significant scientific breakthroughs on crops or meat using less water, so there is no reason to have an EKC relationship. The third reason is that this is based on EU data, and compared to the world, the EU produces fewer crops and meat and, therefore, could have less money spent on making output efficient. The same analysis based on areas with high crop or meat output might give different results. Fertiliser could also be used as a proxy for Y_{it} because if agricultural output increases so will the use of fertilisers. The regression results are below.

	(1) fertiliser
agriuse	-.375
	(3.556)
agriuse2	.019
	(.145)
_cons	223.445***
	(5.913)
Observations	163
R-squared	.001

Standard errors are in parentheses.

**** p<.01, ** p<.05, * p<.1*

The same post-estimation tests were used for this regression. There was no evidence for endogeneity; however, there is heterogeneity in the data, so cluster standard errors are used. We can see the results are insignificant. This means we cannot use fertiliser to model freshwater dynamics with agricultural growth. Fertilisers are correlated to water quality and not the availability of freshwater (Boretti & Rosa, 2019). Therefore, the regression result has some soundness behind it.

From the econometric model, Y_{it} could be agricultural growth or net agricultural output. Below is the analysis relating agricultural growth and water utilisation on levels and logarithms.

The above regression uses instrumental variables for agriuse and clustered standard errors. The regression above used the precipitation variable (National Rainfall Index) as an instrumental variable. The endogeneity test showed that agriuse data is correlated with the error term, so the variable is endogenous. There is endogeneity because of the simultaneity between agriuse and agri_growth or lnargri_growth. Simultaneity is when changes in X cause changes in Y, and changes in Y cause changes in X. Freshwater available and agricultural output are jointly determined (Perrings, 2005). Agricultural output needs freshwater resources, and a lack of freshwater can affect agricultural output, so there is a reason for simultaneity. Therefore, an instrumental variable is required. The instrumental variable needs to be independent of u_{it} (Exclusion criterion). Precipitation is exogenous to $because\ rainfall\ is\ random. Therefore$ exclusion requirement is satisfied. Another requirement for the instrumental variable is to be strongly correlated with agriuse (relevance criterion). A weak instrument can cause biased and inefficient estimates. The minimum eigenvalue of a matrix analogue of the F-statistics was used to estimate if the precipitation variable is a weak instrument (Stock & Yogo, 2005). Using Stock and Yogo's (2005) post-estimation method, the F-statistic value was 18.20, so at 5% significance, we can say that precipitation is not a weak instrumental variable. Next, the fixed effect model was checked to see if it was a reasonable assumption. In a fixed effect model, α_i is time-invariant and can be correlated with the regressors. If α_i is purely random, linear panel data regression will be less efficient than general least square estimation. However, using a random effect model will give inconsistent results if it is a fixed effect model. Hausman test for random effects showed it robustly rejected that α_i is random effects. Therefore, it is more appropriate to perform fixed effects panel regression. Using all the specifications above, we can see that agricultural growth and water utilisation do not have a robust inverted U relationship. One reason is that we are using EU countries to analyse the relationship; different countries have different total agricultural outputs relative to their water resources and technology. However, this difference is not considered when growth rates are considered, which gives us the wrong results. So, a better analysis will be with the total agricultural output.

	(1) agri_GDP	(2) agri_GDP	(3) lnagri_GDP	(4) lnagri_GDP
agriuse	1.928***	-2.979		
	(.564)	(2.278)		
agriuse2	-.07***	.096		
	(.022)	(.074)		
pop		-.046		-.017***
		(.07)		(.004)
fertilizer		.014		-.003**
		(.019)		(.001)
employ_agri		.007*		-.001**
		(.004)		(0)
lnagriuse			.468***	.506**
			(.099)	(.216)
lnagriuse2			-.005	-.081*
			(.028)	(.048)
_cons	-.502	4.334	.966***	2.619***
	(1.135)	(3.49)	(.116)	(.554)
Observations	143	83	143	83

Standard errors are in parentheses

**** p<.01, ** p<.05, * p<.1*

The fixed-effects regression below uses agricultural output as the dependent variable, with the other regressors and precipitation as an instrumental variable. The results also use clustered standard errors.

