LUND UNIVERSITY
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The environmental consequences of demographic change

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Abstract: This paper finds that an increase in population size had a disproportionately large effect on carbon emissions for OECD countries between 1990 - 2007. A 1% increase in total population increased carbon emissions by 1.3%. As the relationship is non-unitary, this suggests that as population size increases, so do emissions per capita. Moreover, countries with higher population densities produced less of their energy from alternative and renewable sources. Further to this, population growth appeared to increase Gross Domestic Product (GDP) per capita by a small increment; this increase in affluence further increased emissions. Surprisingly, and contrary to many other studies, an increase in the percentage of the population aged over 65 actually increased carbon emissions slightly. These results suggest that there are environmental advantages for countries projected to decrease in population size, such as Germany. Although a decreasing population may accentuate the problems of population ageing, the results of this paper suggest that instead of increasing fertility rates, it is far more environmentally friendly for countries to meet this demographic challenge by increasing the retirement age, raising productivity and training the long-term unemployed. Also, as population size in developed countries is a major cause of carbon emissions, by investing in family planning in the developing world now, governments may prevent countless future emissions once these countries gain a certain level of affluence.

Key words: Population growth, population ageing, population aging, carbon emissions, global warming

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1. Introduction

The aim of this paper is to study how demographic change in OECD countries affects carbon emissions (and therefore, in turn, global warming). The broad context in which this thesis is placed is the ability of western nations to meet their targets submitted for the 2009 United Nations Climate Change Conference (what has become known as the Copenhagen Accord). The Copenhagen Accord is set to replace the Kyoto Protocol, which becomes outdated in 2012. Most developed countries are expected to reduce their emissions by between 12 - 18% from their 1990 level, with at present an agreement that two-thirds of these reductions must be made domestically (rather than through carbon offsetting) (Den Elzen et al, 2011).

The effect of demographic change on carbon emissions is an extremely complex matter. Directly, population growth will cause an increase in the number of consumers, because there are more people to feed, clothe, transport and so on. However, the effect of a 1% increase in population will not necessarily lead to a 1% increase in carbon emissions (a unitary relationship) (Shi 2003, 29). Population growth affects CO_2 emissions through various indirect mechanisms, as each extra set of births will change the social, economic and technical conditions of the country. This means that a 1% increase in population can increase carbon emissions by more or less than 1%. Holdren (1991) notes that population growth can increase energy use per person if changes in lifestyle habits also occur. One such example is that population growth has been postulated as being in a relationship with economic growth (either increasing or decreasing GDP per capita). In turn economic growth has been said to either be: heavily linked to increases in emissions, become delinked, or even decrease emissions after a certain level of GDP per capita is reached. Furthermore, if Simon and Boserup are correct, a 1% increase in population may cause a lower than 1% increase in emissions; occurring if population growth encourages technological innovation within a Country and leads to the development of energy saving technologies.

Harte (2007) defines areas where population growth has a disproportionately large effect on carbon emissions as “multipliers”. First, if population continues to grow, we will run out of those natural resources that are non-renewable and easy to source. In turn this can lead countries to switch to materials that are less accessible and may have a higher environmental impact. Harte gives the example that once natural gas runs out, coal will be increasingly used for power generation and heating. York (2007) finds that in one of his models a 1% growth in population increases energy consumption by 2.665%, stating “societies [may] become more energy intensive, all else being equal, as their populations become large (or less intensive as their populations decline)” (2007, 869). York suggests various reasons for this, including different settlement patterns that emerge, lack of planning and the need for building more infrastructure. Dietz and Rosa (1997), using developed and developing countries for their study, note that a 1% increase in population causes a 1.15% increase in emissions, and Rosa et al (2004) find a proportional impact.

This paper is intended to be explanatory in nature. It aims to look at how strong the link is between population growth and other demographic variables to carbon emissions. Various multivariate regressions will be run, using panel data from OECD countries between 1990 - 2007. The results can then be applied to what level individual OECD members will find demographic change to be either a hindrance or a help in meeting their 2020 emissions targets. If a 1% increase in population size causes only a slight increase in carbon emissions, then demographic change is not of great importance. However, if the effect of a 1% increase in population is a 1% or higher increase in carbon emissions, then countries must factor this in when planning to meet their 2020 Copenhagen targets.

1.1 Background to the population debate

Debate has been raging for centuries between those who see population growth as negative (the so called ‘pessimists’), and those who believe technological innovation and economic growth associated with a rising population can mitigate these affects (the so-called ‘optimists’) (Sen, 1994). Malthus was among the first notable scholars to write about the problems associated with population growth. It is widely stated that Malthus in his purest form was proved wrong in terms of society since the Industrial Revolution, as the world’s population has continued to grow coupled with increasing living standards (Brander 2007). On the whole, world population growth has not been impeded by a lack of natural resources. Neo-Malthuasians broadly adopt Malthus’s theory, the main differences being that they put greater faith in birth control, and widen their studies to the effect of population on areas as broad as the natural environment and women’s rights (Schlosser 2009).

There is no doubt that the world’s population is growing. At the time of writing, the population stands at 6,918,593,410, and in one hour will be approximately 10,000 higher (Princeton, n.d.). The UN predicts a world population of between 8.1 billion (its low variant) and 10.6 billion (its high variant) by 2050 (UN 2010 A). Birth rates greatly vary between nations, and high fertility is associated with less developed countries. Furthermore, 42% of the world’s population are living in countries at, or below, replacement level fertility (UN 2010 A). Population momentum means that most countries with below replacement level fertility will not experience population decline for many years. However, various countries in Southern and Eastern Europe have experienced falling populations. Within developed countries most population growth is due to population momentum and immigration.

According to Pebley (1998), in terms of modern history, concerns about whether there were enough natural resources to sustain the world's growing population reached their peak between the late 1940s and early 1950s. Between the late 1960s and early 1970s, attention shifted towards whether the environment could sustain the pollutants that increasing numbers of people were emitting. These included radioactive waste, water pollution and pesticides. Most recently attention shifted to worldwide environmental challenges, such as global warming, acid rain and ozone depletion. These concerns began to develop from the late 1980s onwards. Furthermore, population growth has been attributed to a loss of biodiversity, including species extinction and deforestation.

One of the most prominent books in the 20th century on the dangers of rapid population growth was "the Population Bomb" (Ehrlich 1968). This drew links between the world's population growth and issues of food security and environmental degradation. The catastrophic predictions of this book have been widely criticised, as few have taken place so far; for example there has been no mass starvation in India, despite rapid population growth. Campbell (2007) states that modern environmental discourse is generally directed at excess consumption within the developed world, rather than population growth. The ecological footprint of the United States is 9.7 hectares per person compared to 0.8 in India (Weeks 2008, 479). Therefore it takes over 12 Indians to have the same ecological footprint as one American. However, it seems that consumption patterns will have to increase in the developing world for a certain acceptable standard of living to take place. Dias et al (2004) state that universal access to electricity is an important prerequisite to development; therefore it seems extremely unlikely, and unfair, to assume that countries such as India will retain such a low per capita environmental impact.

