Issues relating to

Behaviour, Wellbeing and the Environment

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Declaration of Authorship

I certify that the thesis I have presented for examination for the MPhil/PhD degree of the London School of Economics and Political Science is solely my own work other than where I have clearly indicated that it is the work of others (in which case the extent of any work carried out jointly by me and any other person is clearly identified in it).

I confirm that Paper 1 was jointly co-authored with Professor Paul Dolan and that I contributed the majority of this work. All other content represents sole-authored work.

I declare that my thesis consists of 56,204 words.

Abstract

As issues of environmental degradation intensify, the interdependency between humans and the natural environment is coming more and more into focus. In particular, questions about the importance of environmental quality for human wellbeing and about how to mitigate the serious negative impacts humans are having on the environment are of ever-increasing significance. The current work addresses these issues in four empirical papers, split into two separate parts. The first section focuses on the first question, exploring the links between air quality and individual wellbeing. Paper 1 presents a spatially detailed analysis of the relationship between air pollution and a range of measures of subjective wellbeing (SWB), providing a rich picture of how the air pollution individuals are exposed to relates to how they feel. Paper 2 uses mediation analysis to investigate the behavioural production process which converts air pollution into ill-being, providing insights into the role of physical activity and visits to the outdoors play as mediators. The second part of this thesis addresses the second question. Paper 3 investigates the relationship between pro-environmental behaviour (PEB) and a range of SWB measures, shedding light on the wellbeing consequences of PEB for the individual undertaking it and providing insights into strategies to encourage it. Paper 4 tests two interventions which target electricity consumption in a hall of residence in London, providing evidence of an effective approach to reduce individuals' environmental impact. Taken together, the results of the papers present evidence of psychological and environmental win-wins which can arise from living in and helping to create a better natural environment.

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Table of Contents

List of Acronyms

APS	Annual Population Survey
ASHE	Annual Survey of Household Earnings Benefit-Cost Analysis
BEIS	Department for Business Energy and Industrial Strategy
CO	Carbon Monoxide
COMEAP	Committee on the Medical Effects of Air Pollutants
DEFRA	Department for Environment and Rural Affairs
DECC	Department of Energy and Climate Change
EQ	Environmental Quality
ESM	Experience Sampling Method
GDP	Gross Domestic Product
GPS	Global Positioning System
HDI	Human Development Index
MCA	Multiple Correspondence Analysis
MENE	Monitor of Engagement with the Natural Environment
MIDAS	Met Office's Integrated Data Archive System
OECD	Organisation for Economic Cooperation and Development
ONS	The UK's Office for National Statistics
PEB	Pro-environmental behaviour
PM_{10}	Coarse Particulate matter
$PM_{2.5}$	Fine Particulate Matter
SO_2	Sulphur dioxide
SWB	Subjective wellbeing
UK	The United Kingdom
US	The United States of America
WHO	The World Health Organisation

List of Tables

List of Figures

List of Appendices

1. Introduction

"....the environmental sciences are concerned with human problems in relation to an environment of which man is both the victim and the conqueror."

(Proshansky et al. 1970, p.5)

As the world faces major ecological crises, questions about the nature of the interdependency between human beings and the natural environment are of increasing significance. Some questions we know more about than others. Our role as conqueror, for example, is well established. Humanity's impact on the Earth since the mid-20th century has been so profound that many scientists are calling for the declaration of a new geological epoch- the Anthropocene (Zalasiewicz et al. 2015). The physical and biological sciences have provided a wealth of evidence of our impact, demonstrating that human activity is the source of many of the environmental challenges that the world is currently facing including climate change and biodiversity loss (Ceballos et al. 2015; Oreskes 2004; National Research Council 2011). With the human population currently at 7.5 billion and growing, and almost half of the Earth's surface given over to agricultural activities to feed us, our dominance is undeniable (Owen 2005; Population Reference Bureau 2017).

Other questions, pertaining to both the social and the environmental sciences, are less well elucidated. Research is all the time uncovering new links between the conditions of the natural environment and human outcomes, suggesting that we underestimate its importance in our lives (Sandifer, Sutton-Grier, and Ward 2015). We are becoming increasingly aware of the many benefits nature has to offer (Zhang et al. 2014; Guéguen and Stefan 2016; Zelenski, Dopko, and Capaldi 2015; Staats 2012; Kardan et al. 2015), for example, but also of the harm poor environmental conditions can cause us (Gatersleben and Griffin 2017; Stansfeld et al. 2005; Hygge, Boman, and Enmarker 2003). How to stem the damage we are causing to our environment is also unclear. While there has been a good deal of research into the technological and economic drivers of environmental degradation, our understanding of psychological

mechanisms underlying environmentally-significant behaviour, and of strategies which can be used to effectively encourage sustainable lifestyles, remains limited (Gifford 2011; Gifford, Kormos, and McIntyre 2011; Clayton et al. 2015). As a result, the degree to which we are, and future generations will be victims of the environment is unclear.

Within this context, the current work explores the reciprocal relationship between human beings and the natural environment, with a view to gaining insights which can benefit both. The dual goals of promoting human wellbeing and protecting the environment are not new; they feature heavily in current political and policy discourses surrounding environmental issues and have been linked to concepts such as green growth and sustainable development (Waage et al. 2015; OECD 2013). To date, however, discussions of green win-wins have largely focused on the economic benefits, for example from job creation from new green industries (Wei, Patadia, and Kammen 2010; Cairncross 1994; Payne, Wetherall, and Downy 2015), or the health benefits, for example, from climate change mitigation policies which concurrently improve air quality (Hosking, Mudu, and Dora 2011; DEFRA 2010). Research and policy discourses have paid much less attention to the psychological and environmental co-benefits that be may be available.

This thesis directly addresses this important gap. It draws on existing research and methods in economics, psychology and epidemiology to do so. Much of what we currently know about the interdependence between humans and the natural environment has come from the separate contributions of these fields (Costanza et al. 2014; Steg, van den Berg, and De Groot 2012; Pope 2000). The approach in the current work is based on the contention that research at the intersection of these disciplines has the potential to significantly further our understanding of this relationship. The research presented is also linked to social policy through its concern with human wellbeing and the policy lessons it draws from the findings.

The bulk of the work comprises four empirical papers falling under two main strands of research (see Table 1.1). Part 1 focuses on investigating the relationship between environmental quality, human wellbeing (Paper 1 and 2) and nature-based behaviour (Paper 2). It does so through the lens of subjective wellbeing (SWB) – using individuals' reports of their own wellbeing. Part 2 is concerned with pro-

environmental behaviour (PEB), investigating both its relationship with SWB (Paper 3) and evaluating behaviour change strategies to encourage it (Paper 4). All of the papers use data from the United Kingdom (UK), but many of the findings are relevant beyond the country's border.

More specifically, Paper 1 presents the first spatially detailed exploration of the relationship between air pollution and life satisfaction for the whole of the UK. It also goes beyond existing literature by exploring the relationship between the local levels of air pollution and wellbeing using a wide range of SWB measures which, in addition to capturing individuals' satisfaction with their life, assess their wellbeing day to day and how worthwhile they consider their activities to be living in their environment.

Paper 2 builds on the findings in Paper 1 by using mediation analysis to test whether less frequent visits to the outdoors and lower levels of physical activity in polluted environment explain why individuals report lower wellbeing when living in polluted environments. In addition, it provides some of the first evidence of the relationship between levels of air pollution and these behaviours, as well as these behaviours with SWB.

Paper 3 focuses on actions that individuals can take to promote environmental quality - pro-environmental behaviours (PEBs) - and investigates their relationship with SWB. Existing studies have mostly explored the relationship between single pro-environmental actions and life satisfaction. The current work, in contrast, uses a wide range of wellbeing measures and carries out multiple correspondence analysis to explore clusters within the PEBs.

Finally, Paper 4 presents the results of two natural field experiments in which intervention strategies to encourage electricity saving are tested in a hall of residence in London. Study 1 tests, for the first time, the effectiveness in terms of electricity savings of forming implementation intentions around pro-environmental behaviours. Study 2 documents a stripped back version of the intervention in Study 1 which involves presenting electricity savings tips in an if-then, 'implementation intentions style', format.

Table 1.1: The structure of the thesis

Topics covered		Subjective wellbeing	Air pollution	Nature-based behaviour	Pro-environmental behaviour
Part 1	Paper 1	X	X		
	Paper 2	X	X	X	
Part 2	Paper 3	X			X
	Paper 4				X

Paper 1 was co-authored with Professor Paul Dolan and was published in the Journal of Benefit-Cost Analysis in July 2016 (Dolan and Laffan 2016). We conceived of the idea for the paper together, then I carried out the literature review and data analysis and prepared an initial draft, following which Professor Dolan and I rewrote the paper together and submitted it for publication. Papers 2 - 4 are all sole-authored papers. Paper 2 was sent out for review by Ecological Economics, and I have been invited to revise and resubmit the paper in October 2017 once I have addressed the reviewers' comments. Both Papers 3-4 are being prepared for submission to peer-reviewed journals in the near future. The versions of the papers presented in this thesis have been adapted from their submitted versions to avoid repeating material and to include fewer and extra details where appropriate.

