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CO_2 Emissions, Economic Growth and Urbanisation: Insights from Vector Error Correction Modelling

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Abstract

In this paper we analyse the impact of economic development and urbanisation on CO_2 emissions in Ireland over the period 1970 to 2011. Using a vector error correction model and impulse response functions we pose two questions. Firstly, what role has economic development and urbanisation played in driving CO_2 emissions in Ireland. Secondly, what impact might government regulations and directives which cut CO_2 emissions have on future economic growth and urbanisation in Ireland. We use data from the World Bank and Penn World Tables to answer these questions. Our findings suggest that in the short run economic growth leads to higher levels of CO_2 emissions but that in the long run economic growth lowers emissions. Regarding urbanisation, increasing urbanisation in Ireland has contributed to lower levels of CO_2 emissions than might otherwise be observed. Our model suggests that cuts to CO_2 emissions will have no impact on urbanisation but will have a negative impact on GDP.

JEL Classification

C32, O13, Q40, Q43

Keywords:

Vector Error Correction Model, Pollution, CO_2 emissions, Impulse Response Analysis, Granger Causality

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1. Introduction

This paper analyses the impact of increased economic growth and urbanisation on CO_2 emissions in Ireland over the period 1970 to 2011. An ongoing international debate questions whether economic growth and/or urbanisation impact CO_2 emissions. Evidence is split between studies which find positive associations between growth, urbanisation and CO_2 emissions [see for example Liddle and Lung (2010)] and those which find negative effects [see for example Fan et al. (2006)]. Much of this analysis however focuses on developing countries or on a panel of countries and is not specific to a small open economy such as Ireland. During the period under investigation CO_2 emissions in some small open economies rose (an increase of 19.6% in Ireland, 15.9% in Finland and 14.7% in Austria), whilst average emissions fell in the EU (drop of 16.4%), the OECD (drop of 5.7%) and most large countries (World DataBank 2016). This research paper focuses on one small open economy, Ireland, and uses applied econometric analysis to isolate the impact of a variety of socio-economic factors on CO_2 emissions.

It is of particular importance and interest to study Ireland given the commitments made by successive governments under the Kyoto Protocol and subsequent EU Commission targets (Environmental Protection Agency 2013) to reduce emissions and environmental pollution. Further to this, in light of recent reports from the Irish Environmental Protection Agency (2016b) which indicate that Ireland will exceed its 2020 EU targets and 2030 EU level targets of the Paris Agreement, it is timely to consider whether any action taken to bring Ireland back in line to meet these targets will impact on economic growth. Given these commitments we ask two specific questions. Firstly, to what extent will continued Irish economic growth and urbanisation impact CO_2 emissions? Secondly, what impact might cutting CO_2 emissions have on Irish economic growth and urbanisation?

A variety of analytical approaches have been used in the literature to analyse the impact of socio-economic factors on CO_2 emissions. Studies such as those by Liu (2005) and Zhu et al. (2012) use semi-parametric data analysis and simultaneous equation systems to highlight the role played by economic growth, urbanisation and energy consumption in explaining rising CO_2 levels across different countries. Others such as Zhang and Cheng (2009) use a vector autoregressive model to perform Granger causality tests on a variety of socio-economic variables including urbanisation and GDP. The contribution of this paper is to create a model which incorporates the variety of socio-economic factors considered in previous papers into a single model and to estimate these using vector error correction (VEC) methods. The advantages of a VEC model is that it allows us to incorporate a variety of variables and to utilise impulse response functions to analyse the impact of a shock to one variable in the system on all other variables. The aim of the paper is to shed light on the role of economic variables

in driving emission levels in Ireland. Our key variable is CO_2 emissions which, as noted by Bacon (2007), is one of the key contributors to the greenhouse gas effect.

Since Grossman and Krueger (1991) there has been substantial focus on what has been termed the economic growth and environmental pollution nexus. The standard approach has been to assume economic growth impacts pollution in an inverted U-shape, the so called environmental Kuznets curve (EKC). However, papers such as Liu (2005) criticise the EKC as it assumes that economic growth is exogenous and no feedback exists between environmental pollution and growth. VEC models, such as the one used in this paper, allow us to overcome this issue and to test for Granger causality from GDP to environmental pollution and *vice versa*.