The above regression proves the U-shaped relationship between agricultural output and water utilisation. First, if we check column 1, we can see $\beta2>0$ and $\beta3<0$ at a 1% significance level. The results from column 1 show a statistically robust inverted U-shaped relationship between agricultural output and water utilisation. When we add other explanatory shift variables, the relation becomes insignificant. When the regression is done on the logarithm relationship, we can see that the model is more robust. First, let us analyse the shifter variables used in the regression. The coefficient on population, fertiliser, and agricultural employment show that those are negative and significant, at least at a 5% significance level. This result means that an increase in these variables will shift the inverted U-shaped curve downwards. The reason behind such shifts is that as these variables increase, there is an increase in demand for agricultural output, which will make the economy reach the turning point sooner (the agricultural economy will be water-stressed sooner).

The turning point for the EU is about 13.77 to 22.72 (using regression results from columns 1 and 4). The result shows that when the withdrawal for agriculture is 13.77% to 22.72% of total water resources, the agricultural output will fall due to water scarcity. This gives evidence that the neoclassical growth model using freshwater as a non-excludable endogenous scarce input can be used to model the agricultural sector in the EU. The analysis shows that countries like Hungary, Croatia, Greece, France, Finland, Estonia, and Spain have reached the tipping point in water utilisation. From the data, the growth rates of agricultural output for these countries showed a slowing down, and for some countries, growth rates are negative and decreasing further (Estonia, France, Hungary). The data also showed that the percentage of agricultural output of total GDP is on a downward trend. From the results, we can see that there is a strong inverted U-shaped relationship between water utilisation and agricultural output. The reason behind this inverted U-shaped relationship can be answered using the model. In the model, we took the appropriation cost of supplying water as a function of water stress. This function was increasing in water stress. So, as water stress increases, supplying water becomes more expensive, which makes agricultural production more expensive. The higher costs because of water stress are because when water becomes scarce, the economy needs to find and invest in new freshwater resources, building dams, pipes, etc. Also, the issuing government will intervene and restrict water utilisation if serious scarcity exists. All these will constrain the agricultural output.

II. EKC Relationship between Water Scarcity and Agricultural Output

From the EKC literature, we learned that environmental degradation would have an inverted U-shaped relationship with increased output. Depleting limited freshwater can be seen as environmental degradation, such as deforestation. So, from the literature, water utilisation can be set up like this

$$W_{it} = \beta_1 + \gamma_i + \beta_2 Y_{it} + \beta_3 Y_{it}^2 + X_{it} + e_{it}$$

The regression below shows agriuse used as a dependent variable. Here, agri_growth and agri_GDP variables are endogenous, and to solve this problem, agricultural raw materials import was taken as an instrument. Using the same specification methods from the section above, it is tested that agricultural raw materials import is a strong instrument. Also, agricultural raw materials import is independent of e_{it} because it is highly unlikely that raw materials import will have a causal impact on water utilisation. The Hausman test for random effects showed that γ_i is a random effect, so random effects panel regression will give more efficient estimates. Another major problem with this regression is that it is assumed that the variance of the idiosyncratic error term e_{it} is constant. To check if the data is homoscedastic, we perform a Breusch and Pagan Lagrangian multiplier test for random effects. This test shows that the null hypothesis of constant e_{it} is rejected, so we have heteroscedastic data. Because we are using EU country data, there is a possibility of clustering, so we need to use cluster robust standard errors for proper inference.

