An Empirical Time Series Model of Economic Growth and Environment

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Abstract

In this paper, I use the Solow (1956) model to examine the impact of water pollution on per worker output. I use data from New Zealand. I use an autoregressive distributed lag model that accounts for endogeneity. I also employ the Granger causality tests to examine the direction of causality between water pollution and per worker output. The findings indicates that water pollution affects the level of output per worker. This implies that a tightened pollution policy may have short-run impacts rather than the long-run.

Keywords: Solow model; water pollution; economic growth

JEL Numbers: O10; Q25

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[*] I am a retired Professor of Economics. I would like to thank Professor B. Bhaskara Rao for suggestions on extending the Solow framework used in this paper. However, all errors are my responsibility.

1. Introduction

How should we analyze the impact of pollution on economic activity? Many empirical researchers have answered this question by utilizing the well known model, so called Environmental Kuznets Curve (*EKC*). In a classic study, Grossman and Krueger (1995) highlighted the existence of an inverted U-shaped relationship between several pollutants and per capita income. According to them, the environmental quality initially deteriorates, but once countries reach a given income level, environmental degradation tends to decline. Panayotou (1993) called this relationship *EKC* because of its similarity with the relationship between income level and inequality in income distribution suggested by Kuznets (1955). However, the *EKC* model has been widely criticised on theoretical and empirical grounds, for instance see Harbaugh et al. (2002), Millimet et al. (2003), Perman and Stern (2003) and Stern and Common (2001). Some argue that the *EKC* is basically too optimistic.[2] Recently, Stern (2004) and Copeland and Taylor (2004) found that the theoretical and empirical works does not support *EKC* hypothesis when structural factors intervene. Consequently, Stern (2005) re-formulated the *EKC* as the best practice technology frontier.[3] His results show that with the exception of Australia, countries are converging toward the frontier but have settled into low pollution abatement and high pollution abatement groups.

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[2] It is argued that over time with globalisation impacts, the curve will rise to a horizontal line at maximum existing pollution levels. This implies that the poor countries will become pollution havens while the advanced countries face decline in the environmental standards. For more details, see Dasgupta et al. (2004).

[3] He used the Kalman filter to model the state of sulphur-emissions abatement technology in a panel of 15 developed countries. The results are used to determine whether and how fast countries are converging to best practice throughout time and what variables affect the level of technology adopted.

In this paper, I use the Solow (1956) model to estimate the impact of water pollution on per worker output for New Zealand. Solow (1956 & 1957) proposed the neoclassical growth model in which the factor accumulation can only explain about half the variations in the growth rate. What remains, known as the Solow residual, is attributed to the growth in technical progress or total factor productivity (*TFP*). Solow growth model implies that the long run growth rate of an economy depends on the rate of technical progress or *TFP*. However, it is not known what factors determine *TFP* and for this reason the Solow growth model is known as the exogenous growth model (*EXGM*). Subsequently, various frameworks have been developed to understand the determinants of *TFP*. In an interesting study, Mankiw, Romer and Weil (1992) have extended the Solow model by integrating an explicit process of human capital accumulation. It has been observed that human capital has only permanent level effects on per worker output and no permanent growth effects. Lately, endogenous growth models of Romer (1986), Lucas (1988) and Barro (1991, 1999) have also attempted to explain the key determinants of growth.