There are a variety of socio-economic factors which impact CO_2 emissions and are relevant for our study. The key variables are GDP and urbanisation. GDP measures economic growth whilst urbanisation is a good proxy for modernisation (Ehrhardt-Martinez et al. 2002) and as economies modernise they tend to generate higher levels of pollution. Other factors can also contribute to increasing CO_2 emissions and therefore we include a measure of openness and energy usage. Kais and Sami (2016) and Suri and Chapman (1998) argue that trade openness is a vital factor that could influence emissions. Grossman and Krueger (1991) suggest that greater openness to trade results in lower environmental standards, while Shafik and Bandyopadhyay (1992) suggest that openness and competition may result in increased investment in new technologies which result in a reduction in pollution. Davis and Caldeira (2010) and Liu (2005) argue that the burning of fossil fuels is one of the primary causes of CO_2 emissions. Zhang and Cheng (2009) note that while previous studies focused on output-emissions or output-energy, recently all three have been included in multivariate systems.

The key contributions of this paper are as follows. It provides a specific analysis of the impact of a variety of socio-economic factors (most notably economic growth and urbanisation) on CO_2 emissions in Ireland. This is the first such study to specifically focus on Ireland as the unit of analysis. Secondly, we ask what impact growth and urbanisation have on CO_2, and we address the extent of any reverse causality by asking what impact cuts to CO_2 emissions have on economic growth and urbanisation in Ireland.

The remainder of this paper is structured as follows. Section 2 presents a review of the relevant literature on economic growth, urbanisation, and CO_2 emissions. Section 3 discusses the data used in this paper. Section 4 outlines the methodology utilised and how this contributes to existing studies on the determinants of CO_2 emissions. Section 5 presents and discusses our results. The final section concludes.

2. Literature Review

2.1 CO_2 Emissions

Concerns about global warming and climate change have resulted in a substantial body of academic research targeted at understanding the nature of the relationship between CO_2 emissions, economic growth, and urbanisation. The main interest in analysing CO_2 emissions arises from its definition as a greenhouse gas. Numerous authors note that while CO_2 emissions

are not the sole greenhouse gas, they constitute the largest component of global greenhouse gas emissions (Bengochea-Morancho et al. 2001; Bacon 2007). These emissions are believed to adversely impact the planet's physical, ecological, and biological systems (Malik et al. 2016), resulting in global warming related issues such as higher temperatures, widespread melting of snow, and rising sea levels (Intergovernmental Panel On Climate Change 2007).

2.2 Economic Growth and Emissions

When it comes to analysing the environmental impact of economic growth Soytas and Sari (2009) and Xepapadeas (2005) note that traditional theories of economic growth have ignored issues surrounding the environment. However, beginning in the 1990s a substantial literature detailing the nature of the relationship between economic growth and CO_2 emissions has emerged [see for example Soytas and Sari (2009), Selden and Song (1994), Holtz-Eakin and Selden (1995), Bhattacharyya and Ghoshal (2010), and Bengochea-Morancho et al. (2001)]. Selden and Song (1994) highlight the role economic development plays in releasing larger quantities of CO_2 emissions into the atmosphere through the increased production of goods and services among other factors. As mentioned above two main streams of analysis exist in the literature – the first examines the link between economic growth and pollution (Kuznets 1955; Grossman and Krueger 1991) while the second examines the link between economic growth and energy consumption (Kraft and Kraft 1978). The empirical research examining the nexus independently and jointly is largely inconclusive [see brief review in Halicioglu (2009)].

2.3 Urbanisation and Emissions

In addition to economic growth, most countries are experiencing increasing levels of urbanisation. The role of urbanisation in driving/constraining CO_2 emissions is another much debated topic in academic research. Zhu et al. (2012) note that much of the evidence on urbanisation and environmental pollution is mixed. On the one hand studies such as Liddle and Lung (2010) and Cole and Neumayer (2004) find a positive relationship between urbanisation and pollution while similar analysis by Cramer (1998) and Cramer and Cheney (2000) find that population growth (a proxy for urbanisation) is also closely linked with higher levels of pollution. On the other hand, Fan et al. (2006) find a negative relationship between urbanisation and pollution while Zhu et al. (2012) and Wang et al. (2015) suggest the existence of a Kurnets curve, implying that as countries become more urbanised pollution levels initially rise, but reach a threshold after which CO_2 emissions begin to decline.