One reason that population policy seems to have become in part a taboo subject is due it being associated with coercive policies, such as China's one-child policy (Campbell 2007). China's one-child policy has been accused of having contributed to major gender imbalances within the country. Zhu et al (2009) state that sex selective abortion as a result of the combination of male birth preference and the one-child policy has meant a disproportionate amount of male children. In their study they found that the gender ratio in the 1-4 age group is as much as 126 males to 100 females. This may lead to various social problems, and it is morally questionable to have a society where a large proportion of males may never marry. Campbell (2007) pinpoints the United Nations International

Conference on Population and Development during 1994 in Cairo as the point where implicating population growth in environmental damage became no longer mainstream or acceptable.

To this day, the impact of population growth on global emissions has been understudied. There are various explanations for this. Pebley (1998) notes three reasons. First, the negative environmental impact of population growth has been taken as obvious. This line of thought holds that demographers should be more concerned with finding out why populations grow, rather than proving what is self-evident. Second, many demographers are technological optimists, or believe that demographic factors are separate from the (main) economic causes of environmental degradation. Third, environmental issues have often been seen as belonging to the natural sciences, rather than the social sciences (although this has begun to change in recent years).

Since the beginning of the 21st century, there seems to have been an increasing acceptance again that overpopulation plays a major role in environmental damage. Various environmental Non-Governmental Organisations (NGOs) have expressed views on the effect of population growth on climate change. The Sierra Club is one notable example of an environmental charity actively advocating population policy as a means of preventing environmental damage (Sierra Club, 2007). Moreover, NGOs whose sole purpose involves advocating population policies in developed countries have come into existence. One example of this is 'Population Matters' (formerly the Optimum Population Trust), who describe themselves as a "leading UK charity campaigning on population, sustainability and the environment" (Population Matters, 2011). In the USA similar pressure groups exist.

1.2 Technological Change

Julian Simon states that population pessimists "leave out entirely from their view of the world people's capacity to meet problems with new ideas which, in fact, leave us better off afterwards than we were before the problem arose" (Simon and Buckley 1982, 207). Simon reasons that if we project forward the whole of human history, we see that resources have become cheaper and more available per capita (Simon and Buckley 1982, 208). Technological optimists such as Boserup and Simon hold that population growth can drive up living standards and mitigate resource depletion, noting that the predictions of mass starvation have continually been proven wrong (Raskin 1995). Technological change appears to be exponential, and it is reasonable to assume that over the next 100 years we will not see 100 years of technological innovation, but more like 20,000 (Brander 2007). Kates (1996) notes that population growth may have been an important driver in encouraging humanity to shift from hunter gatherer society to agriculture, out of necessity, and states that historically one reason why Africa did not develop as technologically fast as Europe was due to too few people. Simon (Simon and Buckley 1982) states that a growing population can spur innovation through both supply and demand factors. In terms of supply, a larger population has more brains, meaning a greater number of potential innovators and geniuses. Moreover, a large population means that demand for new technologies is substantial, as there are more potential consumers.

Replacement is essential according to Simon. He suggests we should not think of any commodity on its own as being finite, but instead the services we get from that particular commodity. Simon (Simon and Buckley 1982) notes that instead of asking whether copper is finite, we should instead question whether the services provided by copper are limitless. The example of satellites is given as a replacement for copper in telephone lines. Satellites have not only maintained, but also enhanced, the services previously provided by telephone cables. Substitution means that the market drives technological development in ways that shift demand from scarce to abundant resources. This line of thought suggests that running out of fossil fuels will unlikely be catastrophic for humanity, as replacements will be found once these sources of energy start becoming scarce (and are thus increasing in price).

One problem with technological optimists is when it comes to global warming. The Intergovernmental Panel on Climate Change has estimated that unless developed nations reduce emissions by between 25% and 40% from their 1990s levels, global temperatures will increase by approximately 2C° (den Elzen et al 2011). If carbon emissions are not reduced, the consequences of human influenced climate change may include: reductions in global agricultural produce, rising sea levels and more natural disasters. Much of this will likely affect the poorest nations of the world most, especially Sub-Saharan Africa and South-East Asia (IPCC, 2007).

Brander (2007) notes that population pessimists observe that most technological developments have taken place in ICT and electronics, which might lead to increased energy efficiency; however, would be unlikely to heavily reduce the world's emissions. It is surprising how few technological gains have been made in non-fossil fuel sources of energy. Solar, wind and biomass have been slow to develop. Nuclear power is perhaps the one exception, but still only makes up a relatively small percentage of total energy production. Moreover, Jiang and Hardee (2011) note that technological advances are just as likely to result in increased emissions, as they create new products that require energy. Without previous technological development and the invention of the combustion engine, global emissions would be far lower.

1.3 Implementation of existing technologies

It is widely accepted that various alternative and renewable energy sources will need to develop in a mixed market for carbon emissions to reduce. No existing technology is superior enough on its own to be the answer to global energy needs. One option is an expansion of nuclear fission. Van der Zwaan notes that, assuming a threefold increase in energy demand (in part due to population growth), “a 10-fold expansion of nuclear energy could avoid about 15% of cumulative carbon emissions over the period 2000-2075” (2002, 288), stating that although this is not a complete answer to carbon emissions, it could make a significant impact in reductions. However, Van der Zwaan admits that there are many problems with nuclear energy. Nuclear power carries with it safety risks and leftover spent fuel. Moreover, Hyde et al (2008) note that there are not enough suitable sources of uranium available to sustain 100 years of nuclear fission (making the assumption of a large switch towards nuclear energy). Therefore the expansion of nuclear fission energy is at best a medium-term solution.

There has been an unprecedented growth in investment in renewable energy production. Biofuels are one example of a renewable energy source. These have been used in transportation, electricity production and area heating. Sources used in transportation include bioethanol (from maize and sugar cane) and biodiesel (from palm and rape seed oil); sources for heating include straw and willow (European Commission 2011). The European Commission places much hope in bio-energy, stating “by 2020, the contribution to the EU energy mix from cost-competitive bio-energy used in accordance with the sustainability criteria of the new RES directive could be at least 14%” (2011, 6). Bio-energy is controversial and has been implicated in deforestation and increasing agricultural prices (as land for growing these needs to either displace agricultural areas or take over previously unspoilt natural habitat) (Upham et al 2011). Algae has been held as a promising biofuel in that it does not compete for agricultural land.

Energy from wind farms generated approximately 4.2% of the electricity consumed within the EU at the end of 2008 (EEA 2009). It appears that the cost of onshore wind farms can be competitive with other energy sources, with only moderate subsidies (or a carbon tax), but the European Environment Agency (EEA 2009) admit it will be some time before offshore wind farms are nearly as cost efficient. Questions remain about potential damage to bird species resulting from wind farms, and marine wildlife (for offshore wind farms). The potential for wind farms seems to be limited by the fact that they only produce energy intermittently and therefore have to be backed up by other energy sources. On the other hand, technology converting wind energy into hydrogen would mean it could be stored and used for fuel at other times. Other options to help cope with intermittent electricity production include storing electricity through pumping it back into hydro plants when wind is producing excess energy, and releasing this hydro energy on less windy days (Murray 2009).