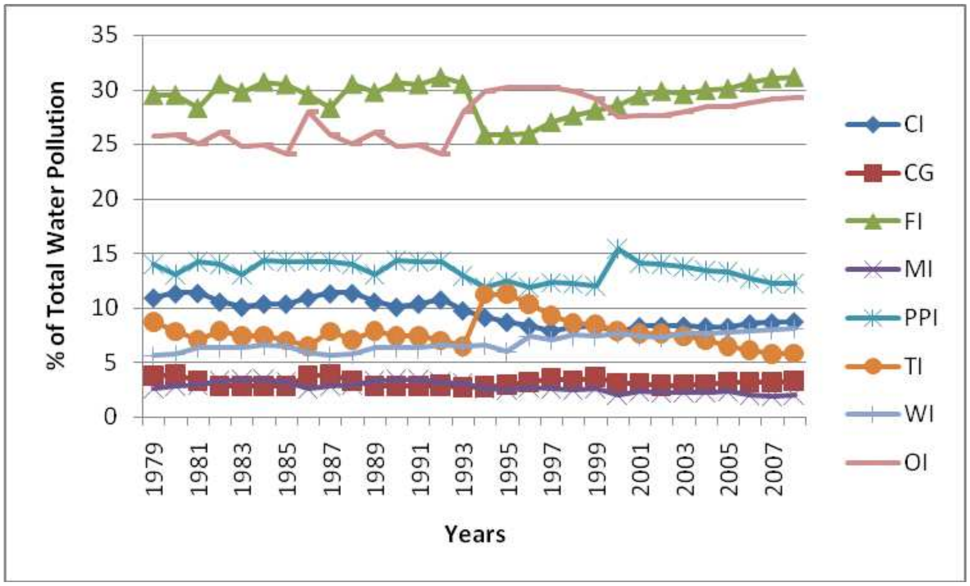
Recently more attempts have been made to utilize the growth models to examine the impact of pollution on economic growth, for instance see, Bovenberg and Smulders (1995), Pittel (2002), Brock and Taylor (2005) and Kalaitzidakis et al. (2007). Kalaitzidakis et al. (2007) examined the relationship between *TFP* growth and pollution using a semi-parametric smooth coefficient model for a range of OECD countries for the period 1981-1998. Their findings imply that there exist a nonlinear relationship between pollution and economic growth as captured by *TFP*. Tzouvelekas et al. (2006) estimated the contribution of pollution to the growth of real per capita output for a panel of 23 OECD countries for the period 1965-1990. They find that the use of the environment approximated by *CO2* emissions contributes to the growth of output, and its contribution should be accounted for in *TFP* measurements. Chimeli and Braden (2005) examined the link between *TFP* and the environmental Kuznets curve. They derive a U-shaped response of environmental quality to variations in *TFP*.

To the best my knowledge, there is no study that has examined the impact of water pollution on economic growth for New Zealand. Therefore, this paper may attempt to fill this gap in this literature. The layout of this paper is as follows: Section 2 provides a brief overview of water pollution in New Zealand. Section 3 and 4, respectively, details the model and empirical results. Section 5 provides the conclusion.

2. Water Pollution in New Zealand

The main sources of water pollution in New Zealand are industry, towns, livestock farming and human waste disposal. Until the 1970s, the major cause of water pollution was the discharge of poorly treated sewage, stock effluent and wastes from primary and other industries. However, water quality improved dramatically following the upgrade in wastewater treatment systems and introduction of the government regulations such as Water and Soil Conservation Act 1967 and the Resource Management Act 1991. The industry based water pollution in New Zealand is related to chemical industry (*CI*), clay and glass industry (*CG*), food industry (*FI*), metal industry (*MI*), paper and pulp industry (*PPI*), textile industry (*TI*), wood industry (*WI*) and other industries (*OI*). This disaggregated data refers to emissions from manufacturing and production activities. These are measured as a percentage of total water pollution. Figure 1 show the trends in the sources of water pollution in New Zealand.

Figure 1. Sources of Water Pollution



Basically food and other industries have contributed between 25-30 percent of water pollution and these have been identified as the most serious freshwater management challenge in New Zealand today. While water pollution caused by clay and glass and metal industries is less than 5%, majority of the industries such as paper and pulp, chemical, textile and wood industries contribute between 5-15 percent. In light of the trends in the water pollution, we argue that water pollution imposes a real cost on the society and economic growth. Therefore improving the water quality for future generations is important for New Zealand. Most importantly, detailed empirical study is required to examine how water pollution affects the long run growth and how policy makers could adopt appropriate policies to curtail pollution.

3. An Empirical Model

There are a few alternative methods of extending the Solow (1956) model for estimation with the country specific time series data. Recently, Brock and Taylor (2010) developed a new framework to examine the relationship between economic growth and environmental outcomes in which the Solow model is amended to incorporate technological progress in abatement. They argued that the *EKC* is a necessary by product of convergence to sustainable growth path. However, their framework is potentially useful in a cross-section or panel data study. In our view, country specific time series studies are useful to estimate country specific steady state growth rates (*SSGR*s) and to identify the positive and negative externalities that affect the *SSGR*.

I suggest a simple extension to the Solow model and this is limited to analysing only the effects of externalities on output. If water pollution is treated as a negative externality, then it can have a detrimental impact on *TFP* and the long run growth. Therefore it is useful to investigate whether this externality produces short-run or long-run effects on output so that policy makers can adopt appropriate policies to reduce its impact.

I may treat water pollution as a growth reducing variable. Let the Cobb Douglas production function with constant returns and Hicks-neutral technical progress be

$$y_t = Tech_t k_t^{\alpha} \qquad 0 < \alpha < 1 \qquad (1)$$

where *y* = per worker output, *Tech* = stock of technology and *k* = per worker capital stock. It is well known that *SSGR* in the Solow model equals the rate of growth of *Tech*. It is common in the Solow model to assume that the evolution of technology is given by:

$$Tech_t = Teche^{gT} \qquad (2)$$

where $Tech_0$ is the initial stock of knowledge and the time trend is expressed as *T*. Therefore, the steady state growth of output per worker equals *g*.