1.2 Part 1

The first part of the thesis explores the significance of environmental quality for individual wellbeing. It focuses on a negative element of environmental quality: air pollution. Air pollution is increasing in many urban areas around the world (World Health Organisation 2016) and is a major policy issue in the UK and beyond (DEFRA 2016, 2010). It is estimated that 59.3% of the UK population are currently living in areas where the level of air pollution is above the legal limits (Laville 2017), and the UK High Court has repeatedly ordered the UK Government to publish plans to tackle the levels of air pollution (Croft, Pilita, and 2017). In many other countries around the world the picture is just as bad, if not worse (Michael, Perry, and Riley 2017). This environmental 'bad' is of particular concern as research has linked high levels of air pollution to a whole host of negative outcomes including cardiovascular disease (Atkinson et al. 2013), traffic accidents (Sager 2016), reduced test scores (Ebenstein, Lavy, and Roth 2016), cognitive impairment (Clifford et al. 2016), criminal activity (Herrnstadt and Muehlegger 2015) and suicide attempts (Szyszkowicz et al. 2010).

Rather than adding to the list of objectively bad outcomes that air pollution is associated with, the current work instead contributes to a nascent body of literature that seeks to understand the relationship between environmental quality (EQ) and wellbeing by examining how characteristics of individuals' environments relate to how they subjectively report feeling. Interest in investigating the determinants of wellbeing using these psychological measures of wellbeing has been growing in both academic and policy circles in recent years (Graham 2012; Layard 2005; OECD Better Life Initiative 2013; Stiglitz, Sen, and Fitoussi 2009; Fujiwara and Campbell 2011; Dolan and White 2007).

Subjective wellbeing measures are not widely considered to be replacements for traditional welfare measures such as income, but rather, as complementary indicators which can provide new insights into who is doing well and who is doing badly and why (Graham 2012; Frey 2008). This approach is particularly promising in the context of non-market goods, including environmental goods such as water and air quality, where standard measures provide limited insight and can even be paradoxically positively related to environmental degradation (Frey and Stutzer 2002). The clean-ups from major oil spills, for example, are positively included in Gross

Domestic Product (GDP) calculations, but the carbon releases from the burning of fossil fuels are not (Halpern 2016). In such situations, it seems to make sense to go beyond GDP (Kubiszewski et al. 2013).

In the first part of this thesis, SWB data is used to do exactly this. The work builds on existing environmental SWB research in at least two key ways: Paper 1 uses a wider and more comprehensive range of SWB measures than has been previously used to investigate the relationship between air quality and wellbeing, and Paper 2 extends the approach by drawing on methods commonly used in epidemiological research to investigate behavioural pathways from environmental quality to SWB.

Paper 1 presents a spatially detailed analysis of the relationship between local air pollution and a range of measures of SWB. Data from the UK Office for National Statistics' Annual Population Survey (APS) and geographic mapping software are used to link local levels of air pollution to individuals' responses to the four SWB measures which have been included in the survey since 2012. These questions, hereafter referred to as 'the ONS four', measure how satisfied individuals report being with their lives, how worthwhile they consider their activities to be and their happiness and anxiety levels on the previous day. The inclusion of these four measures in the APS reflects both the increasing interest in SWB in UK government and the growing consensus within the literature that SWB is a multidimensional construct best investigated using a range of measures (O'Donnell et al. 2014 ; Stone and Mackie 2013). The ONS four assess SWB at an evaluative level, capturing peoples' global judgements of their wellbeing, but also at an experiential level, tapping into how they feel day to day. In addition, the measures assess different types of wellbeing; they assess both hedonic feelings such as happiness and eudemonic sentiments such as worthwhileness (Evans, Macrory, and Randall 2015).

While some existing work has examined the relationship between SWB and air pollution, much of it has been carried out at the macro level and focused on life satisfaction (see for example Welsch 2006, 2002; Luechinger 2010). These studies find evidence to suggest that air quality is an important predictor of SWB, but they leave many questions about the nature of the relationship between air pollution and SWB unanswered. The existing literature cannot speak to questions such as: is local air pollution is differently related to people's experiences day to day compared to how

they evaluate their lives overall? Does local air quality predict eudemonic wellbeing? The inclusion of the ONS four into the APS provides an opportunity to explore and compare the relationship between levels air pollution and different dimensions of SWB. Paper 1 makes use of these data and presents a more comprehensive picture of the relationship between air pollution and SWB than has been available to date, while also providing the first estimates of the relationship between SWB and local air pollution for a representative sample of the UK population.

Although the EQ-SWB literature, Paper 1 included, presents a growing body of evidence linking individuals' physical environments to their SWB, it has almost nothing to say about the mechanisms behind these relationships. By comparison, epidemiological research seeks to understand not only whether but also why environmental quality is related to health outcomes and explores, amongst other things, the existence of behavioural pathways from EQ to health (Maas et al. 2009; Lachowycz and Jones 2014; McEachan et al. 2015). This is commonly done through mediation analysis. Using this approach Richardson et al. (2013), for example, find that physical activity partially explains the positive relationship between green space and health in a sample of New Zealanders. The insights into the pathways from EQ to health presented by this literature highlight its potential usefulness in the context of the, in many ways parallel, environmental SWB literature. This approach can help to shed light on unanswered questions such as: why do people living in more polluted environments report lower levels of SWB? Is the relationship between air and SWB attributable to the influence air pollution has on the activities people engage in?

Upon the inclusion of the ONS four in the APS in 2012, other surveys across UK government began to incorporate the same set of measures, significantly expanding the number of research questions that can be explored in relation to SWB in the UK (Evans, Macrory, and Randall 2015). One such survey is the Monitor of Engagement with the Natural Environment survey (MENE), carried out by Natural England. This survey tracks how individuals use the natural environment in England and has included the ONS four since 2012. Paper 2 uses this data and the same geographical mapping techniques as were used in Paper 1 to explore the extent to which nature-based activities can explain the relationship between air pollution and SWB. More specifically, based on previous literature, spending time outdoors and

physical activity are identified as two potential mediators of the relationship between air pollution and SWB, and their role as pathways is tested using mediation analysis.

Paper 2 represents the first empirical work in the EQ- SWB literature to adopt this technique. The insight this approach provides expand the policy tools available to policymakers interested in enhancing wellbeing; if, for example, improving environmental conditions is not feasible or prohibitively costly behaviours identified as mediating the relationship between the environment and SWB can be targeted directly. By exploring the behavioural production process which converts environmental quality into SWB, Paper 2 deepens our understanding of why people living in polluted environments report lower SWB and what to do about it.

Together, the work presented in the first part of this thesis contributes new evidence as to whether and why air pollution relates to wellbeing, while also yielding more general lessons for SWB wellbeing research and policy.

1.3 Part 2

As we gain a better understanding of the significance of EQ for wellbeing, from the studies in Part 1 and other work, we begin to recognise the cost of our environmentally damaging activities, not just for future generations but also in the here and now, for ourselves. Importantly, while individual behaviour is understood to be at the root of many of these environmental issues, it is also widely agreed that behaviour change which sees individuals adopt more sustainable lifestyles is a necessary element of any strategy seeking to address these problems (Stern 2006; Gardner and Stern 2008; Clayton et al. 2015; Ockwell, Whitmarsh, and O'Neill 2009; IPCC 2014). The influential Stern Review on the Economics of Climate Change, for example, identifies three essential policy elements to achieve climate change mitigation: "*a carbon price, technology policy and the removal of barriers to behaviour change*" (Stern 2007, p.18). While behavioural interventions are most directly related to the last element, individual behaviour is relevant to all three policy strategies as supporting green policies including carbon taxes and purchasing green technologies also represent PEBs (Steg and Vlek 2009; Steg, Perlaviciute, and van der Werff 2015).

Despite the recognised importance of PEB adoption, however, policies which aim to promote sustainable lifestyles have had limited success in the UK and other developed countries (Lucas et al. 2008; Whitmarsh and O'Neill 2010). There is evidence of the adoption of PEBs in a number of developed nations is stagnating and, in some cases, even decreasing. Recycling rates, for example, dropped for the first time in the UK in 2015 (Vaughan 2016). In the US, data from a Gallup poll suggest people were no more environmentally friendly in their actions in 2010 than they were in 2000 (Morales 2010), and another study found that conservation behaviours amongst young people are trending downwards (Wray-Lake, Flanagan, and Osgood 2010).

The encouragement of sustainable lifestyles, therefore, remains a major and important challenge in the behavioural sciences (Kaplan 2000; Gifford, Kormos, and McIntyre 2011). Central to this challenge is understanding the drivers of PEB and identifying behaviour change interventions that deliver real environmental benefits. Part 2 of this thesis contribute to these issues. Paper 3 investigates how PEB engagement relates to individual wellbeing, with a view to understanding the nature

of PEB and gaining insights into how to encourage it. Paper 4 rigorously tests behaviour change strategies looking to promote PEB (Paper 4).