Geothermal electricity production is inexpensive, but the sites available are limited. However, Hammons et al (2010) note that with developments in deep drilling of geothermal wells there is the prospect of geothermal energy providing electricity on a many times expanded scale. In terms of solar energy there is potential for large increases; however, it remains expensive and the sites for efficient production are limited to certain locations around the world (although there is no doubt that the amount of solar energy reaching the earth, if properly tapped into, is astounding). Solar power has the added advantage that unlike biofuels, which compete with agricultural land or natural habitat, solar power cells can be placed in areas such as the deserts, which have a less fragile ecosystem and are not ideal for food production. Advances in solar panel production may make this technology increasingly cost efficient.

Dias et al (2004) note that various incentives to increase energy efficiency can be cost effective. Governments can mandate vehicle manufacturers to adopt certain minimum energy efficiency requirements, limit industrial pollutant levels, and encourage properties to be fully thermally insulated.

There are three technologies that today are postulated as having the potential to replace the internal combustion engine in transportation. These include hydrogen, electric and biofuel vehicles (Struben and Sterman, 2007). Technology is developing, and Struben and Sterman state that the expansion of refueling infrastructure, subsidies, and governments artificially increasing the price of oil, could all encourage an increased market for these vehicles. However, Borjession et al (2009) note that hydrogen and electric powered cars need to be supplied by hydrogen production plants in the former and power stations with the latter. Unless these are fuelled by sustainable sources then essentially the development of hydrogen and electric vehicles is merely shifting emissions from the car's exhaust to the power station. Moreover, biofuels have the problem that they either compete with agricultural land or are grown on previously untouched land (in the former threatening food supply and the latter damaging natural habitat).

Technologies also exist, and are being further developed, that may help the world to deal with the effects of climate change. Desalination can be used to convert salt water into fresh water, thus offsetting the effect of draught; however it is an energy intensive process. Furthermore, genetically modified crops may mean that food can still be grown in increasingly arid regions, at a high yield per acre. Extreme weather can be mitigated through the building of flood defenses. Increases in vecktor-borne diseases may be combated by technology. For example there have been advances in changing the DNA of mosquitoes to decrease their ability to carry malaria; it is believed that if these mosquitos are released into certain areas, their DNA will only take a few generations to spread throughout the general mosquito population (Gallagher 2011).

Population optimists such as Simon and Boserup put their faith in future technologies to provide the ability for the world's population to endlessly grow. Nuclear fusion has the potential to provide the world's energy needs for countless generations; however, we are far from having the technical means to produce a fusion plant that has a higher energy output than input. There are questions about whether an economically viable fusion power plant could ever be built (see Tokimatsu et al 2003 for an in-depth discussion on the prospects of nuclear fusion).

New generation thorium reactors are promising. Hyde (2008) states that they have the advantage of there being no possibility of a reactor meltdown, and the world's thorium reserves could supply global energy needs for the foreseeable future. Spent nuclear fuel from today's fission reactors could potentially be used as a power source for these fast breed reactors (thus having the advantage of burning up radio-active waste) (Hyde et al, 2008). However, there are still many technical issues, especially in regard to their economics.

Geo-engineering to halt global warming may make advances in the future. Carbon capture and storage (CCS) is a promising technology. The process involves capturing CO2 from industrial processes or power generation and storing it. Areas of storage include previous oil and gas wells. Bowen (2011) suggests that this technology could reduce CO2 emissions from industrial production and power generation by 85%. However, there are operational challenges (the technology is in its infancy) and there are also doubts about whether it can be economical in terms of cost and the long-term success of storage. Another proposed geo-engineering project is cloud whitening (Black, 2011). This would involve spraying substances such as sea water into clouds making them whiter. The theory holds that whiter clouds reflect more solar energy away from Earth, thus having a cooling effect. This method of geo-engineering is at present just a theory, and there are concerns that if done incorrectly it might actually result in further global warming.

1.4 The effect of population growth on alternative energy and energy efficiency

One problem with renewable energy is that it has a far lower energy density than fossil fuels. Whilst fossil fuels require a very small amount of land to operate, vast amounts of land are needed for renewable energy. Smil estimates that twice the amount of land that is in cultivation in the USA would be needed to supply its entire transport energy needs through biofuels (2006). Similarly there are questions about whether there is enough useable land available for efficient wind generation. As the world's population continues to grow, an increasing amount of renewable energy will be needed. Unless huge gains are made in agricultural production yields per acre, biofuels are going to be ethically questionable, as usually they either compete with arable land or forest. Moreover, population growth accentuates the problems of biomass by causing a decrease in the amount of global arable land per capita.

Hydroelectricity, wind and geothermal energy suffer from the fact that they are confined to limited sites (Smil 2006). Diseconomies of scale mean that the most suitable sites for renewable energy are built on first, increasing the marginal cost of sustainable energy afterwards, as less than ideal land starts to be used. This means that population growth can make investment in renewable energy more expensive and less efficient, as the marginal cost of producing renewable energy in increasingly dense countries is high (see section 3.5). Moreover, gains in energy efficiency may be wiped out by population growth; a global reduction of 20% in energy demand would be offset by a 20% increase in population (all things being equal).

1.5 The Copenhagen Accord and the OECD

To many, the Copenhagen Accord was a spectacular failure. The targets submitted were non-legally binding; each country voluntarily selected their own terms of agreement and a range of different measurements of emissions have been used (both in terms of base year and what was included in the calculations) (Den Elzen et al 2011). The EU27 have the most ambitious aims for carbon emissions reductions, aiming for between 20%-30% cuts in CO_2 emissions on 1990 levels, with an uneven distribution across these twenty-seven countries. Various technicalities are still to be agreed upon when it comes to emissions trading (Den Elzen et al, 2011).

The Copenhagen Accord shows that the majority of developed countries aim to cut their emission levels, at least to some extent, by 2020. This reflects the acceptance of the extreme negative effects that global warming may cause. Discussion of the exact dynamics of the Copenhagen Accord is not within the scope of this paper; instead it will examine how changing demographic patterns may affect both the cost and viability of achieving these targets.

The OECD's population increased by 144,894,137 between the years 1990 - 2009 (World Bank 2011). However, there is a large variance in the demographic patterns between these countries. Germany has an aging population and an increasing share of elderly people. The UN (medium variant) (2010 A) predicts that Germany's population will have increased by 989,000 between 1990 - 2020, and is projected to fall by 1,635,000 between 2010 - 2020. The percentage of those over 65 in Germany is projected to increase by 8% between 1990 - 2020, and 2.5% between 2010 - 2020. On the other hand, the UK's population is increasing fast by western standards. It is predicted that the population of the UK in 2020 will be 7,853,000 higher than in 1990, and will have increased by 3,191,000 between 2010 - 2020. The percentage of those over 65 has increased far less rapidly than in Germany (due to the UK in recent history sustaining a higher fertility rate). Between 1990 - 2020 the percentage of the population over 65 in the UK is predicted to have increased by 2.45%, and between 2010 - 2020 by 1.9%.

2. Theory

The aim of this paper is to study the effect of demographic change on carbon emissions between 1990 - 2007 for OECD countries. These results can be projected forward to give an indication of how much demographic change will affect individual OECD countries in meeting their 2020 Copenhagen Accord targets. Moreover, the results have wider applications which will be discussed in further in this chapter.