2.4 The Irish Case

There is substantial debate surrounding CO_2 emissions in the Irish context focusing on factors such as the identification of CO_2 footprints in Irish households (Kenny and Gray 2009a; Kenny and Gray 2009b), and the possible impact of carbon taxes on the Irish economy (Wissema and Dellink 2007; Callan et al. 2009). However, the impact of economic development and urbanisation on CO_2 emissions has not been assessed using time series econometric techniques. The Irish Environmental Protection Agency (2016a) notes that "Ireland's greenhouse gas emissions per person are amongst the highest of any country in the world … [and that] the argument that we are too small a country to make a difference holds no ground". Ireland, has also, under the EU Commission's Climate and Energy Package, committed to delivering a 20%

reduction, relative to 2005 levels, in non-ETS greenhouse gas emissions by 2020 (Environmental Protection Agency 2013). However, recent evidence provided by the Irish Environmental Protection Agency (2016b) suggests that "Ireland is not currently on the right track to meet its 2020 targets, nor is it on the right emissions trajectory to meet future EU targets or our national 2050 decarbonisation goals". Given these constraints on CO_2 emissions, and the need to take action to ensure that these emission targets are placed back on track, it is timely to analyse the impact of future economic growth and urbanisation on CO_2 emissions as well as analyse what impact reductions in CO_2 emissions will have on Ireland's capabilities to generate sustained economic growth and urbanisation.

3. Preliminary Data Analysis

Our analysis is conducted for Ireland from 1970 to 2011.[1] Our study utilises two complementary data sources – the World Bank and the Penn World Tables. The World Bank provides information on GDP, CO_2 emissions, energy consumption, and the proportion of the population in urban concentrations, while the Penn World Tables provide information on openness and capital stock.

To measure economic growth we use Gross Domestic Product (GDP). GDP is extensively used in economic literature to measure economic development and growth. Specifically, we utilise GDP in US$ (constant 2005 prices). The use of constant prices removes the impact of inflation on GDP and is standard in the literature. However, it has been criticised by authors such as Ward et al. (2016) as not being an appropriate metric for measuring societal wellbeing. However, despite this limitation GDP is the most commonly used metric for measuring economic output while also proxying for living standards (Soytas and Sari 2009). We return to this issue again in the conclusion when contextualising our results. CO_2 emissions (CO_2) is the total metric tons of CO_2 produced in a given year and includes carbon dioxide produced during the consumption of solid, liquid and gas fuels and the manufacture of cement.[2] Studies such as Bacon (2007) Zhang and Cheng (2009), and Wang et al. (2015) use this measure as a proxy for greenhouse gases. Urban population (URBAN) refers to the number of people living in urban areas as defined by national statistics offices. This provides a crude, but effective measure of the degree of urbanisation present in Ireland and its evolution over the period of

[1] We note that this is the most comprehensive time series available using the two datasets and variables employed. However, we acknowledge that, as more data becomes available, the statistical discrepancies in Ireland's 2015 GDP figures may limit future analysis of GDP and environmental pollution using time series analysis. However, this problem is not confined to environmental analysis and the 2015 statistical issues will impact any time series analysis using GDP figures for 2015.

[2] We note that we are using a production measure of CO_2 emissions. This measure has some limitations. In recent years, Motaal (2011) notes that developed economies have been offshoring much of their 'dirty' production to developing countries, thereby reducing their own CO_2 emissions but increasing the CO_2 emissions of developing countries. However, the consumption of these 'dirty' goods still takes place in developed countries, meaning that, even though CO_2 emissions may have fallen in the developed countries as they are producing less 'dirty' products, they are still importing these dirty products from the developing world. This makes them ultimately responsible for the CO_2 emissions. It is not possible given the data needs of our methodology to shift our analysis to an emissions consumption prism as proposed by Motaal (2011), however, we acknowledge this potential weakness of our data.