The production function is estimated by taking into account that the variables are generally non-stationary in levels and stationary in their first differences. Therefore, some researchers use specifications based on the error correction models (*ECM*). I may employ the widely used autoregressive distributed lag (ADL) specification taking account of the constant returns Cobb-Douglas production function with the Hicks neutral technical progress:

$$\begin{aligned}\Delta \ln y_t = -\lambda[\ln y_{t-1} - (Tech + gT + \alpha \ln k_{t-1})] \\ + \sum_{i=0}^{n1} \gamma 1_i \Delta \ln k_{t-i} + \sum_{i=1}^{n2} \gamma 2_i \Delta \ln y_{t-i} \qquad (3)\end{aligned}$$

where λ is the speed of adjustment to equilibrium. The coefficient of trend (*g*) captures the rate of technical progress. Note that equation (3) serves as the baseline equation without the negative externality viz., water pollution.

Next, I introduce water pollution (*WP* henceforth) as a shift variable into the production function. According to Brock (1973), environmental damage created by pollution affects economic growth and therefore environment should be used as an unpaid factor input. Consequently, the use of environment in the production process can be captured by introducing pollution as an input in the production function. This can be justified by assuming that

$$Tech_t = Teche^{gT} WP_t^{\beta} \qquad (4)$$

The shift variables are introduced into the specification with the implicit assumption that they affect the level of output. However, if I assume that water pollution simply shifts the production function, then it can be introduced into (3):

$$\begin{aligned}\Delta \ln y_t = -\lambda[\ln y_{t-1} - (Tech + gT + \beta \ln WP_{t-1} + \alpha \ln k_{t-1})] \\ + \sum_{i=0}^{n1} \gamma 1_i \Delta \ln k_{t-i} + \sum_{i=1}^{n2} \gamma 2_i \Delta \ln y_{t-i} + \sum_{i=0}^{n3} \gamma 3_i \Delta \ln WP_{t-i} \qquad (5)\end{aligned}$$

Now I suggest a simple empirical specification that tests whether *WP* affects the growth rate of output. If *WP* affects the growth rate of output, then it should affect the magnitude of *g* in equation (2).

$$\begin{aligned}\Delta \ln y_t = -\lambda[\ln y_{t-1} - (Tech + (g_1 + g_2 \ln WP_{t-1})T + \alpha \ln k_{t-1})] \\ + \sum_{i=0}^{n1} \gamma 1_i \Delta \ln k_{t-i} + \sum_{i=1}^{n2} \gamma 2_i \Delta \ln y_{t-i} + \sum_{i=0}^{n3} \gamma 3_i \Delta \ln WP_{t-i} \qquad (6)\end{aligned}$$

where g_1 captures the growth effects of trended but ignored variables. g_2 is an estimate of the growth effects of *WP*.

4. Results

Unit Root Tests

I test the time series properties of *y, k,* and *WP* with the Augmented Dicky-Fuller (*ADF*) and Elliot-Rothenberg-Stock (*ERS*) tests.[4] The tests indicate that the level variables are I(1) and their first differences are I(0). I used the annual data for New Zealand over the period 1979-2008.

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[4] The unit root test results are not reported to conserve space.

Data is obtained from the International Financial Statistics (2010) and World Development Indicators (2010). Definitions of the variables are provided in the Appendix.

ADL Estimates

I use the ADL procedure to estimate the economic growth and pollution relationship. This is done within a nonlinear least squares framework. This technique minimises endogeneity bias and also performs parameter restrictions. I did not use other time series techniques such as Stock and Watson's (1993) dynamic ordinary least squares, Phillip and Hansen's (1990) fully modified ordinary least squares and Johansen's (1988) maximum likelihood because these techniques are inconvenient when utilizing the parameter restrictions. It is well known that *ADL* estimates I(0) and I(1) variables together and if the I(1) variables are cointegrated then their linear combination is I(0).