2.1 Why OECD countries are used in this study

It might be questioned why this paper chooses to study demographic change within the OECD when the majority of its member states have a replacement, or lower, fertility rate. There are various reasons for studying these countries. First, the results from OECD countries have implications for developing countries that strive to meet the developed world's living standards (which, in turn, are likely to affect their emissions per capita). Dias et al (2004) note that a certain level of carbon emissions are needed for a reasonable standard of living, for example we cannot even think about development without introducing universal electricity. India currently has an environmental footprint per person of 0.8 hectors compared to 9.7 in the USA (Weeks 2008, 479). However, with economic development it seems very likely that India's footprint will converge with that of developed nations. In one sense it seems immoral to assume that the environmental footprints of the developing world will not rise, because a certain level of carbon emissions are probably needed for an acceptable standard of living. Hot water, a guaranteed number of calories per day and a certain level of disposable income are widely accepted as important for a good quality of life. Admittedly there is the possibility of developing countries "leapfrogging over some of the steps originally followed by industrialized countries [by incorporating] currently-available modern and efficient technologies into their development process" (Goldemberg 2998, 730). However, even if leapfrogging reduces emissions associated with a country's economic development, only the most extreme optimist would argue that the developing world's ecological footprint will not rise at all in the future.

This paper makes the assumption that carbon emissions in the developing world will converge with those in the developed world. Therefore, by finding evidence that population contributes heavily to carbon emissions in the West, this will give extra credence to the view that aid given to developing countries through family planning is environmentally friendly. There is much evidence for a significant unmet need for contraception in the developing world, the UN stating that "29 per cent of women in developing countries have an unmet need for modern contraception" (UNFPA 2004). Moreover, female education (Schultz 2004, Hirschman 1997), and the encouragement of women's rights and employment opportunities (Hurschman 1997, Friedlander et al 1999) have been charged with contributing to low fertility rates.

Another reason for studying OECD countries is that it helps to put population and fertility decisions back on the agenda, rather than focusing primarily on excess consumption as the cause of environmental problems. Although most OECD countries will experience a negligible growth in population, the community is not homogenous. In 2000, a UN report (UN 2000) suggested that for the UK to keep a constant population between the years 2000 - 2050 it would need a net migration of approximately 53,000 annually. Britain is receiving more immigrants than this amount and is therefore experiencing population growth. On the other hand, the report predicted that Germany needs a net migration of 344,000 annually to keep its population constant, less than it has been receiving (and in the next few years its population will begin to fall). This issue presents various questions. Should the United Kingdom get some kind of dispensation on its 2020 Copenhagen carbon reduction pledges as a result of its population growth? On the other hand, Germany has maintained a much lower fertility rate than the United Kingdom; so should there be some reward for having a society that encourages a low birth rate? (As it is total emissions that cause global warming and not emissions per capita).

Much population growth within the OECD is caused by immigration from the developing world, further complicating the issue of demographic change and its environmental impact. Each immigrant obviously adds one extra person to the population of the receiving country; however, immigration can cause more rapid population growth if immigrants are of child-bearing age, have higher birth rates, or conceive their first child at a younger age (thus narrowing the space between generations). Moreover, if the immigrant adopts the lifestyle of the receiving OECD country, their individual emissions will increase as compared to when in their homeland (Kraly 1998). Perhaps it could be seen that it might be more environmentally friendly for countries with low birth rates to encourage immigration, rather than attempt policies to increase fertility levels, in an effort to prevent population decline. It must be noted, however, that replacement migration is a short-term, or at most medium-term, solution to population ageing, as immigrants also become old themselves (UN 2000).

2.2 What this study aims to achieve

There are various moral arguments for limiting carbon emissions and thus global warming. The list of problems that may develop as a result of global warming are huge, and the following are by no means exhaustive: rising sea-levels affecting low lying coastal regions around the globe; increases in extreme weather (including the potential for more rainfall at higher latitudes and less in regions already prone to drought); reduction in crop yields in much of the world (although there is a potential for increased crop yields at higher latitudes); saltwater intrusion into fresh water sources; an increased pace of species extinction; a threat of an increase in diseases such as malaria (UNFCC C n.d.).

Within the discipline of demography there appears to be much literature that is pro-natalist in terms of population in the developed world. Many articles view lowest-low fertility (below 1.3) as exclusively negative (for example see Kohler et al 2006). Population ageing is caused by low fertility rates combined with mortality decline in the elderly; this lowers the old-age dependency ratio and puts pressure on public services, especially pensions and healthcare. Therefore the effect of population ageing is postulated as being disastrous for public finances and the ability for countries to provide for their elderly. This study provides a counterweight to pro-natalist literature, suggesting that if population growth is a major contributor to climate change, then there are also advantages in regard to countries with very low fertility rates. This means perhaps that instead of developed countries encouraging higher fertility rates, they could look to alternative means of offsetting the problems of a worsening old-age dependency ratios, such as: training and incentivising unemployed citizens back to work, raising the pensionable age, and encouraging those finishing school and university to enter employment as soon as possible (see Anderson and Hussey 2000). Moreover, various other cuts to public expenditure could help keep state finances healthy.

2.3 Why the OECD is a fairly homogeneous entity to study

Environmental issues are different between OECD countries and developing countries. The OECD has many shared characteristics, and these include the causes of carbon emissions. In the developing world a major cause for CO_2 emissions is a decline in forested area, especially rainforest. However, this is not the case among the OECD. See below:

Table 1: percentage of land total made up by forest:

Country	Forested Area 1990(%)	Forested Area 2010 (%)	Difference (%)
OECD			
Denmark	10.5	12.8	2.3
France	26.5	29.1	2.6
Germany	30.8	31.8	1
United Kingdom	10.8	11.9	1.1
Sweden	66.5	68.7	2.2
Non-OECD			
Bangladesh	11.5	11.1	-0.4
Brazil	68	61.4	-6.6
India	21.5	23	1.5
Indonesia	65.4	52.1	-13.3
Pakistan	3.3	2.2	-1.1
Peru	54.8	53.1	-1.7
Venezuela	59	52.5	-6.5
Taken from World Bank 2011			

Another reason for using OECD countries in this paper is because they are all free-market, and at least moderately developed, economies. We can use the situation within the OECD to predict what might occur when developing countries gain a certain level of affluence and development.

2.4 Existing literature

Jiang and Hardee (2011) have noted the lack of studies in demography and the environment. Moreover, they question why the studies that do exist have often been disregarded by the scientific community and policymakers. Previous relevant studies include the following:

Shi (2003), used panel data between 1975 - 1996 from developed and developing countries to look at the effect of population on emissions. Cole and Neumayer (2004) looked at the effect of population variables on CO_2 and SO_2 between 1975 - 1998 for 86 different countries. Martinez-Zarzoso et al (2007) looked at variables contributing to carbon emissions (including population) within EU countries between 1975 - 1999, finding that there is a more than 1% effect on CO_2 from a 1% growth in population in accession EU countries, and a less than 1% effect for the established EU countries. York (2007) looked at the 14 founding EU members between 1960 - 2000; applying the coefficients to 2025 (the dependent variable that was used was commercial energy instead of CO_2 emissions). York found population growth had a disproportionately large effect on emissions. Hamilton and Turton (2002) implemented a decomposition analysis to look at the main factors causing emissions to either rise or fall between 1982 - 1997 in OECD countries; population and GDP growth were major causes of increasing emissions. During times of falling emissions, decreasing energy intensity in the service and industry sector were the main contributing factors.