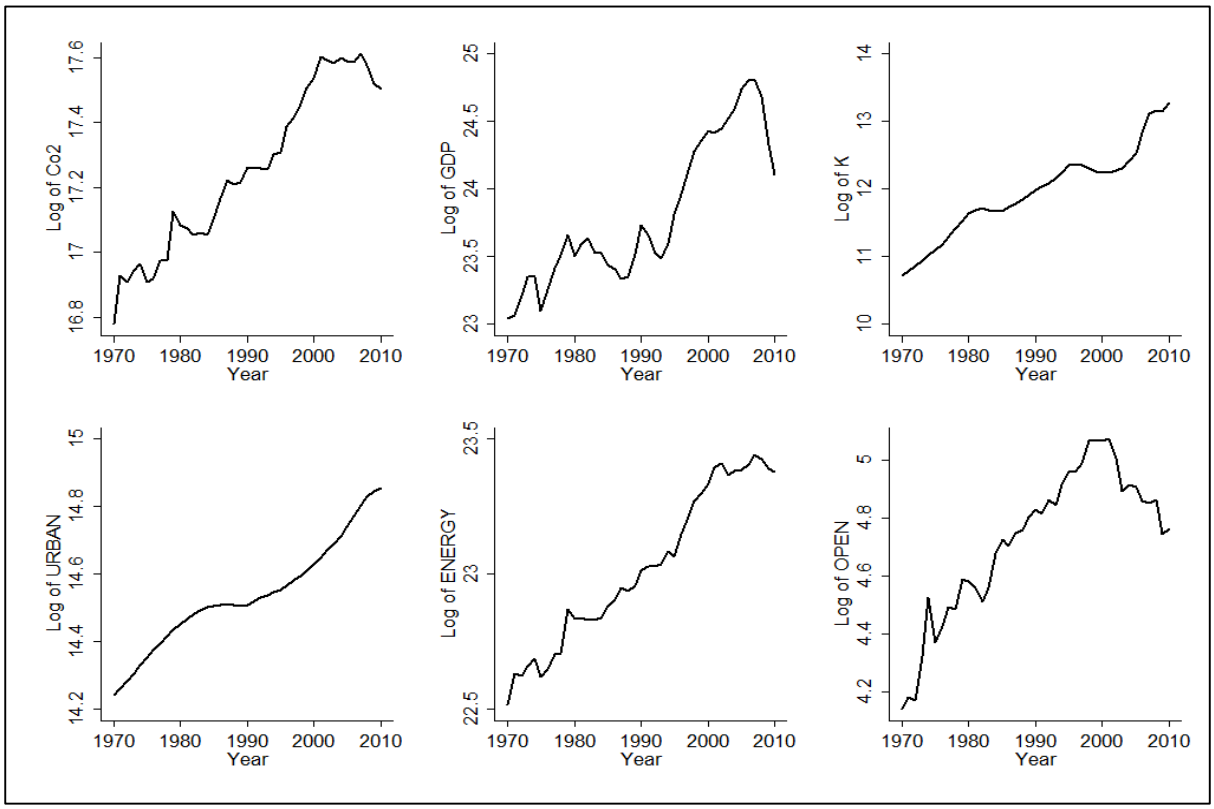
this study. The use of this variable is consistent with existing literature, see for example Zhu et al. (2012).

In addition to the three key variables, we also control for energy use, capital stock and openness. Energy use (ENERGY) is in kilotons of oil equivalent and refers to primary energy before transformation to other end-use fuels. Capital stock (K) is the stock of physical capital used for the production of goods and services and is measured in US$ (constant 2005 prices). Openness (OPEN) is measured as the sum of exports and imports divided by GDP. The higher this value the more open Ireland's economy is deemed to be to trade.[3]

Figure 1 presents a plot of our variables. All variables exhibit a strong upward trend with CO_2, GDP, ENERGY, and OPEN all showing dips after 2008 (when Ireland experienced a severe economic downturn). It is notable that CO_2 emissions appear to be tied to the business cycle, falling significantly when GDP falls. However, we note that during the economic crisis Ireland continued to grow more urbanised. While the rate of urbanisation slowed slightly, we did not observe a reversal of urbanisation. We also note that energy consumption and openness fell post-2008. Again this is not surprising as we would anticipate that both of these variables would follow the business cycle, with lower economic output resulting in lower energy requirements and with the global economic crisis in 2008 resulting in falling demand for Irish exports driving a falling openness indicator.

Figure 1: Graphs of Variables

[3] Note that this variable is designed to capture a country's openness to trade. It does not allow for inferences into emission offshoring except that we might infer that higher levels of openness (i.e. more exports and imports) might imply that Ireland is importing more goods which may in turn imply that Ireland's CO_2 emissions are artificially low based upon a consumption measure of CO_2.