Paper 3 of the thesis focuses on understanding the wellbeing consequences of pro-environmental behaviour for the individual themselves. SWB data is increasingly being used, as it was in Paper 2, to understand the extent to which 'the good life' relates not only to who and where we are but also to what we do. Existing research has explored how many activities, including commuting (Stutzer and Frey 2008) physical activity (Dolan, Kavetsos, and Vlaev 2014) and social media use (Valenzuela, Park, and Kee 2009), relate to reports of life satisfaction. Some work has also gone beyond life satisfaction, and linked activities to different types of SWB measures. White and Dolan (2009), for example, find that spending time with children is reported to be more purposeful than pleasurable, while the opposite was found to be true of watching television.

The relationship between activities and SWB is particularly of interest in the context of pro-social behaviours, of which pro-environmental behaviour is a subset. A long-standing debate exists within the literature as to the 'purely altruistic' nature of pro-social behaviours, i.e. the extent to which these behaviours involve individuals forgoing their own wellbeing without gain and for the benefits of others (Andreoni 1990; Fowler and Kam 2007; Schwartz 1977). PEB has traditionally conceptualised in this way, as involving costs for the individual and benefits for the planet, others and future generations (Kaplan 2000; Allen and Ferrand 1999; Geller 1995). Indeed, some existing empirical work has highlighted individuals' perceptions of PEB as being inconvenient and costly to carry out (Lorenzoni, Nicholson-Cole, and Whitmarsh 2007; Stoll-Kleemann, O'Riordan, and Jaeger 2001). At the same time, other work has found evidence that individuals who engage in PEB, and other pro-social activities, report higher levels of life satisfaction, suggesting that there might be psychological benefits to be gained from going green and doing good (Kasser 2017; Meier and Stutzer 2008). These incompatible findings beg the following research questions: do conflicting ideas around the wellbeing implications of PEB arise from differing views of what constitutes wellbeing? Could PEB result in higher life satisfaction while at the same time leading to negative experiences?

In addition to data on nature-based activities, the MENE survey used in Paper 2, also contains data on individuals' self-reported pro-environmental behaviours. Paper 3, uses these data to explore the abovementioned questions. The paper provides the first empirical comparison of the relationship between PEB and such a wide range of SWB measures. In doing so, it enhances our understanding of the wellbeing impact of PEB.

Alongside research which helps us to conceptualise PEB better, there is also a need for research which identifies behaviour change interventions that deliver real environmental benefits. Paper 4, presents two natural field experiments which evaluate interventions to reduce electricity consumption. Both studies build on research which explores implementation intentions. Implementation intentions represent a behaviour change technique from social psychology which requires individuals identify situations ('if') which, when encountered, should be met with specific behavioural responses ('then'), that relate to an overall goal (Gollwitzer and Sheeran 2006).

Implementation intention based interventions have previously been evaluated in the context of many health-related behaviours such as breast cancer screening (Rutter, Steadman, and Quine 2006), influenza vaccination (Milkman et al. 2011) and exercising (Milne, Orbell, and Sheeran 2002), as well as other non-health related behaviours including voting (Nickerson and Rogers 2010) and making pension contributions (Lusardi, Keller, and Keller 2009). They have also recently been shown to influence teenagers self-reports of energy saving behaviours (Bell et al. 2016). While the literature highlights the potential for implementation intention strategies to deliver real environmental benefits, it does not provide answers to questions such as: can encouraging individuals to form implementation intentions around PEBs achieve real electricity and cost savings? Are implementation intention strategies more effective for individuals who express concern over the natural environment?

Using and building on this technique, the interventions in Paper 4 involve encouraging individuals to furnish their intentions towards electricity saving behaviours (Study 1) and providing information tips with situational cues (Study 2). The interventions are carried out in the context of a student hall of residence in London, and their effectiveness is evaluated by examining the targeted individuals'

electricity consumption. In addition to presenting rigorous evaluations of the two interventions, Paper 4 includes a discussion of the methods used in order to draw lessons for the PEB literature more broadly. In particular, the advantages and disadvantages of natural field experiments with objective consumption outcomes are discussed, and their ability to provide a clear picture of whether and why an intervention is successful or not is weighed up.

Together the papers contribute to the behavioural science literature in relation to PEB in a number of ways. Paper 3 presents the first empirical work to explore how PEB relates to SWB across such a wide range of measures, importantly reflecting both hedonic and eudemonic dimensions of wellbeing, while also investigating whether different clusters of PEBs are differentially related to wellbeing. Paper 4 presents the first evaluation of an implementation intention based strategy targeted at electricity use and based on real consumption outcomes. It also presents the first test of furnishing electricity saving tips with situational cues.

Both papers highlight promising directions for the encouragement of PEB and provide insights for future research looking to contribute to that goal.

1.4 Bridging the gaps

Existing research demonstrates that there is often a gap in how we expect environments and activities to make us feel and how they actually do (Wilson and Gilbert 2003). A number of studies have identified such gaps in relation to conditions and behaviours which are linked to the environment and pro-social goals. In a study with a German sample, for example, participants were shown to underestimate the intensity of the negative emotions they experienced when exposed to air pollution on a trip to Bangkok (Böhm and Pfister 2008). Other research found that people underestimated the positive emotions they go on to experience from walking in nature compared to indoors (Nisbet and Zelenski 2011b), and from spending a windfall of money on others compared to themselves (Dunn, Aknin, and Norton 2008).

Another gap is also commonly identified between what people say and what they do. This gap is particularly evident in relation to environmental issues and can take on at least two forms; value-action gaps reflect the observed disparity between individuals' stated concerns about issues and the lifestyle choices they make which relate to those issues (Kollmuss and Agyeman 2002); and intention-behaviour gaps represent the commonly found mismatch between peoples' intentions to carry out PEB and what they actually end up doing. The results of a survey of Canadian residents, for example, find that 72 per cent of people self-report a value-action gap, in terms of not doing what they feel is best for the environment (Kennedy et al. 2009). Relatedly, although a majority of people commonly report intentions to buy green products and use sustainable energy sources, the market share for these good tend to be small (Terlau and Hirsch 2015; Nyborg, Howarth, and Brekke 2006).

These gaps represent serious challenges to research and policymakers focused on the dual goals of protecting the environment and promoting human wellbeing. If individuals and policymakers underestimate the negative consequences for themselves and for society of having polluted air, and are unaware of the full benefits of nature-based activities and PEB or how to convert good intentions into pro-environmental actions, then their actions are likely to jeopardise their own wellbeing as well as that of future generations. Within this context, better understanding the interdependency between our wellbeing, behaviour, and the wellbeing of the environment has the potential to motivate and inform mutually beneficial solutions. The studies outlined

above contribute to this understanding by exploring the importance of environmental quality for individual wellbeing and by investigating the nature of PEB and how best to encourage it.

In what follows, a background note on subjective wellbeing is presented (Section 2, p.23), the specific research questions investigated in all fours papers in the thesis are outlined, and the methodological approach and data used to address these questions are discussed (Section 3, p.31). Following that, the papers themselves are presented (Sections 4-7, p.46). Finally, the work concludes by summing up the findings and limitations and discussing lessons for policy (Section 9, p. 183)183

2. Background note on subjective wellbeing

Questions of what constitutes a good life, and how to measure how well individuals' lives are going, have long been the topic of debate (Estes and Sirgy 2017). This unresolved debate can be distilled down into three main accounts of wellbeing; the objective list account; the preference satisfaction account; and the mental state account. These three accounts form the basis of most contemporary discussion of wellbeing (Dolan and Metcalfe 2012; Angner 2009; Parfit 1984; Diener and Suh 1997; Seligman and Royzman 2003), and all three are, at least implicitly, present in policy discussions.

The objective list account posits that certain things and states are objectively good or bad for us. The philosopher Martha Nussbaum's 'Central Human Functional Capabilities' represents one such list, it consists of; life, bodily health, bodily integrity, senses, imagination and thought, emotions, practical reason, affiliation, play, other species and control over one's environment (Nussbaum 2000). Outside of philosophy many indices of social indicators, such as the UN Human Development Index (HDI), reflect an objective list account of wellbeing in their approach to the assessment of quality of life (Adler and Posner 2008). Like other objective lists, the HDI identifies conditions which are considered to be objectively good for wellbeing and bases wellbeing judgments on the degree to which individuals, or nations in this case, fulfil those needs.

In contrast to the objective list account, the preference satisfaction account considers wellbeing to be a matter of desire fulfilment. This account is considered to be the *"dominant account among economists and philosophers over the last century or so …"* (Haybron 2008, p.3). According to this account people's lives go better when that get more of what they prefer. This account is closely aligned with traditional ideas of wellbeing within economics, i.e. utility is an index of individuals' preference satisfactions (Mongin and d'Aspremont 1998). The preference satisfaction account does not attempt to provide an enumerative list of all the thing which are good for us, but rather, in its most basic form sees whatever we want as being what's good for us (Fletcher 2013). Current discourse in economics presents a further developed form of this account; wellbeing is the fulfilment of informed preferences - the hypothetical

preferences we hold if we had all the relevant information and made full use of it (Harsanyi 1996). Within the preference satisfaction account of wellbeing, measures of economic indicators, such as income and GDP, are often seen as proxy measures of wellbeing. These measures are adopted on the basis that people are assumed to maximise their utility subject to a budget constraint and the bigger the budget, the more preferences they can satisfy, and the greater the utility achieved (Dolan and Metcalfe 2012; Fujiwara and Campbell 2011).