The output per worker growth equations were estimated with a lag structure of 3 periods. This optimal lag length was selected by Hendry and Krolzig's (2001) automated general to specific modeling program.[5] The estimated general dynamic equations were later reduced to manageable optimal versions as reported in Table 1. Column (1) provides estimates of the baseline equation without water pollution. Columns (2) and (4) present the estimates of equations (5) and (6), respectively. The Ericsson and McKinnon (2002) (*EM*) cointegration test showed that the null of no cointegration can be rejected at the 5% level for all equations. The *EM* test statistics are absolute *t*-statistics of λ. Interestingly, the *EM* test statistics exceeds the sample size adjusted absolute critical values at 5% level.[6] This implies that there exists a unique cointegrating relationship between the variables in the respective equations.

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[5] This automated software searches for the optimal dynamic lag structure by minimizing the path dependency bias.

[6] The *EM* cointegration test results are not reported to conserve space.

Table 1. ADL Estimates of the Effects of Water Pollution on Economic Growth
(Dependent Variable: $\Delta \ln y_t$)

Variables	(1)	(2)	(3)	(4)	(5)
Intercept	4.782	7.072	1.277	2.355	2.036
	(2.36)*	(3.00)*	(3.27)*	(2.06)*	(2.34)*
λ	-0.387	-0.401	-0.365	-0.317	-0.319
	(6.27)*	(5.37)*	(5.43)*	(4.76)*	(4.80)*
	0.042	0.016	0.059		
g	(6.09)*	(4.06)*	(4.38)*		
α	0.307	0.319	0.333	0.305	0.333
	(4.37)*	(2.46)*	(c)	(3.12)*	(c)
β		-0.006	-0.005		
		(3.02)*	(3.21)*		
g_1				0.012	0.008
				(4.55)*	(3.89)*
g_2				-0.002	-0.001
				(0.64)	(0.23)
$\Delta \ln y_{t-1}$			1.268	0.475	0.236
			(2.06)*	(1.88)**	(1.69)**
$\Delta \ln y_{t-3}$	3.276	1.203	0.975		
	(3.21)*	(3.24)*	(1.97)*		
$\Delta \ln k_t$	0.367			1.236	1.754
	(2.35)*			(2.37)*	(2.68)*
$\Delta \ln k_{t-2}$			0.846	1.267	
			(2.64)*	(4.32)*	
$\Delta \ln k_{t-2}$	1.002	0.284			0.673
	(2.64)*	(2.88)*			(1.75)**
$\Delta \ln WP_t$		-0.013	-0.165		
		(1.98)*	(2.48)*		
$\Delta \ln WP_{t-1}$			-0.007	-0.014	-0.007
			(3.45)*	(1.70)**	(1.84)**
$\bar{R}^2$	0.713	0.718	0.720	0.717	0.686
SEE	0.025	0.024	0.024	0.024	0.027

Notes: Absolute *t*-ratios are in the brackets below the coefficients. Significance at 5% and 10% level, respectively, denoted by * and **. (c) denotes the restricted or constraint estimate. λ is the speed of adjustment to equilibrium.

The estimated profit share of output (α) is around 0.3 and significant at 5% level. The estimate of β in column (2) implies that negative externality due to water pollution is significant at the 5% level and implies an impact on the level of per worker output. This finding corroborates with the estimates of column (3) where the profit share of output is restricted to the stylized value of one third. However, when I estimated for the growth effects, the estimates of the growth effects of water pollution (g_2) is insignificant at conventional levels; see columns (4). The same finding is achieved when we restricted the profit share of output to the stylized value of one third; see column (5). Further the growth effects of trended and ignored variables (g_1) seem to be significant. These empirical findings suggest that negative externality due to water pollution affects the level of output per worker and not its growth rate. This indicates water pollution may not be a long-run dilemma.

The speed of adjustment to equilibrium (λ) has the expected negative sign. This implies the negative feedback mechanism. The results are free from serial correlation, misspecification, non-normality and heteroscedasticity issues.

Granger Causality

The existence of a long run relationship among per worker output, water pollution and per worker capital advocates that there must be Granger causality in at least one direction. To identify the direction of temporal causality we apply the Granger causality tests for both short and long run situations. Evidence of a cointegrating relationship implies that the Granger causality model should be augmented with a one period lagged error correction term; hence the following models are to be estimated:[7]

$$\Delta \ln y_t = \upsilon + \sum_{i=1}^{n} \theta_i \Delta \ln y_{t-1} + \sum_{i=1}^{n} \phi_i \Delta \ln k_{t-1} + \sum_{i=1}^{n} \varphi_i \Delta \ln WP_{t-1} + \pi_1 ECT_{t-1} + \varepsilon_{1t} \tag{7}$$

$$\Delta \ln WP_t = \upsilon + \sum_{i=1}^{n} \varphi_i \Delta \ln WP_{t-1} + \sum_{i=1}^{n} \varpi \Delta \ln k_{t-1} + \sum_{i=1}^{n} \delta_i \Delta \ln y_{t-1} + \pi_2 ECT_{t-1} + \varepsilon_{2t} \tag{8}$$

$$\Delta \ln k_t = \upsilon + \sum_{i=1}^{n} \phi_i \Delta \ln k_{t-1} + \sum_{i=1}^{n} \varpi_i \Delta \ln y_{t-1} + \sum_{i=1}^{n} \delta_i \Delta \ln WP_{t-1} + \pi_3 ECT_{t-1} + \varepsilon_{3t} \tag{9}$$