4. VEC Model Specification

In order to model the impact of economic growth, urbanisation and our other control variables on CO_2 emissions we employ a vector error correction (VEC) model. The VEC model can be thought of as a specific type of time series regression model which allows us to analyse the impact of our variables on each other. The advantage of this type of model is that, not only can we analyse the impact of GDP and urbanisation on CO_2 emissions, but we can also see whether decreasing CO_2 emissions have a positive or negative effect on GDP or urbanisation.

While other methods of analysis are available we believe that when considering a single country over a long time period VEC modelling provides numerous advantages. While authors such as Liu (2005) and Zhu et al. (2012) use semi-parametric data analysis and simultaneous equation systems to highlight the role played by economic growth, urbanisation and energy consumption in explaining rising CO_2 levels across different countries, this approach relies on a panel of countries being assembled. This is useful for providing insights into overall trends across heterogeneous country contexts, but not robust when considering a single country over time. A similar time series model is a vector autoregressive (VAR) model. Zhang and Cheng (2009), amongst others, use VAR models to perform Granger causality tests on a variety of socio-economic variables including urbanisation and GDP. However, a VAR model assumes that no co-integrating relationship exists between the variables under consideration. Our tests in the Irish context suggest that co-integration is indeed present for the Irish data, and this suggests that VAR models, while still functional, would be less efficient when compared to a VEC model approach as the VAR estimation would ignore the co-integrating relationships. In

summary, the advantage of a VEC model is that it allows us to incorporate a variety of variables for a long time period using just Irish data and to utilise impulse response functions to analyse the impact of a shock to one variable in the system on all other variables.

In order to estimate our VEC model we follow four steps:

1) We test whether each variable is stationary.
   - Variables entered into a VEC model should be integrated of the same order. For instance the data is appropriate if it is non-stationary in levels but stationary in growth rates (i.e. GDP versus growth in GDP). A Dickey-Fuller test is used to assess whether the data is stationary or not (Dickey and Fuller 1979).
2) We test the appropriate lag length to include in our model.
   - As it is likely that CO_2 emissions are affected by GDP in the current year and in past years we include lagged values of each variable. We use a formal statistical test known as the Schwarz's Bayesian Information Criterion to assess the exact lag length we should include (Greene 2008).
3) We test for cointegration between the variables.
   - Cointegration refers to a long run relationship between the variables. It is likely that CO_2 emissions and our variables are linked, not only in the short term, but also in the long run. A Johansen test is used to test for the presence of cointegration (Johansen 1988; Johansen and Juselius 1990).
4) We estimate our VEC model.
   - The VEC model is estimated using the integration of the variables identified in step (1), the lag length identified in step (2) and the number of cointegrating vectors identified in step (3).

4.1 Testing for Stationarity

We test for stationarity using Augmented Dickey-Fuller tests, the results of which are displayed in Table 1. The variables are non-stationary (i.e. possess a unit root) in levels but stationary in first differences, implying that all variables are integrated of order one, *I*(1). As the data is all *I(1)* this implies it is possible to progress to stage 2 of our estimation strategy.

Table 1: Dickey Fuller Tests

	Levels	Growth Rate
CO_2	-1.886	-3.616***
GDP	-1.996	-3.412***
K	-1.786	-3.605***
URBAN	-2.077	-1.734* .
ENERGY	-2.067	-4.220***
OPEN	-2.04	-4.803***

Note: ***, ** and * indicate significance at the 99, 95 and 90 percent level.

4.2 Selecting the Appropriate Lag Length

When specifying our VEC model we begin by selecting the appropriate lag length using Schwarz's Bayesian information criterion. A lag length of two was selected. It is standard in

existing literature to select the appropriate lag length of a model using an information criteria test such as Schwarz's Bayesian information criterion (Doran and Fingleton 2013).

Table 2: Selecting lag Length

Lag Length	SBIC
0	-12.4932
1	-23.5138
2	-23.5991*
3	-22.7759
4	-23.485

Note: * indicates optimal lag length.