Lastly, there is the mental state account of wellbeing. This account understands wellbeing as a state of mind – you are well when you feel well. It is the most commonly adopted account of wellbeing within psychology (Diener et al. 1999). Wellbeing, according to this view, is not only concerned with individuals' subjective experiences, as both the objective list and the preference satisfaction account could be, but it is actually defined by them (Diener and Suh 1997). A mental state account of wellbeing encompasses hedonistic theories relating to the excess of pleasure over pain, in the tradition of Jeremy Bentham (Dolan and Kahneman 2008), but also eudemonic philosophies of wellbeing, which relate to concepts such as purpose, flourishing, and meaning (Ryff and Singer 2013).

Over the past few decades, academics and policymakers have become increasingly interested in advancing how measuring human wellbeing in accordance with a mental state account of wellbeing (Layard 2005; Kahneman, Diener, and Schwarz 1999; Forgeard et al. 2011). In particular, extensive research has been focused on developing measures of subjective wellbeing (SWB) as complements to traditional measures of welfare which are more closely linked to the objective list and preference satisfaction accounts of wellbeing, such as health, education levels and income (Helliwell and Barrington-Leigh 2010). Subjective wellbeing is an umbrella term which encompasses both individuals' reports about their how they think about their lives and also their feelings as they go about them (Diener 2006).

Dolan and Kudrna (2016), put forward a taxonomy of SWB measures which allows for the classification of the different measures of SWB. Their taxonomy is recreated in the heavily bordered part of the table in Table 2.1 below. In the taxonomy, SWB is understood to be measured at two levels. Subjective wellbeing can be measured at the level of experiences, capturing individuals' feelings of wellbeing and

ill-being, moment-to-moment. Alternatively, SWB can be measured as an evaluation, requiring an individual to reflect on and make cognitive judgements about their wellbeing. Additionally, the columns of the two-by-two table reflect the two different types of wellbeing which refer to pleasure and purpose and broadly reflect hedonic and eudemonic philosophical schools of thought around wellbeing.

The cells in the below table represent the idea that hedonic wellbeing, or pleasure, can be captured by questions which measure both the happiness of an experience and overall reflective happiness with life. Similarly, eudemonic wellbeing measures can assess the meaning of moments and the meaning of life (Dolan 2014). Beyond the two-by-two there are also other commonly used measures, including life satisfaction, which combine both types of wellbeing, or straddle both levels. These other questions are included in the additional cells marked by the dashed lines, in Table 2.1 below.

Table 2.1: Extended SWB Measures Table

		Type		
Level		Pleasure	Purpose	Combinations and other
	Evaluation	"How happy are you with your life overall?"	"How worthwhile is your life overall?"	"How satisfied are you with your life overall?"
	Experience	"How much pleasure do you feel right now?"	"How much purpose do you feel right now?"	"How satisfied are you right now?"
	Combinations and other	"How happy did you feel yesterday?"	"How worthwhile are the things you do in your life?"	"How satisfied were you yesterday?"

It is widely agreed that SWB measures capture reliable and useful information about how individuals' lives are going. There is evidence showing that SWB measures have reasonable test-retest scores (Krueger and Schkade 2008) and that they are positively correlate with things that could be considered proxy measures for wellbeing such as how often individuals' smile (Ekman, Davidson, and Friesen 1990) and friends, family members and clinical experts' ratings of their wellbeing (Frey and Stutzer 2002; Schneider and Schimmack 2009). SWB measures are also negatively associated with cortisol levels (Steptoe, Wardle, and Marmot 2005), hypertension (Blanchflower and Oswald 2008a) and suicide rates (Koivumaa-Honkanen et al. 2001).

Alongside this work, the inclusion of SWB measures in large international surveys has extended interest in SWB beyond psychology, capturing the attention and imagination of policymakers and economists, among others. Many national statistical agencies, for example, including those in France, Italy, Canada, New Zealand, the UK and Australia are now collecting SWB data. Additionally, high profile international and non-governmental organisations, such as the Organisation for Economic Cooperation and Development (OECD Better Life Initiative 2013) and US National Academy of Sciences (Stone and Mackie 2013) have recognised the potential of SWB to inform and shape social policy and written reports on the topic, with a view to promoting that goal. The 2009 Stiglitz–Sen–Fitoussi Commission, for example, endorsed SWB research, stating that it has been "*shown that it is possible to collect meaningful and reliable data on subjective wellbeing*" and recommending that "*national statistical agencies ... incorporate questions on subjective wellbeing in their standard surveys*" (Stiglitz, Sen, and Fitoussi 2009 p.216).

Existing research that has used SWB measures to investigate the causes and correlates of 'the good life' has mostly considered evaluative measures, principally because variants of the life satisfaction question described above have been more commonly used in large, longitudinal and international surveys (Dolan, Peasgood, and White 2008). These surveys also typically contain data on people's objective life circumstances, and so we now know quite a lot about how income, education, employment and marital status are all positively associated with life satisfaction (Clark, Frijters, and Shields 2008; Dolan, Peasgood, and White 2008). There is also now a well-established U-shaped pattern in relation to age, i.e. people in middle age

appear less satisfied on average than younger and older individuals (Blanchflower and Oswald 2008b).

In recent years, a richer set of right-hand-side variables has been considered in the investigation of the potential determinants of wellbeing. This research has focused on investigating how peoples' life satisfaction relates to, not just who they are, e.g. in terms of their age, income, and marital status etc., but also where they live and what they do (White et al. 2013a, 2013b; Meier and Stutzer 2008). Including determinants related to the society and area individuals live in helps to explain SWB. Economic conditions including inflation and inequality have been linked to with life satisfaction (Frey and Stutzer 2010; Graham and Felton 2006; Alesina, Di Tella, and MacCulloch 2004; Oishi, Kesebir, and Diener 2011) and Brereton, Clinch, and Ferreira (2008) find that including spatial variables such as climate and local amenities in life satisfaction regressions greatly increases their explanatory power. How people spend their time, including whether they exercise, volunteer and the number of hours they work, is also predictive of how satisfied they report being with their lives (Dolan, Peasgood and White, 2008).

A separate research enterprise has begun considering whether the measure matters; that is, whether our conclusions about what affects SWB and by how much is affected by whether evaluative, experiential or eudemonic measures are used as left-hand-side variables. This shift from a sole-focus on life satisfaction has come about, in part, due to a number of issues that researchers have raised with this measure of SWB. Life satisfaction responses have been shown to be susceptible to the respondent's mood or immediate context; having just found a dime, the weather on the day of interview and the questions that proceed it, for example, have all been found to influence evaluations of satisfaction with life overall (Schwarz and Clore 1983; Schwarz 1987; Bertrand and Mullainathan 2001). Additionally, as they represent retrospective judgements, they are subject to biases relating to remembered utility such as the peak-end effect (Kahneman et al. 1993). Beyond being subject to bias, it has been argued that measure of life satisfaction may reflect an imperfect measure of a presence satisfaction account of wellbeing, more so that assessing an individuals' mental states (Dolan and Peasgood 2008).

In addition to these critiques, the degree to which the philosophical schools of thought which have developed around the topic of wellbeing – namely hedonia and

eudemonia - are represented in reports of life satisfaction is unclear (Peterson, Park, and Seligman 2005; Ryan and Deci 2001). Emerging evidence suggests that these different types of wellbeing are differently related to a range of determinants of wellbeing including both life circumstances and activities (Dolan and Kudrna 2016; Dolan, Kudrna, and Stone 2017; White and Dolan 2009). White and Dolan (2009), for example, find that working is reported to be a largely purposeful activity while watching TV is a largely pleasurable one. Some related work has also shown that evaluative and experiential measures of wellbeing also tell different stories about what matters to wellbeing (Kahneman and Deaton 2010; Knabe et al. 2010; Luhmann et al. 2012). Knabe et al. (2010), for example, find that the unemployed report lower levels of life satisfaction but that their experiences of wellbeing are equivalent to those in employment.