This study is novel in various respects. Previous studies did not include alternative and renewable energy as a variable. Only York (2007) applied their results to the situation past 2000. Moreover, only Hamilton and Turton (2002) looked exclusively at OECD countries (the biggest emitters per capita). None of these papers quantitatively studied the effect that population growth has on economic growth (and in turn the environment).

See below for a summary of the results found by previous studies:

Table 2: Results from other studies

Study	**% increase in carbon emissions per 1% increase in population**
Dietz and Rosa 1997	1.15%
Shi 2003	1.43%
York et al 2003	0.98%
Rosa et al 2004	1.02%
Cole and Neumeyer 2004	0.98%
Taken from Jiang and Hardee (2011)	

2.5 definitions

The labeling of the terms “developed” and “developing” is in regard to a country’s place on the Human Development Index. Countries that the UN classes as “very high human development” and “high human development” will be classed as ‘developed nations’ or ‘advanced economies’. Countries that are classed by the UN as “low human development” are classed as developing countries (See UN 2010 B for a full list of these countries).

2.6 Limitations

As this paper uses panel data from 33 countries, the results do not cohere to any individual nation-state. Instead the results give us an indication of the general opportunities and threats that might result from changing demographic patterns within advanced economies. The results lose some validity when applied to the future, as the relationship between demographic change and carbon emissions will in all likelihood change to some extent over time and space, especially due to future technological innovations. Nevertheless, the results of this study may show that population size is at least as important as excess consumption in damaging the natural environment. It is unlikely that these results can be applied to developing nations in their present state, as the links between population, economic growth and the environment is likely to be totally different (see section 3.4 for an explanation of this).

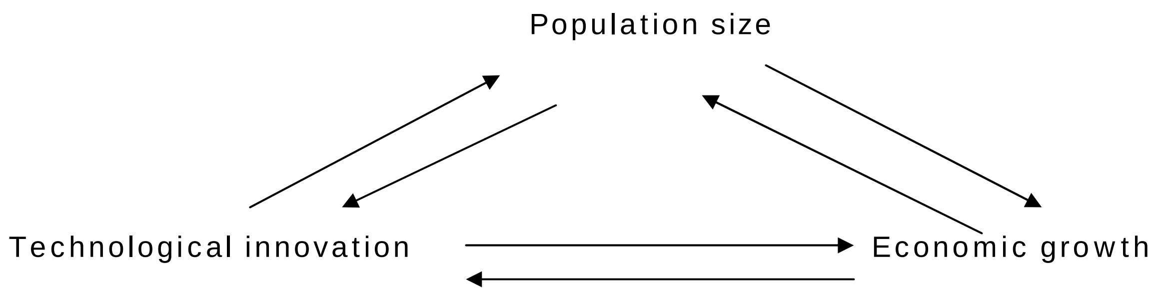
Migration as a variable will be omitted because, as Kraly (1998) states, if we look at the effect of migration on emissions we have to study the extent to which immigrants adopt the consumer habits of the receiving country, their birth rate, the age of the immigrant and their chance of being involved in environmental groups. However, immigrants are a heterogeneous bunch and their environmental impact is likely to vary hugely. Due to this difficulty, migration will be linked to the wider topic of population policy. Therefore immigration will only be viewed in terms of its impact on the age structure and population of the receiving country (for example one immigrant to the UK aged 27 years old = one UK citizen aged 27 years old).

2.7 Theoretical framework

Pebley (1998) notes that studies in environmental demography can be divided into either case studies or macrosimulations/projections. Due to the limited nature and breadth of case studies, this thesis takes the projections approach, which means the results can be applied to future changes in population size and structure. Most previous studies have included the IPAT formula, originally developed by Paul and Anne Ehrlich (Weeks 2008). This views emissions as a result of the following formula: environmental impact = population size * affluence * level of environmentally damaging technology (Martinez-Zarzoso et al 2007). Rosa et al (2004) use what they call the STIRPAT approach (Stochastic Impacts by Regression on Population, Affluence, and Technology). This measurement is useful because it indicates that CO_2 emissions are multi-causal (no factor on its own can explain everything).

The IPAT approach is shrouded in controversy, and is not universally respected. IPAT can be seen as overly simplistic, for the reason that “technology” and “affluence” can be in part a product of “population”. This has lead Jiang and Hardee (2011) to question the IPAT model for assuming that population, affluence and technology all have proportional effects. This is because, as noted in section 1, technological optimists tend to assume that population growth fuels technological innovation and affluence.

Figure 1: the problem with IPAT's assumption of proportional impacts:



Due to the problems with IPAT, this thesis will regress economic growth on population growth, and then carbon emissions on economic growth.

Although the IPAT model is overly simplistic in assuming a unitary relationship between the 'P', the 'A' and the 'T', it is useful in so far as it shows that population growth without environmentally damaging technology and affluence is not particularly harmful to the environment. Moreover, it warns us that once affluence and technological development take place in the developing world, high populations in these countries will become an increasing threat to the natural environment. This study therefore keeps IPAT in mind as a starting point; however, it sides with those more skeptical of the ability of this approach to explain the complicated tripartite relationship between population, the economy and technology.

3. Hypotheses

3.1 Hypothesis 1: population size has a 1% or higher effect on carbon emissions

From previous research, as well as a priori reasoning, population size appears to have a direct effect on emissions. As mentioned in section 2, the relationship can be unitary or non-unitary (if non-unitary, a 1% increase in population may cause a correspondingly higher or lower than 1% increase in emissions).

3.2 Hypothesis 2: those over 65 years old emit less carbon emissions than the general population

The number of people over sixty-five years old is expected to increase between now and 2020 for the majority of OECD countries. Between 2010 - 2020 the percentage of Germany's population over 65 years old is projected to grow by 2.5%, and the United Kingdom's by 1.9% (UN 2010 A). The number of those aged 65+ within the OECD as a whole has already increased by 2.4% between 1990 and 2007 (World Bank 2011). An ageing population may contribute to reductions in emissions.

Dalton et al (2008), using the example of the USA, found that population ageing significantly reduces the potential for emissions (using households as the unit for analysis). The reason for this is due to consumption patterns, especially in regard to transport (prskawetz et al 2004). Moreover, it is stated that retirees produce less emissions because they are not involved in the productive capabilities of the economy. Similarly Liddle and Lung (2010) found that retirees have lower emissions when it comes to transport and residential energy use. On the other hand, some studies have found different results. O'Neill and Chen (2002) found that energy use for heating and cooling was higher among retirees. York (2007) found, despite his original hypothesis being the opposite, that a higher percentage of the population over 65 does in fact increase carbon emissions.

3.3 Hypothesis 3: Population growth among the OECD countries increases GDP per capita

This relationship is important to test because if economic growth increases emissions, and population growth increases economic growth, then population size has an even larger effect on emissions than might seem apparent. We can see from the IPAT model that if population growth increases affluence, then the effect of population size on the environment may be far greater than previously thought. If, for example, population growth of 1% increases carbon emissions by 1% directly in a unitary relationship, this might miss out on the fact that population may further increase GDP per capita by 1% during the same time period. If GDP per capita growth of 1% increases carbon emissions by 0.5% then population growth of 1% has in fact increased emissions by 1.5% (1% directly through having more consumers, and 0.5% indirectly by supporting economic growth).