4.3 Testing for Cointegration and Estimating the VEC Model

Next we choose the appropriate model specification using the Pantula principle. This principle helps us identify the number of cointegrating vectors and determine whether it is appropriate to include a constant or a trend in the short run or long run components of the model. The full unrestricted VEC model is specified in equation (1):

$$\Delta Z_t = \Gamma_1 \Delta Z_{t-1} + \ldots + \Gamma_{k-1} \Delta Z_{t-k-1} + \mu_1 + \delta_1 t + u_t + \alpha\left(\beta' Z_{t-1} + \mu_2 + \delta_2 t\right) \quad (1)$$

Where Z_t is an n*6 matrix containing our six endogenous variables for n time periods. The Γs are n*n matrices of coefficients, μ_1 and δ_1 are n*1 vectors of parameters and u_t is an n*1 vector of error terms. Also α and β are n*r rank matrices, so that μ_2 and δ_2 are r*1 vectors of parameters.

We start with the most restricted form of the VEC specification (placing restrictions on all the parameters in equation (1)) and sequentially progress to the most relaxed specification, testing along the way for cointegration using Johanson's rank test [see Doran and Fingleton (2013)]. We find that our model should include constants (not trends) and that there are two cointegrating vectors.[4] We estimate this model using ordinary least squares (OLS). The next section presents the results of our empirical analysis.

5. Results

To analyse the results of our analysis we present impulse response functions (IRFs). A selection of orthogonalised IRFs obtained from our estimated VEC model using a Cholesky decomposition are presented in Figures 2 and 3. Impulse response functions summarize the impact of one variable on another. Essentially they assume a hypothetical shock to one variable and display how this shock propagates throughout the other variables. We present two graphs of IRFs. The first (Figure 2) shows the impact of our socio-economic factors on CO_2 emissions. The second (Figure 3) shows the impact of CO_2 emissions on the other variables in our system. The graphs show the impact of a one standard deviation shock in each equation on/from CO_2

[4] Results available from the authors by request.

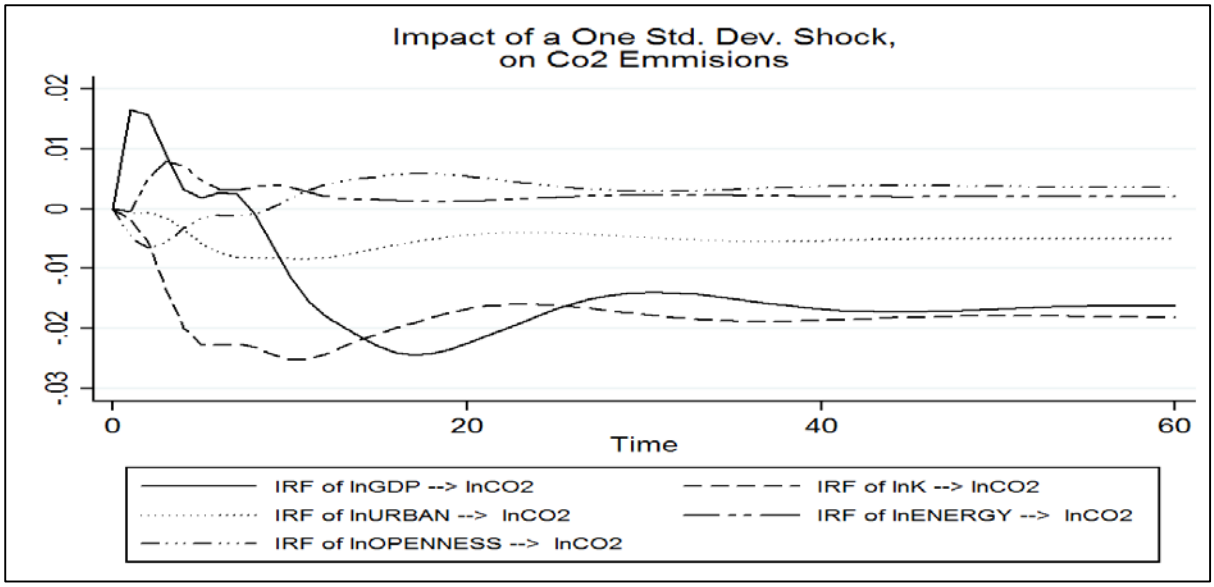
emissions. For instance we can assess the impact of a hypothetical increase in GDP on CO_2 emissions or we can assess the impact of a cut in CO_2 emissions on urbanisation. The VEC model allows for any combination of our variables to be assessed to see how they respond to increases or decreases in another variable.