That the relationships vary across different dimensions of wellbeing highlights the importance of capturing a range of SWB measures in order more fully explore the relationship with determinants of interest. There is an emerging consensus that the various measures of SWB capture different, though related, aspects of how well an individual's life is going and that they should be measured separately in order to gain a more complete understanding of the multifaceted nature of SWB (Kahneman and Krueger 2006; Forgeard et al. 2011). In line with this, the 2013 U.S. National Academy of Sciences panel on Measuring Subjective Wellbeing suggests that:

> "*To make well-informed policy decisions, data are needed on both experienced wellbeing and evaluative wellbeing. Considering only one or the other could lead to a distorted conception of the relationship between SWB and the issues it is capable of informing, a truncated basis for predicting peoples' behaviour and choices, and ultimately compromised policy prescriptions*".
>
> (Stone and Mackie, 2013, p.10)

Moreover, it indicates that:

> "*An important part of people's experiences may be overlooked if concepts associated with purpose and purposelessness are not included alongside hedonic ones like pleasure and pain*".
>
> (Stone and Mackie, 2013, p.43)

Using a range of SWB measures also presents a number of problems, however. For instance, is the list of wellbeing indicators, enumerated in Table 2.1 (p.25), complete? Are some thoughts and feelings more valuable than others? For example, are feelings of purpose objectively more valuable than feelings of pleasure for example? As John Stuart Mill famously put it, "*is better to be a dissatisfied human than a happy pig*?" (Mill 1861 quoted in Lowenstein and Ubel 2008, p.1801). Moreover, should we care more about how people evaluate their lives when they sit back and reflect on them or do we care about how they feel as they go about them? Graham (2016) has suggested that investigating the determinants of wellbeing should focus on the dimension of wellbeing that is most relevant to the context, with experiential wellbeing measures being more suited to assessing day-to-day effects and evaluative measures more suited to assessing circumstances which relate to long-term outcomes. While this argument certainly has its merits, there are some contexts, such as when considering nonmarket goods as in Part 1 of this thesis, where there is considerable ambiguity about which measure is best fit for purpose.

If a range of SWB measures are to be used, how can they be aggregated for a given individual? One suggestion put forward by O'Donnell and Oswald (2015) is to allow the target population indicate the importance they place on different dimensions of wellbeing and weigh the wellbeing components accordingly. However, this approach relies on individuals' stated preferences (Dolan et al. 2016). One of the key motivations for the use of SWB is that avoids the some of the main issues identified by the behavioural science literature in relation to preferences – such as their being subject focusing effects and affective forecasting errors (Fujiwara and Campbell 2011). Using individuals stated weighting of the various dimensions to aggregate SWB data, therefore, undermines a large part of what makes SWB data appealing in the first place.

Despite these unresolved challenges, by capturing a range of SWB measures, ideally including those which reflect both levels and types of SWB discussed above, we are better placed to inform the ongoing debate and contribute to the further development of SWB measures as indicators of wellbeing. Additionally, this approach provides a more comprehensive picture of how different determinants relate to SWB, enabling us to better understand the potential trade-offs and complementarities between a given determinant and different dimensions of wellbeing. By focusing on how different dimensions of wellbeing, as captured by a range of SWB measures, relate to environmental quality (Paper 1 & 2) and behaviour (Papers 2 & 3) this thesis does exactly that.

3. Research questions, data and methodology

3.1 Research questions

This thesis explores questions which, broadly speaking, address issues relating to behaviour, wellbeing and the environment. The main questions addressed in each of the four papers are detailed below.

- Paper 1 investigates how different measures of SWB are related to local levels of air pollution.
- Paper 2 explores whether visits to the outdoors and physical activity help to explain the relationship between SWB and local air pollution.
- Paper 3 examines how PEB engagement is related to different measures of SWB and whether this relationship depends on characteristics of the PEB themselves.
- Paper 4 tests if interventions based on situational cues around impactful pro-environmental behaviours lead to substantial energy savings.

3.2 Data and data matching

Data are drawn from a number of sources in order to address the above-detailed research questions. The first three studies use secondary data sources, and the fourth study is based on data collected from a field experiment site. This section outlines any measures and data sources that are common across at least two of the papers in the thesis. Each of the individual papers will then discuss data measures that are unique to each paper.

3.21 Subjective wellbeing data

Common to all of the first three papers is the use of responses to the ONS four. In 2011 the Office for National Statistics (ONS) commissioned a report on 'Measuring Subjective Wellbeing for Public Policy' (Dolan, Layard, and Metcalfe 2011). This report led to the development and inclusion of four SWB questions in the UK's Annual Population Survey (APS). These questions have now been incorporated in over 20 other surveys across UK government (Evans, Macrory, and Randall 2015), including the Monitor of Engagement with the Natural Environment (MENE) carried about by Natural England. The questions capture the different dimensions of wellbeing highlighted in the literature.

They are;

- Overall, how satisfied are you with your life nowadays?
- Overall, to what extent do you feel that the things you do in your life are worthwhile?
- Overall, how happy did you feel yesterday?
- Overall, how anxious did you feel yesterday?

The life satisfaction question is the most traditional indicator in the set. It represents an evaluative SWB measure which can be considered a combination measure, incorporating both hedonic and eudemonic dimensions of wellbeing, as detailed in Table 2.1 (p.25). The worthwhile question is also a combination measure; while it is a purely eudemonic measure of SWB, by asking individuals to evaluate

their activities it spans both evaluative and experiential levels of wellbeing. The happiness and anxiety based questions are measures of positive and negative hedonic wellbeing, respectively. They are also proxy experiential measures. That they relate to 'yesterday' rather than 'right now' as per the question in the hedonic experiential cell in Table 2.1, requires the respondent to evaluate their feelings. As a result, the measures arguably do not directly assess experienced wellbeing. Despite this, that the questions reference yesterday allows for the measurement of individuals' mood states on days when they are not responding to the survey and can still be considered largely experiential as they inquire into how the individual felt over a short period which was recently experienced. These global yesterday measures are considered a practical methodology for use in large population surveys, and are commonly used in the literature that has compared experienced and evaluative SWB in relation to socio-demographics such as income, age, health and employment status (Stone and Mackie 2013). In addition, work by Christodoulou, Schneider, and Stone (2014) has found a high level of correspondence between such measures and the more detailed activity-based daily reconstruction method, suggesting that they do provide reliable insights into individuals' experiences.

The responses to these questions are drawn from a separate source in Paper 1 than in Papers 2 and 3. For Paper 1 the SWB data are drawn from the APS. The APS is a major survey series which consists of a cross-sectional survey of a representative sample of the UK population (Office for National Statistics 2013). The study is carried out by the Office for National Statistics (ONS) and has interviewed approximately 165,000 respondents each year since 2004. Its goal is to provide reliable estimates of a range of individual characteristics at a local authority level. The data are publicly accessible, and a Special Access User License which allows access to the survey data in a spatially disaggregated format can be applied for through the UK Data Service. The ONS four have been included in the APS since 2012. This dataset also contains information on individuals' gender, age, self-reported health status, ethnicity, education, employment status, housing tenure, marital status, socio-economic status, disability and mode of interview amongst other measures. The survey interviews take place either at home or over the phone.

In both Papers 2 and 3, SWB data were drawn from the MENE survey. The MENE is a nationally representative English cross-sectional survey which collects

information about the ways that people engage with the natural environment. It is funded by Natural England – the UK government's advisory body on the English natural environment – with support from DEFRA and the Forestry Commission (Natural England 2013). The survey began in 2009 with around 800 respondents interviewed every week across England using an in-home interview format. The ONS four were introduced to the MENE survey as a trial in 2012, and ran quarterly for a year starting in June 2012. From May 2014, the questions were formally adopted into the main survey, and the question frequency was increased to weekly. The survey contains behavioural and attitudinal measures such as frequency of visits to the outdoors, physical activity, a range of pro-environmental behaviours, and reports of concern about damage to the natural environment. Additionally, the survey captures socio-demographics such as gender, self-reported health status, age group, ethnicity, disability, socio-economic group, marital status, employment status, housing tenure and an urban/rural classification of the local area.

3.22 Air pollution data

Air pollution data feature in the analysis presented in both Papers 1 and 2. Particulate matter was chosen as the air pollutant of interest as it is a key pollutant highlighted by the EU's Air Quality Directive and existing evidence suggests that it is the air pollutant most strongly associated with increased mortality risks (Committee on the Medical Effects of Air Pollutants 2010a). Particulate matter is a measure of the respirable solid and liquid particles suspended in the atmosphere. The particles are categorised as either coarse particulate (PM_{10}) if they are greater than 2.5 micrometres (μm) in aerodynamic diameter, or fine particulate ($PM_{2.5}$) if they are smaller than 2.5 μm in diameter. In general, particulate matter is a complex mixture consisting of many different components from a range of sources including man-made materials such as dust, smoke and soot, as well and natural ones like pollen and soil particles.

Much evidence exists documenting the detrimental effects of both PM_{10} and $PM_{2.5}$ on ecosystems and population health (see, for example, Air Quality Expert Group, 2012). Particulate matter has direct negative impacts on our natural environment through the degradation of vegetation and indirect effects on the acid and nutrient status of soils and waters (DEFRA 2007a). It also negatively impacts visibility

(US Environmental Protection Agency 2011). In addition, research on public health has demonstrated that long-term exposure to particulate matter is associated with a range adverse health effects, including the development of lung dysfunction and cardiovascular diseases, leading to increased mortality risk (Pope 2000; Atkinson et al. 2013; Committee on the Medical Effects of Air Pollutants 2010b). Recent research suggests that there are no clear concentration levels below which adverse health effects do not occur and that $PM_{2.5}$ is more closely associated with the aforementioned negative health outcomes than is PM_{10} (Air Quality Expert Group 2012). On this basis, the current work focuses on $PM_{2.5}$.