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[7] Engle and Granger (1987) provide a comprehensive discussion of Granger causality tests.

where the lagged error correction term derived from the long run cointegrating relationship is represented by ECT_{t-1}. The serially independent random errors are ε_{1t} ε_{2t} and ε_{3t} which have zero means and finite covariance matrices. Causality results are obtained by regressing the respective dependent variables against past values of both itself and other variables, the Schwarz Bayesian Criterion (SBC) is employed to select the optimal lag, *n*, and χ^2 statistics from the causality results are used to identify rejection of the null hypotheses.

The *F* test of the lagged exogenous variables indicates short run causal effects while the long run causal effect is determined by the significance of the lagged error correction term. These results are shown in Table 2.

Table 2. Results of Granger Causality Tests 1979-2008

Dependent Variable	$\Delta\ln WP_t$	$\Delta\ln y_t$	$\Delta\ln k_t$	ECT_{t-1}
$\Delta\ln WP_t$	-	-0.025 (0.25)	0.139 (0.22)	-0.277 (0.63)
$\Delta\ln y_t$	-0.012 (0.02)*	-	0.106 (0.03)*	-0.305 (0.00)*
$\Delta\ln k_t$	0.064 (0.43)	0.158 (0.30)	-	-0.276 (0.35)

Notes: Absolute *p*-values are reported in the parentheses. * denotes statistical significance at the 5% level.

In the short run, per worker output and capital are insignificant at the 5% level in the water pollution equation implying that per worker output and capital does not Granger cause water pollution in the short run. Similarly, water pollution and per worker income are insignificant in the per worker capital equation. However, both water pollution and per worker capital are significant at the 5% level in the per worker output equation, implying that there is a uni-directional causality running from water pollution and per worker capital to per worker output in the short run. The long run results suggest that the coefficient of ECT_{t-1} is significant at the 5% level with the expected negative sign in the per worker output equation, which implies that in the long run water pollution and per worker capital Granger causes the per worker output. Note that the causality relationship from water pollution to per worker output is negative in both short and long run. Overall, our results suggest that the endogeneity problem is limited because water pollution and per worker capital are weakly exogenous. An implication of our findings is that environmental policies which aim to decrease the level of water pollution can improve the per worker output.

5. Conclusions

In this paper, I used the Solow (1956) model to estimate the impact of negative externality viz., water pollution for New Zealand. My empirical methodology is based on the autoregressive distributed lag (ADL) model. Using the Ericsson and McKinnon (2002) cointegration tests, I find that there exist cointegrating relationships between the variables in the model. The estimated capital share of output is significant and plausible (around 0.3). I find that water pollution affects the level effect of per worker output. It may be unlikely to generate any long-run effects on the growth of per worker output. The Granger causality tests reveal that both in short and long run, water pollution Granger causes per worker output and the causality is negative. With this finding, I argue that environmental policies which aim to decrease the level of water pollution can improve the per worker output.

Lifting the steady state growth rate is, arguably, the pursuit of every economy. My results imply that steady state growth rate will not be affected by water pollution. This implies that a tightening of pollution policy will lower the level of water pollution and thus will increase the level of per worker output. Therefore, an environmental policy may be directly linked to the level of per worker output. It is obvious that to improve the steady state growth rate in New

Zealand, it is important to allow for greater positive externalities such as trade openness, investment in human capital, etc.

There are some limitations in this paper. I have used a simple model and this ignores other factors that may have significant externalities. There are alternative proxies for pollution and it is desirable to use them to examine the sensitivity of our results. However, this is beyond the scope of the current paper. Further, I have ignored the effects of the structural breaks in the estimation. I hope some other researchers may fill these gaps.

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Data Appendix

Variables	Definition	Source
Y	Real Gross Domestic Product	International Monetary Fund (2010)
K	Capital Stock; Derived using perpetual inventory method .	Authors computations
L	Labour force	World Bank (2010)
WP	Pollution proxied by water pollution (Organic water pollutant (BOD) emissions)	World Bank (2010)