Beginning with Figure 2 we note that while a positive shock to GDP causes an initial increase in CO_2, this impact changes direction in the long run and results in a long term reduction in emissions. This implies that the impact of economic growth on CO_2 emissions in Ireland is complex, with differentiated short and long run effects. In the short run (roughly up to 10 years following the GDP shock) higher levels of economic growth will result in increased CO_2 emissions, as would be anticipated. However, in the long run (after 10 years) the effect is negative. Suggesting that as the economy develops CO_2 emissions fall. This implies that in the short run economic growth can be 'dirty' leading to increased pollution, but that over time the impact diminishes and in the long run economic growth leads to lower levels of CO_2 emissions.

Regarding urbanisation, this effect is more straightforward, with the short and long run implications identical. A positive urbanisation shock (i.e. an increase in the proportion of individuals living in urban areas) leads to a decrease in CO_2 emissions, *ceteris paribus*. This suggests that as a result of increasing urbanisation in Ireland, CO_2 emissions are lower than they otherwise would have been (even though they have increased over the last 40 years). This negative association between urbanisation and CO_2 emissions is consistent with Fan et al. (2006) and implies that as Ireland continues to become more urbanised this could result in lower levels of pollution than would otherwise have been the case.

Regarding the remainder of our control variables, a positive shock to capital stock also leads to a substantial reduction in CO_2 emissions in both the short and the long run. Positive shocks to energy and openness, on the other hand, lead to short term increases in CO_2 emissions and persist as slight increases in CO_2 over the long term.

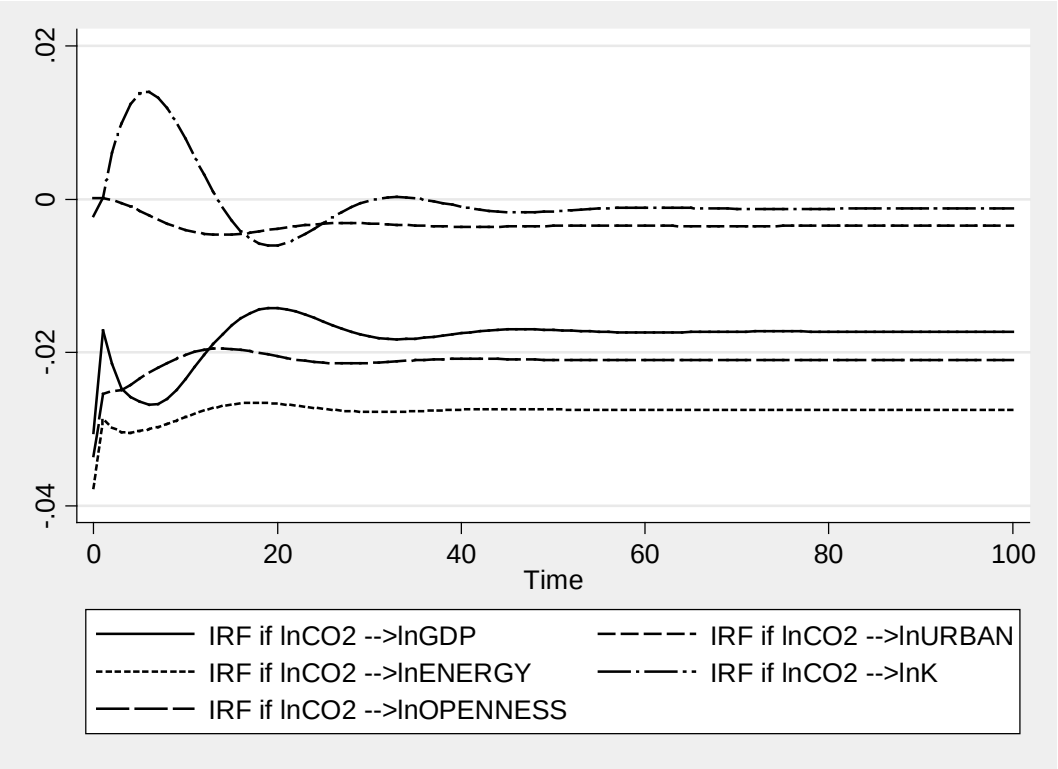
Figure 2: Impact of Shocks on CO_2 Emissions



When we consider the impact of a negative CO_2 shock on our system in Figure 3 we observe some interesting finding. This essentially addresses the second question posed by this paper; what impact might cuts in CO_2 emissions have on economic growth and urbanisation? In this instance, rather than looking at the effect of a positive shock as we did in Figure 2, we now structure our impulses to analyse the impact of a negative shock to CO_2 emissions, which is the challenge facing Ireland given its commitments under various environmental regulations.