The UK's Department for Environment, Food and Rural Affairs (DEFRA) produces modelled background concentration maps of air pollutants with the goal of assisting local authorities in carrying out reviews and assessments of the local air quality (DEFRA 2014). The maps are created under the UK's Ambient Air Quality Assessments contract and as part of the UK's obligations under the European Commission's Air Quality Directive. Annual average levels of $PM_{2.5}$ were identified for each local authority using the DEFRA's 2012 map of background concentrations of fine particulate matter. The map models background annual average $PM_{2.5}$ concentrations on a 1 km x 1 km grid using an air dispersion model which incorporates measured observations from DEFRA's Filter Dynamics Measurement System (FDMS) in their Automatic Urban and Rural Network; emissions inventory data from the National Atmospheric Emissions Inventory, which provides information on emissions to the atmosphere from sources such as cars, trucks, power stations; and point source data for secondary inorganic compounds. The FDMS captures hourly measurements of particulate matter at 27 stations around the UK which are aggregated into annual means for the purpose of the dispersion model.

The direct monitoring of air pollution only provides data for specific locations, and so it is common practice to adopt an air pollution modelling approach to convert information about atmospheric emissions into estimates of air pollution concentrations in order to supplement this information. This strategy is helpful in providing estimates for areas in which pollution is at a long distance from observation sites. However, as with any modelling, this strategy entails the simplification of real-world conditions into a series of algorithms, and therefore suffers from issues around uncertainty, for example, in relation to emissions from missing sources (Air Quality Expert Group

2012). Outputs from air pollution modelling are imperfect measures of ambient air pollution in any given location, which need to be checked against monitored data to assess their reliability.

In order to do this the DEFRA's background pollution maps are verified using independent monitoring data from other measurement networks that are not used in the calibration of the model (see Ricardo AEA 2013 for further details). Expert assessment contained in the relevant technical report, which was published alongside the air pollution map used for the analysis in the current work, considers the level of the agreement between measured data and the modelled values of $PM_{2.5}$ to be good (Ricardo AEA 2013). The average modelled concentration at background sites was 11. 8 annual mean micrograms per cubic meter (μg m-3) while the average measured concentration, as captured by the National Network of Filter Dynamics Measurement Systems was 12.5 μg m-3. The modelled $PM_{2.5}$ concentration estimates fell within the modelled data quality objectives set out by the European Commission's Air Quality Directive at 97% of the monitoring site locations (Ricardo AEA 2013). Reflecting this reliability, these maps have been widely used in UK-based epidemiological studies, to investigate the relationship between air pollution and various health conditions, including all-cause mortality (Carey et al. 2013) and cardiovascular diseases (Atkinson et al. 2013).

3.23 Local area characteristics

In addition to air pollution, other local area characteristics feature in the analysis in Papers 1 and 2. These characteristics include population density, local mean and median income, and climate conditions.

A measure of local authority level population density comes from the 2011 Census. The local authority estimate includes information on population density in persons per hectare. In addition, population-weighted centroids based on the 2011 Census data were also obtained from the ONS Open Geography portal (used in the data matching described in more detail below). A centroid is a single summary reference point which represents how the population at census time was spatially distributed and grouped within an area. These points allow for data linking to higher levels using a geographical information system.

Measures of local economic conditions were taken from the UK's Annual Survey of Household Earnings for 2012. The ASHE is the UK's most detailed and comprehensive source of earnings information. It is based on a 1% sample of employee jobs, drawn from Her Majesties Revenue and Customs' 'Pay As You Earn' records. This dataset provides estimates of mean and median weekly earnings for UK employees at a local authority level.

Finally, data on the UK climate were obtained from the UK's Met office gridded observation datasets. This dataset consists of climate data on variables including temperature, rain and snowfall, storminess, and sea-surface temperature and sea levels since 1900. Gridded sets of 5x5 km modelled data representing the long-term average (1981-2010) climate conditions were included in the analysis. Measures of maximum temperature in January and July (in degrees Celsius), average rainfall (in millimetres), and sunshine hours (in minutes) were used in the analyses. These climate measures are similar to those that commonly found in the literature (Brereton, Clinch, and Ferreira 2008; Cuñado and de Gracia 2013) and, rather than representing climate extremes, these summer and winter conditions act as proxy measures for the overall climate conditions in the area.

3.24 Data matching

In both Papers 1 and 2, it was necessary to link local area characteristics to individuals' survey responses. In order to link individuals to the modelled air pollution data, it was necessary to identify points which represented how the population at census time was spatially distributed in each local authority. To do this ONS's median population-weighted centroids (PWC) for output areas from the 2011 population census were downloaded from the ONS's Open Geography portal and loaded into QGIS – an open source geographic information system the support the analysis of spatial data.

Following the ONS's population-weighted centroid guidance (Office for National Statistics 2011) output area centroids are fit to the local authority level by plotting the PWCs into the boundaries of the output geography and assigning the output area to that unitary authority when the centroid falls within that boundary. Population-weighted centroids of unitary authorities are then calculated by finding the mean coordinates of the PWCs of the output areas contained within each area (see Figure 3.2 below). This method provides a point for each unitary authority to which air pollution data is matched. These data points are then spatially joined to the air pollution map using the QGIS join attributes by location tool. The other local area characteristics are linked to survey responses via the local authority identifiers in both the APS and the MENE.

FIGURE 3.1: MAP OF THE UK SHOWING POPULATION-WEIGHTED CENTROIDS OF LOCAL AUTHORITIES.

Note: Output area PWCs are shown in white. PWCs calculated for each of the unitary authorities are shown in red.

3.3 Methodology

This section details the main methodological approaches adopted in the four papers.

3.31 Cross-sectional data analysis (Papers 1-3)

Paper 1 is concerned with whether and how living in a polluted environment affects individual SWB across a range of different dimensions. Similarly, Paper 2 is concerned with the causal chain between air pollution – the behaviours of interest – and SWB. Lastly, Paper 3 seeks to understand how engaging in pro-environmental behaviour affects wellbeing. In order to answer all the research questions directly, it would be ideal to randomise the independent variables of interest, air pollution or behaviour, and identify their causal effect on the outcomes of interest – SWB wellbeing and behaviour.

Unfortunately, due to the nature of the main dependent variable of interest in Papers 1 and 2 – air pollution – it is not possible to randomise individuals' exposure to air pollution outside of a controlled laboratory setting and answer questions of interest such as: how does air pollution affect a representative sample of the UK populations' wellbeing? A second possible approach would be to use an instrumental variable to estimate the causal effect of air pollution on wellbeing. Such an approach was adopted by Luechinger (2009), who exploited a natural experiment involving the installation of scrubbers at power plants in Germany, and used wind directions to identify treatment and control groups, in order to investigate the effect of SO_2 concentrations on life satisfaction. His results indicated that the instrumented estimates of the relationship between life satisfaction and air pollution were larger than the conventional ordinary least squares estimates using cross-sectional data. In a non-SWB US-based example, non-attainment status, which is that status given to counties that fail to meet the US's National Ambient Air Quality Standards, was used by Chay and Greenstone (2005) as an instrument to explore the causal effect of air quality improvements on house prices. In examining the UK context, however, no such natural experiment or viable instrumental variable was available.

A third approach that could be considered would be to use longitudinal data to try to identify the causal relationship between air pollution and wellbeing. Although this approach would allow for the control of time-invariant characteristics, and in doing so lessen omitted variable bias concerns, this method was also not possible as no available dataset longitudinally measured SWB across all of the dimensions of interest. The British Household Panel Survey (BHPS) and the subsequent Understanding Society Panel, for example, only collect responses to measures of life satisfaction. While this would have allowed for the replication of other work from other countries, it would not have enabled a direct comparison of the relationship between air pollution and SWB across a range of dimensions, which is the primary goal of Paper 1.

Lastly, there is the option of carrying out analysis on repeated cross-sections which are now available for the APS used in Paper 1. This approach would allow for the investigation of the effects of changes in air pollution over time. This option was not chosen, however, as air pollution data as upon examination, it was clear that over the years that air pollution data are available from DEFRA and the APS, there has been almost no variation in the levels of air pollution. The below table shows the correlation matrix of the modelled UK grid cell fine particulate matter metrics across the four years for which data are now available.

Table 3.1: Correlation matrix of $PM_{2.5}$ values 2012-2015

	2012	2013	2014	2015
2012	1.0000			
2013	0.9898	1.0000		
2014	0.9876	0.9941	1.0000	
2015	0.9815	0.9886	0.9873	1.0000

On the basis of the above considerations, spatially detailed cross-sectional analysis of the relationship between air pollution and SWB is carried out. Although care is taken in the analysis to control for local conditions as well as individual characteristics, due to the nature of the analysis in Paper 1 is not possible to answer the causal question – how does air pollution affect wellbeing? Instead, the analysis can only speak to the more loosely defined question – how is air pollution related to local levels of air pollution in the UK controlling for a number of individual and local area

characteristics? A robustness check which investigates whether the relationship between air pollution and wellbeing for a subsample of non-movers provides some evidence that issues of selection do not bias the estimates to a great degree. However, issues of omitted variable bias, reverse causality and selection cannot be ruled out completely. For the same reasons as were just detailed, the second paper also focuses on local levels of air pollution and examines the relationship between air pollution, behaviour and SWB using a cross-sectional approach.