Links between population growth, economic growth, and carbon emissions are firmly based on previous research (for example see Ahlburg 1998). Population optimists point to the economic advantages of population growth for the economy. Those who believe that population growth increases GDP per capita tend to argue that this is due to an increased domestic market, more innovators and gains in economies of scale. Bloom et al (2001) note the variety of views on the effect of population growth on the economy. These can be divided into those who believe it has a negative effect, those who believe it has a positive effect, and those who believe it has no effect at all. Population pessimists tend to argue that when a population grows, capital has to be diverted to building infrastructure to accommodate people (housing, transport, and so on). This means that as a country experiences population growth, many of the productive capabilities of the economy are used to accommodate these people (Bloom et al, 2001). This idea holds that much available capital has to be used to build infrastructure for these extra people, which is a relative constraint on investment in other parts of the economy.

3.4 Hypothesis 4: increased GDP per capita among the OECD countries increases carbon emissions

Dinda (2004) notes that before the 1970s, people thought that the relationship between economic growth and emissions was largely unitary: a 1% increase in GDP per capita would roughly equal a 1% in CO2 per capita. However, since the 1990s there has been a growing school of thought that there is an Environmental Kuznets Curve (EKC). This is an application of the Kuznets Curve, which states that income inequality rises in the early stages of economic development, but then the trend reverses after a certain level of economic growth takes place. This can be demonstrated by an inverted U-shape curve. Similarly this can be applied to the environment. During early economic development, with growth in GDP per capita and a shift towards an industrial economic base, emissions increase; however, once GDP reaches a certain level, further economic growth no longer increases emissions, and may even lead to improvements in the environment. Martinez-Zarzoso et al (2007) state that although there have been many studies on the link between GDP and carbon emissions, results have varied considerably. Studies can be grouped into those who find increasing GDP always increases emissions, those who found an EKC (and a decrease in emissions after a certain level of economic growth), and those who state that there is no relationship at all. Because of the proposed EKC it seems reasonable to assume that the relationship between economic growth and carbon emissions changes over time and space.

Dietz and Rosa (1997) and Dinda (2004) suggest that there are two main structural reasons for the EKC:

First, before a country starts to develop economically it is usually an unmechanised agrarian economy, with very few emissions per capita. Once a country starts to develop, it builds an industrial base, which is very energy intensive. However, with further development, when a country reaches a certain level of affluence, it begins shifting to a less carbon intensive service economy. Countries with highly advanced economies appear more likely to regulate environmental pollutants, causing a race to the bottom, whereby firms within heavy industry move to developing countries (where there is less regulation on pollution). This process may have increased due to globalization (Dander 2004).

Second, as a country becomes more affluent, it becomes more likely to invest in energy efficiency. There are many reasons for this. In higher income countries people may invest in environmental charities, change their consumer habits to buying environmentally friendly goods, and lobby government for regulations on pollution. Also wealthier countries can afford to spend more on positive environmental measures such as investing in energy efficiency initiatives (Dinda 2004).

When it comes to carbon emissions, Dinda (2004) notes that previous studies have found some evidence for the EKC for local air pollutants, but less for carbon emissions. The importance of the EKC in the population debate becomes apparent if population growth increases economic growth (see section 3.3).

3.5 Hypothesis 5: Alternative and Renewable energy sources will be lower in countries with higher population densities

When there is less land per capita available, renewable sources may become more expensive and less efficient. There can be economies of scale with regard to installing alternative energy, for example the more wind energy set up, the cheaper each individual turbine may become. However, economies of scale in manufacturing may be completely outweighed by diseconomies of scale, where the most efficient sites for renewable energy are built on first, increasing the marginal cost for additional sites (as the most efficient areas are used up first).

4. Data and Methods

This paper will use panel data from OECD countries (apart from Israel, due to data issues) between 1990 - 2007 to run three separate regressions. Most variables have 594 observations, with a strongly balanced dataset. All data is taken from the World Bank (2011). All the variables are expressed in their natural logarithm, unless they are in percentages to begin with (for example the percentage of the economy made up by industry). By logging these variables we can see how much a 1% increase in the independent variable affects the dependent variable, meaning that we can speculate on the effect of growth. The regression will test for fixed effects (for more information see Hill et al 2008, 391-398), and a significant P-value is taken as being 95% or over. See appendix I for a table of descriptive statistics.

4.1 Population (total), population growth (%) and population density (per sq. km).

The highest population throughout the whole period was the United States, being 301,580,000 in 2007. Population growth is used in ‘regression 2’ instead of population total; this is because hypothesis 3 is seeing whether GDP per capita is higher in countries with faster growing populations. The majority of countries in the dataset have seen a growth in population; however, there is a large divergence in this increase. Australia, Luxembourg, New Zealand, Turkey, the United States and Chile have seen their population grow on average by over 1% per year between 1990 - 2007. The

Czech Republic, Hungary, Poland and Estonia have seen a slight decline in their population (mainly due to emigration, low fertility and high mortality rates).

In the final regression testing of how population affects alternative and renewable energy, population density is used. This is because it is hypothesised that population growth decreases the ability of countries to provide clean energy for themselves due to an increased population density. The densest population recorded was the Republic of Korea with 500 people per square kilometer in 2007. The lowest population density was Australia in 1990, with 2.2 people per square kilometer.

4.2 Percentage of the population over 65 years old (Over 65 (%))

This is the percentage of the total resident population aged over 65 years. The reason why this variable has been used instead of mean age is because a higher mean age could merely be caused by a fall in those at younger ages (rather than an increase in the elderly). As mentioned in section 3.2, it has been postulated that those aged above 65 emit less carbon per capita. The country with the highest percentage of their population over 65 years was Japan in 2007, with 20.9%. The lowest percentage of the population aged over 65 was Turkey in 1990 with 4.08%. Again there have been great disparities between countries in terms of change throughout the period. Denmark, Ireland, Norway, Chile and the United States have seen a slight average annual decrease across the period.

4.3 Agriculture as a percentage of the economy (Agriculture%)

This is the percentage of GDP in an economy gained from the agricultural sector, derived from each country's national accounts. Hamilton and Turton (2002, 70) state that during the last two decades agriculture has become increasingly energy intensive. In all countries within the OECD the share of the economy made up by agriculture has fallen throughout the period.

4.4 Energy Imports (%)

This variable is used to control for the possibility that a country's carbon emissions may appear lower if energy is purchased from another country, or higher for net exporters of energy.

4.5 Imports of goods and services (%)

This takes the value of goods that are imported from, and exported to, the rest of the world. Curran and De Sherbinin (2004) note that there is essentially an interlinked framework between production, consumption and population. Ultimately if developed countries simply reduce emissions by shifting production of heavy industrial goods abroad then we are essentially at a zero-sum game in terms of global emissions. This thesis speculates that if an OECD country derives a high percentage of its GDP from imports and exports, this means that much of its heavily polluted industry will have been outsourced abroad, therefore making the country's CO2 emissions appear lower than they really are.