Firstly, in terms of urbanisation, CO_2 emissions have a very small short term impact and in the long run do not significantly increase or decrease the rate of urbanisation. This leads us to believe that worsening or improving CO_2 emissions will not play an important role in determining the level of urbanisation in Ireland. Urbanisation is most likely driven by other socio-economic factors such as job opportunities, wage differentials and amenities. However, a negative CO_2 shock has a profound negative impact on economic growth. In Figure 3 it can clearly be seen that a negative CO_2 shock reduces GDP and GDP does not recover but remains permanently depressed. This suggests that by imposing cuts to CO_2 emissions economic growth will be negatively impacted. This provides an important insight and challenge for policy makers. It challenges them to consider what other policies might be implemented to ensure that GDP is not negatively impacted by curtailing CO_2 emissions. Recent research on Irish firms suggests that, at an individual level, firms adapt to changes in environmental regulation and do not suffer negative consequences (Doran and Ryan 2012; Doran and Ryan 2014). Policy makers must now consider how this might be achieved, at a national level, in the Irish case.

Figure 3: Impact of CO_2 Emissions on Socio-Economic Variables



6. Conclusions

This paper has analysed the environmental pollution and economic growth nexus for Ireland using a VEC model and data from 1970 to 2011. The results have provided four key findings which are of importance to policy makers.

The first is confirmation that economic growth results in increasing levels of CO_2 emissions. However, our results suggest that the relationship is more complex than initially envisaged. It would appear that higher CO_2 emissions arising from economic growth are only a short run problem and that in the long run economic growth actually results in lower levels of CO_2 emissions. This suggests that economic growth need not be thought of as environmentally unfriendly. However, measures may need to be adopted to ensure that the short run negative consequence of growth are mitigated as much as possible, as increased pollution, even though only present in the short run, is not a desirable outcome of growth.

The second finding is that increased urbanisation leads to lower levels of CO_2 emissions. There are a number of possible reasons for this, such as reduced emissions from transport as more individuals can avail of public transport networks and the ban on smokeless fuels in Irish cities and large towns. This finding suggests that, from an environmental perspective, urbanisation in Ireland should not be viewed negatively as it actually reduces CO_2 emissions. This may suggest that increasing investment in public infrastructure in urban areas may further contribute to cutting emissions.

The third finding relates to CO_2 emissions having no significant effect on the degree of urbanisation, suggesting that Ireland's urbanisation is driven by factors other than emissions (as would be expected). This may be the availability of employment, amenities, higher wages, or a range of other factors.

Finally, we find that a negative shock to CO_2 emissions has a negative effect on GDP. This suggests that by imposing cuts on CO_2, through government policies, while positively effecting the environment, may negatively impact the economy. The implications of this finding depend upon the reader's view of GDP and whether it is an indicator of societal wellbeing. As noted previously, Ward et al. (2016) highlight that GDP is a poor proxy for societal wellbeing and that the goal of maximising wellbeing may not necessitate maximising GDP, with other factors such as the wellbeing of natural assets, and protecting and restoring the climate and marine eco-systems being perhaps more important than a focused goal of economic growth at all costs. However, in an economy such as Ireland, which is emerging from a period of economic crisis and high levels of unemployment, the political costs of reducing GDP growth (which can reasonably be assumed will increase unemployment) may not be attractive to elected representatives. This suggests that environmental policies targeted at reducing CO_2 emissions may require two prongs; the first carbon controls to reduce emissions as is standard, but the second would be an economic policy designed to mitigate for potential damage caused to the economy resulting from these carbon controls. It is undoubtedly the case that government intervention is required to reduce emissions in order to protect the environment, however, the consequences of this intervention will have negative spillovers for the economy which may need to be mitigated but may result in net societal gains even if there is falling GDP.

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