Paper 3 is concerned with the effect of engaging in PEB on individual wellbeing. Ideally, the research would be able to identify the causal effect of PEB engagement on a range of SWB measures. This question could have been approached in a number of ways, but none are without issue. One possible method which could be used to answer this question would be to carry out experimental work in which individuals are nudged into engaging in PEB and their wellbeing is compared to the wellbeing of those who were not encouraged in an intention-to-treat analysis. An example of this approach is detailed in Gosnell, List, and Metcalfe (2016), in which the authors' find evidence that the use of pro-social incentives to encourage fuel efficiency behaviours in a sample of pilots leads to increased job satisfaction, compared to a control group. However, it is likely that providing pro-social incentives in order to encourage PEB, will interact with PEB engagement, to create distinct wellbeing effects. These effects would be expected to differ from the wellbeing produced via other interventions or from individuals autonomously choosing to engage in PEB (Weinstein and Ryan 2010). Analysis of this kind serves to evaluate the wellbeing effects of PEB engagement encouraged through a given intervention but cannot answer the more general question – how does PEB affect SWB?

As was the case in Papers 1 and 2, a second viable approach to try to assess the causal relationship between PEB and SWB would be to use longitudinal data analysis, i.e. to see how changes in engagement in PEB over time relate to changes in wellbeing while partialling out time-invariant characteristics using individual fixed effects. This approach is not possible in the current work, however, as existing longitudinal datasets containing information on PEB, such as the Environmental Module in waves 1 and 4 of the Understanding Society Panel Survey, do not include information on different dimensions of SWB (Understanding society 2016). For this paper, it is key that a range of SWB wellbeing measures are available which tap into

both hedonic and eudemonic types of wellbeing, rather than solely representing combination of the two, as is the case with the measure of life satisfaction in Understanding Society.

Lastly, there is the possibility of a third approach involving experience sampling. The Experience Sampling Method (ESM) is considered the gold standard for assessing how people feel on an experiential level as it avoids some of the problems inherent in measures which as people to reflect on their wellbeing, such as imperfect recall and duration neglect (Kahneman et al. 2004; Csikszentmihalyi and Larson 2014). ESM involves eliciting peoples' responses to questions about their activities and moods in real-time. This method is most directly relevant to the relationship between PEB and experiential wellbeing. Bissing-Olson, Fielding, and Iyer (2016), for example, use experience sampling to investigate the extent to which individuals reported the feeling pride or guilt during their PEB engagement, over the course of the preceding 2.5 hours. While theirs is an interesting and valuable approach, the paper does not use experience sampling in its truest form. The individuals are asked to reflect on the past 2.5 hours and specifically about PEB and their experiences of pride and guilt. As a result, the study design is likely to focus individuals' attention on their PEB, and therefore, to produce biased estimates. Importantly, this approach also does not assess how PEB relates to evaluative measures of SWB. While it was not financially feasible to carry out an ESM study over the course of the current work, it would be of interest in future research to explore how PEB relates to experienced wellbeing as reported in a general ESM study, and compare this to evaluative measures of SWB.

On the basis of these limitations, cross-sectional analysis using the MENE data is carried out to explore how individuals SWB relate to PEB engagement. This does not answer the causal question of interest, but it provides insights into the links between PEB and a range of SWB measures, which can be further explored if longitudinal data become available and it can complement findings from experimental and experience sampling methods.

3.32 Natural field experiment (Paper 4)

Lastly, Paper 4 involves two natural field experiments. A natural field experiment is defined, under Harrison and List's (2004) taxonomy of field experiments, as an experiment in which the subjects naturally undertake the tasks which are of interest and where the subjects do not know that they are in an experiment. In both studies in Paper 4, the participants are unaware that the field experiment was taking place and that their electricity consumption was being monitored. This approach is preferred to other forms of field experiment such as artefactual field experiments and framed field experiments for at least two reasons. First, it limits the chances that participants will alter their behaviour due to their being observed (often termed a Hawthorne effect). Second, it investigates the behaviours of interest, in this case, PEB, in the actual setting in which the behaviour typically takes place. The randomisation of individuals into treatment and control allows for the evaluation of the causal effect of the two interventions on the outcome of interest. Questionnaire data were also collected in order to investigate the effectiveness of the intervention on participants reporting different levels of environmental concern.

4. Bad Air Days

The effects of air quality on different measures of subjective wellbeing

(Paper 1)

4.1 Introduction

Air pollution is a key policy issue currently facing the UK Government and one which features widely in public debate (Carrington, 2016). In 2017, the High Court ordered the UK government to implement plans to tackle the UK's air pollution levels, which are in breach of EU limits and have been linked to 40,000 premature deaths and health-related costs of over £20 billion every year (Croft, Pilita, and 2017; Royal College of Physicians 2016). Despite the scale of these figures, however, it is possible that they do not fully capture the negative impact on wellbeing in the UK arising from this environmental problem. Subjective wellbeing (SWB) literature has documented that air pollution is negatively associated with individuals' evaluative assessments of their own wellbeing, as captured by questions about their life satisfaction, while controlling for health status (Welsch, 2002; Welsch, 2006; MacKerron and Mourato, 2009; Menz and Welsch 2010; Luechinger, 2010; Ferreira et al., 2013). Focusing the health costs of air pollution alone, this research would suggest, underestimates the true cost to society of having polluted air (US Environmental Protection Agency 2017; DEFRA 2011).

Over the past decade, SWB research has provided new insights into the importance of environmental quality for human wellbeing. Both the environmental goods and 'bads' that we are exposed to in our environment appear to matter for how we feel; characteristics of the local environment including proximity to the coast (Brereton, Clinch, and Ferreira 2008), the amount of green space (White et al. 2013b), the level of airport noise (Van Praag and Baarsma 2005), air pollution and traffic congestion (Smyth, Mishra et al. 2008, Luechinger 2010, Levinson 2012, Ferreira, Akay et al. 2013) and the prevailing climate (Rehdanz and Maddison 2005) have all been linked to life satisfaction. Other research also suggests that experiencing more transient environmental conditions, such as flooding and drought, can influence people's satisfaction with their lives (Carroll, Frijters, and Shields 2009; Luechinger and Raschky 2009).

Of the environmental characteristics explored in this literature, the one which has been investigated most frequently is air pollution. Beginning with Welsch (2002), many studies have documented evidence that countries with higher levels of pollution report lower wellbeing (Welsch 2006; Menz and Welsch 2010; Luechinger 2010;

Ferreira et al. 2013). Luechinger (2010), for example, finds a negative relationship between country-level sulphur dioxide and life satisfaction across 13 European countries. Other research also links local levels of air pollution to individuals' wellbeing; MacKerron and Mourato (2009) find that local levels of nitrogen dioxide are significantly negatively associated with the life satisfaction of a sample of Londoners. Similarly, Luechinger (2009) documents a negative relationship between local levels of sulphur dioxide and life satisfaction in a German sample.

This literature highlights the importance of environmental quality, and air quality in particular, for individual SWB. It also, however, reflects a more general tendency in SWB research to explore the determinants of wellbeing using life satisfaction as the only outcome measure of interest. The sole focus on this evaluative measure of SWB is increasingly being eschewed within the SWB literature, and a number of recent studies compare and contrast how determinants of wellbeing relate to SWB using separate measures of hedonic and eudemonic wellbeing as either experiences or evaluations, in addition to life satisfaction (Dolan and Kudrna 2016). These studies show that the relationship between SWB and many socio-economic factors, such as income and unemployment, depends on the measure used. Importantly, this highlights the fact that these measures capture different aspects of wellbeing, and suggests that analysis that focuses on a measure which captures only one dimension may be highly problematic and of limited use to policy (Stone and Mackie 2013).

Despite the fact that a multidimensional approach to modelling SWB appears to provide a more complete picture of how a determinant relates to individuals' wellbeing, it has seldom been adopted in research relating to the environment. To the authors' knowledge no study exists which compares the relationship between air quality and a range of measures of SWB, assessing wellbeing at the different levels, and types, discussed in Section 2 (p.23). While we have quite a lot of evidence linking living in a polluted environment to lower evaluations of life, for example, we know much less about its influence on how people feel day to day.