4.6 The percentage of the economy made up by industry (Industry %)

This is the percentage of GDP that a country derives from manufacturing, mining, construction, electricity, water and gas. There are wide disparities in this dataset. Many of the ex-Soviet countries had industries which made up a large part of their economy in the early 1990s. Poland and the Czech Republic had around 50% of GDP made up by industry in 1990, with this decreasing to 25% and 29% respectively by 2007. The Slovak Republic had over 60% of its GDP derived from industry in 1990. The economies least made up by industry were Greece with 18.7% in 2004 and Luxemburg with 15.4% in 2006. Norway is one of the few countries that had seen its percentage of industry increase throughout the decade, reaching a peak of 44% in 2006. This has much to do with the extraction of North Sea oil and gas.

4.7 Alternative and renewable energy (%)

This is the percentage of the total energy use which a country produces from sources that do not emit CO2. The data is highly mixed in regard to this variable. Iceland has the highest percentage of energy derived from alternative and renewable sources with 80.6 % in 2007 (up from 67% in 1990). In most years France has derived around 45% of its energy from these sources; however, this has much to do with nuclear energy (making up 78% % of its electricity supply in 2007).

4.8 Nuclear Energy (%)

This variable is used in 'regression 3' to control for whether a country has a high level of alternative and renewable energy due to the fact that they use nuclear fission for much electricity generation. 15 countries in the dataset did not generate any energy from nuclear fission during the period. France and Belgium generated the highest percent of their electricity through this energy source, with the former varying from between 75 - 78% and the latter 55 - 61%.

4.9 GDP (constant $US 2000) and GDP per capita (constant $US 2000)

As discussed in section 3.4, GDP has been postulated as having an Environmental Kuznets Curve. The country with the highest GDP was the US with $11,671,492,957,946 in 2007, and the highest recorded GDP per capita was Luxemburg, above $56,625 in 2007. The lowest GDP per capita was Estonia in 1993 with $2744.

4.10 Carbon emissions (kt)

This is the total level of CO2 emissions measured in kilotonnes (kt). Other greenhouse gasses are added by taking their equivalent effect given in carbon emissions. For all years, the US was the largest emitter of carbon emissions, with 5,836,474 kt in 2004. Between 1990 - 2007 various countries experienced a decline in carbon emissions; this was especially prevalent in Central and Eastern European countries. Germany's carbon emissions reduced by 18% (between 1991 - 2007), and the United Kingdom's emissions reduced by 5.4% during this period.

5. Results

These are the results of the three regressions of OECD countries between 1990 – 2007.

Table 3: regression 1

VARIABLES	Carbon Emissions
Over 65 (%)	0.011** (0.004)
Industry (%)	0.010*** (0.001)
Agriculture (%)	-0.012*** (0.004)
Energy Imports (%)	0.000*** (0.000)
Imports of Goods and Services (%)	-0.004*** (0.001)
Alternative and Renewable Energy (%)	-0.012*** (0.002)
Population (total)	1.313*** (0.113)
GDP (constant $US 2000)	0.164*** (0.039)
Constant	-14.170*** (1.539)
Observations	571
R-squared	0.611
Number of Countries	33
Standard errors in parentheses	
*** p<0.01, ** p<0.05, * p<0.1	

Table 4: Regression 2

VARIABLES	GDP per capita (constant $US 2000)
Population Growth (%)	0.048*** (0.010)
Over 65 (%)	0.039*** (0.004)
Industry (%)	0.001 (0.001)
Agriculture (%)	-0.053*** (0.003)
Energy Imports (%)	-0.001*** (0.000)
Imports of Goods and Services (%)	0.006*** (0.001)
Constant	8.997*** (0.095)
Observations	590
Number of Countries	33
R-squared	0.738
Standard errors in parentheses	
*** p<0.01, ** p<0.05, * p<0.1	

Table 5: Regression 3

VARIABLES	Alternative Energy (%)
Nuclear (%)	0.349*** (0.029)
Density (%)	-4.350** (1.996)
Agriculture (%)	-0.213*** (0.069)
Industry (%)	-0.128*** (0.027)
Over 65 (%)	-0.086 (0.088)
Energy Imports (%)	0.005 (0.003)
Imports of Goods and Services (%)	0.036*** (0.011)
Constant	32.657***
	(8.701)
Observations	590
Number of countries	33
R-squared	0.299
Standard errors in parentheses	
***** p<0.01, ** p<0.05, * p<0.1**	

5.1 Hypothesis 1: An increase in population size increases carbon emissions by more than 1%: ACCEPTED [see regression 1]

A 1% increase in population size raises carbon emissions by 1.3%, and is statistically significant.

5.2 Hypothesis 2: An increase in the percentage of those over 65 years of age decreases carbon emissions: REJECTED [see regression 1]

The results suggest that those over 65 years old emit more carbon emissions than the general population. We can see in table 3 that an increase in the percentage of the population over 65 years of age actually increases emissions by 0.01%%, with a significant p-value.

5.3 Hypothesis 3: Population growth increases GDP per capita: ACCEPTED [see regression 2]

We see here that population growth of 1% increases in GDP per capita by 0.048%, with a significant p-value. These results are only important for the environment if the next hypothesis is accepted (that increasing GDP per capita increases carbon emissions).

5.4 Hypothesis 4: An increase in GDP increases carbon emissions: ACCEPTED [see regression 1]

An increase in GDP of 1% increases carbon emissions by 0.16%, and is statistically significant.

5.5 Hypothesis 5: Countries with dense populations provide a lower share of energy from renewable sources: ACCEPTED [see regression 3]

We can see from the regression results that a 1% increase in population density results in a 4.4% decrease in the percentage of energy gained from renewable and alternative energy sources. The p-value is significant.

Table 6: Results table

Figure 4: Results Summary		
	Hypothesis	**Result**
Hypothesis 1	An increase in population size increases carbon emissions by 1% or more	Accepted
Hypothesis 2	Those over 65 years old emit less carbon emissions than the general population	Rejected
Hypothesis 3	Population growth increases GDP per capita	Accepted
Hypothesis 4	Increases in GDP per capita increase carbon emissions	Accepted
Hypothesis 5	Higher population densities within countries lead to lower levels of alternative and renewable energy	Accepted

6. Discussion

Hypothesis 1 being accepted suggests that population had a disproportionate effect on carbon emissions, even when GDP and alternative energy were controlled for. This means an increase in population size changes the socio-economic character of a country in a way that makes it more carbon intensive. There are various potential explanations for this. Extra housing and infrastructure must be built to accommodate an increasing population (when there is no population growth there is not the same need to build additional infrastructure). We can apply the population coefficients to the UN's (2010 A) medium variant population predictions for the UK and Germany. The UK's population is expected to increase from 62,036,000 in 2010 to 65,802,000 in 2020, which would entail just under an 8% increase in carbon emissions. Germany's population is predicted to fall from 82,302,000 in 2010 to 80,988,000 in 2020, and this would result in a 2% reduction in CO_2 emissions.

Hypothesis 2 can be rejected, as an increase in the percentage of those over 65 years old slightly increased emissions. Slowly growing populations tend to lead to an increased percentage of elderly people within the country. It has been proposed that this may in turn lead to reductions in emissions, but this was not the case for the countries studied in this paper. The coefficient was small; meaning 1% more of the total population over 65 resulted in a 0.01% increase in emissions. This means that Germany may suffer slightly in terms of carbon emissions as compared to the UK, which has a higher and more rapidly increasing share of those aged over 65. As the coefficient was small it seems governments do not need to be overly concerned with the environmental impact of an ageing population.