	(1) agriuse	(2) agriuse	(3) agriuse	(4) agriuse	(5) agriuse	(6) agriuse
agri_GDP	-2.235			1.607*	1.687**	
	(2.542)			(.831)	(.768)	
agri_GDP2	.137			-.06*	-.064*	
	(.162)			(.036)	(.034)	
irrigated	.183	.387				
	(.139)	(.244)				
pop	.059	.07	.046	.095		
	(.146)	(.129)	(.089)	(.087)		
agri_growth		-.31	-.006			.437
		(.258)	(.443)			(.514)
agri_growth2		-.002	0			-.006
		(.008)	(.007)			(.009)
_cons	8.116	1.743	5.4**	.392	1.713	6.457***
	(7.212)	(2.204)	(2.167)	(3.596)	(2.819)	(1.887)
Observations	48	48	152	153	153	152

Standard errors are in parentheses
**** p<.01, ** p<.05, * p<.1*

From the regression above, we can see that the coefficients of agricultural growth are insignificant. Therefore, water utilisation does not follow an EKC trend with agricultural growth. The shifter variables used are also insignificant in all the regressions. This is because the use of fertiliser and population does not affect the change in water utilisation for agriculture. The regression above shows significant coefficients on agri_GDP and agri_GDP2 ($agri\_GDP2$) are significant (columns 4 and 5). The coefficients on agri_GDP and agri_GDP2 are important in identifying the relationship's trajectory. We need to use a one-sided test using the normal distribution (not the student's t distribution because it is a random effect panel regression) to check if the coefficients are significantly less than or more than zero.

From columns 4 and 5, the z-values for the coefficient of agri_GDP are 1.93 and 2.21, respectively. The critical value for the 5% significance level for standard normal distribution is 1.645; we can say with 95% confidence that the coefficient of agri_GDP is positive. For the coefficient of agri_GDP2, the z-values are -1.66 and -1.91; we can say with 95% confidence that the coefficient is negative. This shows that there is an inverted U-shaped relationship between agriuse and agri_GDP. This proves an EKC relationship between water scarcity and agricultural output.

The threshold at which water utilisation will start falling with greater agricultural output is about 13.18 to 13.40 billion dollars (coefficient values from the above regression table columns 4 and 5). The countries that crossed this threshold before 2017 (because water data was only available till 2017) were Poland, Netherlands, Germany, Spain, Italy, and France. For Germany, Netherlands, and France, there is a downward trend of freshwater withdrawal for agriculture, but there is no downward trend for Italy, Spain, and Poland. However, we cannot entirely deny the EKC trend from this observation because the data set is concise. Future data on freshwater withdrawal might give us some more insights. This phenomenon could be because when water becomes very scarce, the government will restrict how much water can be used for agriculture. Also, if water is becoming scarce, farmers can use better irrigation techniques that efficiently use the water supply (Molden, 2007). The data uses EU data not from extensive agriculture-producing regions; therefore, when water becomes scarce, the EU will shift from producing agricultural output to importing it (similar to the pollution haven hypothesis; Fracasso, 2014). Also, with the EU being a very environmentally conscious region, we might see a shift in people's preferences and dietary routines. The standard agricultural policy of the European Commission aims to ensure that agriculture follows the EU's water policies. They have made a Green Direct Payment system where farmers must comply with mandatory practices that increase the soil's ability to retain more water and get monetary benefits. New policies also support farmers trying to use innovative techniques to do farming. All these measures support an EKC relationship between water utilisation and agricultural output.

Research Evaluation

I. Analysis Shortcomings

Data on water utilisation was 5-year averages. A more dynamic and better estimation would be possible if more frequent water utilisation data existed. Also, the EU region is not very agriculturally dependent globally. Hence, there is an inverted U-shaped relationship because they can shift their economy to a sector where the economies have a comparative advantage. So, regions like South Asia or Southeast Asia, where agriculture is their primary agricultural growth, may not have an inverted U-shaped relationship. Also, the EU has been very environmentally conscious in recent years, which could be another reason these countries are shifting to more environmentally and less water-straining production methods (van Dijk, 2015). Another major problem due to the lack of data is how water pollution and urbanisation will affect the agricultural ecosystem. For example, agriculture is primarily done in rural areas. If there is water scarcity, workers in the farming sector will migrate to other areas, causing a detrimental effect on the output. Also, fertilisers get washed up into the rivers and lakes, which causes water pollution, and this will cause freshwater resources to deplete faster. If data is available, such variables should be included in the research to find if there still is an inverted U-shaped relationship. Future research should also be done on agrarian economies so there can be a comparative study between regions.