Hypothesis 3 suggests that population growth has a small effect on economic growth. Population growth of 1% increases GDP per capita by 0.048%. This is not a large amount, as an average annual population growth rate of 1% or higher growth was only recorded in 6 countries within the data set, therefore the highest growing populations would only benefit by a 0.048% increase in GDP per capita. Hypothesis 4 shows that a 1% increase in GDP increases carbon emissions by 0.16%. Therefore hypothesis 3 and 4 together show that population growth has an indirect effect on emissions through increasing economic growth. As both the coefficients are small, we can see that the relationship between population growth, economic growth and carbon emissions is not all that important.

Hypothesis 5 shows that an increase in population density results in a reduced ability for energy needs to be met through alternative and renewable means. Obviously all OECD countries with growing populations will experience an increased population density. Therefore, not only will countries with growing populations experience increased emissions through having more consumers, but they will also find it increasingly difficult to meet their energy needs without using fossil fuels. This suggests that the UK will find it more onerous than Germany to provide renewable and alternative energy for its population.

6.1 Policy recommendations

1) Countries must factor in the costs of demographic change when meeting carbon dioxide reduction pledges.

Countries with growing populations will have to invest more, publically and privately, in reducing their emissions to even keep there levels constant. Germany will find that carbon emissions fall purely due to a reducing population; this will increase the ease in which they can meet their 2020 Copenhagen targets. These results suggest that the UK's carbon emissions will increase by 8% between the years 2010 - 2020 as a result of population growth. In reality the UK government is unlikely to let their emissions increase, due to their Copenhagen pledges, therefore the results show that an increased population size will substantially increase the costs of Britain reducing its carbon emissions.

2) **The benefits of increasing fertility rates in low fertility countries must be weighed against the environmental damage this may cause. Countries should therefore consider solutions to population ageing that do not include increasing fertility levels.**

In an effort to reduce the old-age dependency ratio, countries have attempted to encourage higher fertility rates. For example in Russia, Prime Minister Putin has promised to devote resources to increasing the country's fertility rate (BBC 2011). The results of this thesis suggest that countries must weigh the benefits of higher fertility (such as reducing the old-age dependency ratio) against the fact that a higher population will make it far more difficult for countries to reduce carbon emissions. Whilst countries that are expecting population decline might find this negative economically due to population ageing, environmentally it is beneficial. This paper advises that before attempting to increase fertility rates, countries should consider: increasing their retirement age, providing training for the long-term unemployed, pushing young people into employment straight after education and increasing productivity.

3) **Family planning aid to the developing world should be increased.**

As developing countries focus on economic growth in an attempt to emulate the living standards of advanced economies, their emissions per capita are likely to converge with western countries. Meeting the large unmet need for contraception in the developing world will prevent a large amount of emissions when these countries emissions per capita eventually increase. If family planning causes a developing country's population size to grow by 1% less, then this may cause a 1.3% reduction in carbon emissions when this country reaches the status of an advanced economy.

7. Conclusion

This thesis found that changes in population size had a significant effect on carbon emissions among OECD countries between 1990 - 2007. The effect appears to have been disproportionately large, suggesting that as populations increase in size, energy use per capita also increases. Ever since Thomas Malthus, there have been those who emphasise the negative effects of population growth (which include the impact on food supply, environmental degradation and living standards), and those who emphasise the benefits (such as increased innovation and economic growth). Since the 1990s, making an association between population growth and environmental damage became unpopular, with excess consumption being seen as the sole cause. However, in the twenty-first century, an increasing number of NGOs and academic papers have implicated demographic change in environmental problems.

Population optimists may struggle with their faith in technological innovation when it comes to global warming. Carbon emissions must decrease significantly on their present levels to prevent future global warming; however, as mentioned in section 1.3 of this paper, there is no new technological innovation that at present appears advanced enough to replace non-renewable sources. By the time any such innovation develops, global warming may be completely out-of-hand.

This thesis has found that changes in population size have a non-unitary effect on carbon emissions growth; with an increase in population of 1% raising carbon emissions by 1.3%. This suggests that society increases its per capita energy use when it increases in population size (and decreases its energy use per capita when its population falls). The effect is even greater when we consider that an increase in population density greatly decreases the amount of energy provided by alternative and renewable sources.

The number of those aged over 65 was found to slightly increase carbon emissions (by an increment of 0.01%). This contradicts various other studies. The effect of an ageing population on carbon emissions is small and should not be of too much concern. Population growth appears to increase GDP per capita; this increase in GDP per capita in turn increases carbon emissions. The effect of population growth on GDP is small, and the effect of GDP on carbon emissions is also small.

The results of this study have great relevance to the social sciences, and for policymakers, partly as a counterweight to the large amount of literature encouraging pro-natalist policies to prevent population ageing. These results therefore add credence to the view that population ageing should not be met with attempts to increase fertility rates, but instead through raising the retirement age, trying to implement full employment among those available to work and even replacement migration.

The results of this paper only apply to OECD countries, and it is likely that the complex relationship between population growth and carbon emissions is different in the developing world. However, these findings suggest that family planning aid to the developing world is sensible environmentally; because once a certain level of economic prosperity takes place, nations which are becoming increasingly affluent will find that population size has a disproportionally large effect on their carbon emissions.

8. Acknowledgements

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9. Appendix

9.1 Appendix I: Descriptive statistics:

OECD countries between 1990 - 2007					
Variable	**Observations**	**Mean**	**Std. Dev.**	**Minimum**	**Maximum**
Carbon Emissions (kt)	593	377529.9	937398.3	1890.624	5836474
over 65 (%)	594	13.37922	3.391473	4.078157	20.90595
Industry (%)	592	30.55888	6.065226	15.4009	60.11886
Agriculture (%)	592	4.204477	3.04076	.3838373	18.0929
Energy Imports (%)	594	16.87227	133.5957	- 841.7895	99.09465
Imports of Goods and Services (%)	592	39.91814	21.90016	6.893258	143.7228
Alternative and Renewable Energy (%)	594	16.25302	16.59514	0	80.62934
Nuclear (%)	594	18.03534	21.1596	0	79.07424
Population Growth (%)	594	.5963338	.6302387	- 2.576951	2.530086
Population (total)	593	3.44e+07	5.29e+07	254800	3.02e+08
Density (per sq. Km)	594	126.5831	123.8539	2.221353	499.9587
GDP (constant $US 2000)	577	5.05e+11	9.84e+11	4.03e+09	1.17e+13
GDP per capita (constant $US 2000)	594	18615.35	11241.73	2744.22	56624.73
Data from World Bank 2011					

10. Abbreviations

CCS	Carbon Capture and Storage
CO2	Carbon Dioxide
EEA	European Environment Agency
EU	European Union
GDP	Gross Domestic Product
ICT	Information and Communication Technology
IPCC	Intergovernmental Panel on Climate Change
NGO	Non-governmental Organisation
OECD	Organisation for Economic-cooperation and Development
RES	Renewable Energy Sources
SO2	Sulfur Dioxide
UK	United Kingdom
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
UNFPA	United Nations Population Fund

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