II. EKC Shortcomings

The Environmental Kuznets Curve gives an excellent theory of the model relating to the environment and economic growth. Most research showed that in recent years, developed economies have reduced their pollutant emissions. Beckerman (1992) asserted that economic growth in developing countries would reduce environmental degradation. However, in recent years, environmental degradation has been increasing faster than economic growth in developing countries; examples of this phenomenon are Indonesia, the Philippines, and Thailand (Economist, 1993). often overlooked from EKC analysis is that even if a particular pollutant decreases with economic growth, societies tend to create more different toxic pollutants (Dasgupta et al., 2002). There is only data on the well-known pollutants; therefore, research was only done on those pollutants. Thousands of toxic pollutants that can be disastrous for the world are still untested and unregulated (Dasgupta et al., 2002). Hydrological research showed that a lack of freshwater resources is terrible for the ecology, affecting the agricultural output (EEA, 2009). Such indirect effects are not included in the EKC model. Researchers have acknowledged that if pollution continues, the environment will lose its ability to respond to high demands. Most EKC literature assumes countries should continue their usual economic growth trend. EKC encourages unrestricted economic growth and believes that environmental degradation will eventually start to fall. However, this is very unsustainable. EKC critics say that fixating only on economic outputs and allowing temporary environmental damage is immensely problematic (He, 2003). Once certain environmental limits have been surpassed, there is no going back to original conditions, limiting economic output. Also, EKC does not consider other environmental issues like animal extinction; no money or time can revert this change. A significant theory behind the shape of the EKC is that when pollution increases, citizens will start to invest in conservation practices when they reach an amount of wealth. However, this is only true if the environmental damage is reversible (Mills & Waire, 2009). Freshwater depletion is an irreversible ecological degradation because the technology to recycle water at a large scale that can be used for irrigation for agricultural output is unavailable.

EKC suggests that developing countries should focus on economic prosperity and that the environment will be conserved in the long run. Nevertheless, critics indicate that developing nations should embrace sustainable development (Gara, 2019). Environmental degradation has an external cost effect. However, most EKC literature on developed economies showed that economic degradation decreased with economic growth; however, the amount of pollution that the Industrial Revolution caused in the world is immense. The pursuit of economic growth caused climate change and a dangerous world for future generations. The EKC theory also downplays how much investment and technological advancement are required to fix the environment (Neumayer & Van Alstine, 2010). It also does not specify its duration to decrease environmental degradation after the tipping point. Therefore, although EKC could be an excellent model to relate water shortages and agricultural output, it should not be used to make significant environmental policy decisions.

Conclusion

The purpose of this study was to model water utilisation and the agricultural sector. The panel of 27 EU member countries was used to find how water shortages could affect agricultural output. The empirical analysis strongly supports an inverted U-shaped relationship between water scarcity and agricultural output production. It shows that water utilisation will grow with agricultural growth and then reach a tipping point where the farm output production. The model suggested in the methodology can be used to model water scarcity and agricultural production. From this analysis, we cannot claim with certainty that some EU countries will overcome the water scarcity problem more efficiently. Some EU countries are well endowed with natural freshwater reserves, which may help them improve agricultural output. Proper infrastructure is also required; a country might have massive freshwater resource reserves but lack the capacity to withdraw water efficiently. Extending this analysis to countries where agriculture is their primary sector is suggested for future research on agriculture and freshwater. Further research should also include how water scarcity will affect global agriculture trade and inequality.

The empirical study also proves that water scarcity followed the EKC trajectory, where water utilisation will fall with greater agricultural output. However, using the EKC theory to make environmental policy on water scarcity is unjustified. EKC can be a guideline; however, it should not be the only justification for increasing agricultural growth and hoping the economy will automatically fix itself.

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