Beyond considering different measures of SWB on the left-hand-side, there is also a need for a more rigorous consideration of the right-hand- side. First, the research currently lacks spatial detail. Much of the analysis to date has used cross-country comparisons of average pollution levels (for example Menz and Welsch; Welsch

2006), but there are large variations in air pollution levels within countries, and so country-mean concentrations are very imprecise measures of individuals' exposure to air pollution (Luechinger 2009). Second, much of the literature to date has not dealt with the issue of omitted variable bias sufficiently. Existing evidence suggests that air pollution is simultaneously determined by local characteristics, including population density and economic conditions and these characteristics are also associated with SWB (Cuñado and de Gracia 2013; Schmitt 2013). Many studies fail to control for these local characteristics, which affect SWB and therefore will often paint a misleading picture of the association between air pollution and SWB (Orru et al. 2016).

Against this background, this paper considers the impact of a more precise measure of air pollution on a more expansive range of measures of SWB. It presents an analysis of responses to a range of SWB questions in the UK's Annual Population Survey (APS). Since 2011, SWB data in the APS has been used to make international wellbeing comparisons between the UK and other OECD countries (Beardsmore and Randall 2015), monitor changes in the UK's wellbeing (Evans, Macrory, and Randall 2015), and investigate links between the individuals socio-economic characteristics and their SWB (Deeming 2013). The current work considers their relationship to modelled concentrations of particulate matter at the local authority level while controlling for a range of local area characteristics which have previously been shown to be associated with SWB.

The analysis presents evidence of a strong and statistically significant negative association between background concentrations of fine particulate matter ($PM_{2.5}$) and reports of life satisfaction. This finding is in line with existing literature and additionally provides a detailed estimate of the magnitude of the negative association between evaluative wellbeing and levels of $PM_{2.5}$ in a UK context. The analysis also provides evidence of similarly sized negative associations between air pollution and how worthwhile individuals consider their activities to be and their reports of happiness on the previous day. The association with the worthwhile measure is the first evidence to suggest that air pollution is linked to eudemonic wellbeing. The happiness result suggests that air pollution not only impacts how individuals evaluate their lives but also how they feel on a day to day basis. Moreover, all three associations remain statistically significant when self-reported health status is controlled for. In

contrast, no relationship is found between air pollution and individuals' reports of their anxiety on the previous day, both when health controls are included and excluded from analysis.

Some of the issues emanating from these findings are discussed in Section 4.4. Sections 4.2 and 4.3 now detail the methods and results, respectively.

4.2 Data and methods

4.21 Data

Data on SWB, air pollution and other relevant control variables are drawn from a number of sources and merged using QGIS and Stata 12 (discussed in Section 3.2, p.32). Descriptive statistics of all of the variables included in the analysis are documented in Appendix 4A. The dependent variables are taken from responses to the UK's Office for National Statistics Annual Population Survey's SWB questions – the ONS four. The March 2012–April 2013 APS wave is the focus of this paper because of the availability of concurrent modelled air pollution (Office for National Statistics 2013). It contains SWB data from around 165,000 individuals. In addition, survey weights are provided which make the SWB responses representative of the UK's adult population at the time. The survey dataset also provides other demographic information including age, sex and ethnicity and other indicators relating to education, employment, housing and marital status, which act as important control variables. Of the 165,000 SWB responses, a sample of just under 127,000 is available with complete cases for all of the socio-demographics of interest in the main analysis here. The tables below show summary statistics for the four SWB variables of interest and report the correlations between the measures. The averages and the correlations are illustrative of the fact that the questions are disparate, though related, aspects of SWB.

Table 4.1: SWB Summary Statistics

Variable	N	Mean	Std. Dev
Satisfaction	126,686	7.390856	1.862775
Worthwhile	126,686	7.697646	1.748481
Happiness	126,686	7.245576	2.205514
Anxiety	126,686	3.103461	2.881478

Table 4.2: SWB correlation matrix

	Satisfaction	Worthwhile	Happy	Anxious
Satisfaction	1			
Worthwhile	0.6468	1		
Happiness	0.5833	0.5117	1	
Anxiety	-0.3512	-0.2701	-0.4744	1

4.22 Models

Ordinary least squares (OLS) regression models are estimated in order to investigate the relationship between the local average background concentration of fine particulate matter and responses to the SWB questions contained in the APS.

The regression models take the general form:

$$\text{EQ1:} \qquad SWB\ ijt = \alpha Pjt + \beta Xijt + \pi Zjt + \eta t + \varepsilon ijt$$

Where SWB_{ijt} is the subjective wellbeing rating of the respondent i in location j at date t. P_{jt} is the annual average background particulate matter concentration at location j at date t. X_{ijt} is other demographic and interview characteristics, Z_{jt} are local area characteristics in location j at date t, ηt are month and year fixed effects, and ε represents the error term.

The APS Subjective Wellbeing Population weight is applied to all regressions apart from Model I, and standard errors are clustered at local authority level (Cameron and Miller 2011; Jones 2012). SWB responses are treated differently across studies with some researchers treating them as cardinal while others respect the strict ordinality of the data and use ordered logit or probit models to analyse the data. Ferrer-i-Carbonell and Frijters (2004) find that assuming cardinality or ordinality of the responses to SWB questions has little effect on the results. The results from OLS regressions are therefore presented in this work.

In order to investigate the relationship between modelled background concentrations of particulate matter at the population centroid of each local authority and reports of SWB, various specifications of the models are estimated, regressing background concentrations of fine particulate matter on all four SWB measures. An outline of the different models estimated between SWB and air pollution is below. $PM_{2.5}$ and responses to the life satisfaction question are chosen for illustrative purposes, but model output for all SWB measures can be found in the appendices 4B-E.

Model I presents an unweighted simple linear regression model of the relationship between SWB and average background air pollution levels. Model II adds the SWB weights, which causes the total number of cases in the dataset to be grossed

up to the estimated population of adults (aged 16 and older) within the UK as at the end of September 2011, and controls for individual characteristics that previous studies suggest to have an impact on SWB: age, sex, marital status, housing tenure, educational level, employment status, socio-economic classification (Dolan, Peasgood, and White 2008; Deeming 2013). In addition, whether the interview took place on the phone or in person is controlled for as Dolan and Kavetsos (2016) find interview-mode to be significantly associated with SWB in the APS data.

Model III adds month fixed effects. Model IV introduces climate controls and other local area characteristics; a measure of population density and local area mean and median income. Country controls are avoided as Northern Ireland is considered a country, but also a single unitary authority in the APS and as such only has one pollution value. Model V is estimated as Model IV except for the exclusion of self-reported health status. Other models that are estimated but not shown include: a model incorporating country and regional fixed effects (these controls introduce issues of multicollinearity into the model which according to a variance inflation factor (VIF) test; a model that includes local unemployment rate (this variable is insignificant and also introduces issues of multicollinearity into the model).

4.3 Results

4.31 Pollution effects

Table 4.3 shows the relationship between satisfaction and $PM_{2.5}$. See appendices 4B-E for tables detailing the full results across all of the SWB measures. The different specifications of the models outlined above do not qualitatively change the associations between $PM_{2.5}$ and all of the positive measures of SWB. Significant negative associations are found between $PM_{2.5}$ and reports of life satisfaction, happiness yesterday and the worthwhileness of activities across Models I to IV. Anxiety is found to have a significant association with $PM_{2.5}$ in Models I-III, but this association disappears once the local area characteristics are included in Model IV.

Model IV is chosen as the preferred specification to present in Figure 4.1 because it provides estimates of the associations between the measures of SWB and concentration of $PM_{2.5}$, holding constant sociodemographic, and local area and interview characteristics, which have previously been shown to be linked to SWB or suggested as potential confounders. In this model, the decrease in satisfaction associated with a 1 μg m^{-3} increase in fine particulate matter in the main analysis is -0.0146 on an 11-point scale. This result is remarkably similar to those of analysis carried out by Orru et al. (2016) which documents a negative association of - 0.0171, on a 10-point scale, with 1 μg m^{-3} increase in coarse particulate matter, using data from the European social survey. Interestingly, the associations between $PM_{2.5}$ and how worthwhile individuals consider their activities to be and their reports of happiness yesterday are almost as large in magnitude: an increase of 1 μg m^{-3} in $PM_{2.5}$ concentrations is associated with an average reduction of -0.0131 and -0.0125 points, respectively.

The socio-demographic predictors of SWB are many, and while the coefficients on particulate matter are much smaller than those relating to unemployment and poor health, characteristics which are consistently identified as having the strongest negative associations with SWB (Dolan et al. 2008), they are still substantive. The coefficients between SWB and other important negative characteristics such as being disabled are of a similar order of magnitude to those relating to particulate matter. Controlling for other individual and local area

characteristics the relationship between how worthwhile and individual considers their activities to be and being disabled is -0.0314, while there is a negative association of -0.0131 for every one unit increase in particulate matter.

For the most part, the SWB measures are not found to be significantly associated with the local area characteristics included in the analysis. Some exceptions include population density which is positively associated with happiness and January temperature which is positively associated with anxiety. The interpretation of these coefficients is problematic, however, as they suffer from multicollinearity issues. This does not pose a problem for the analysis as these variables are simply acting as controls, and a low variance inflation factor scores is reported across all of the models for the $PM_{2.5}$ coefficients, but conclusions should not be drawn about the relationships between SWB and other local area characteristics from these results.

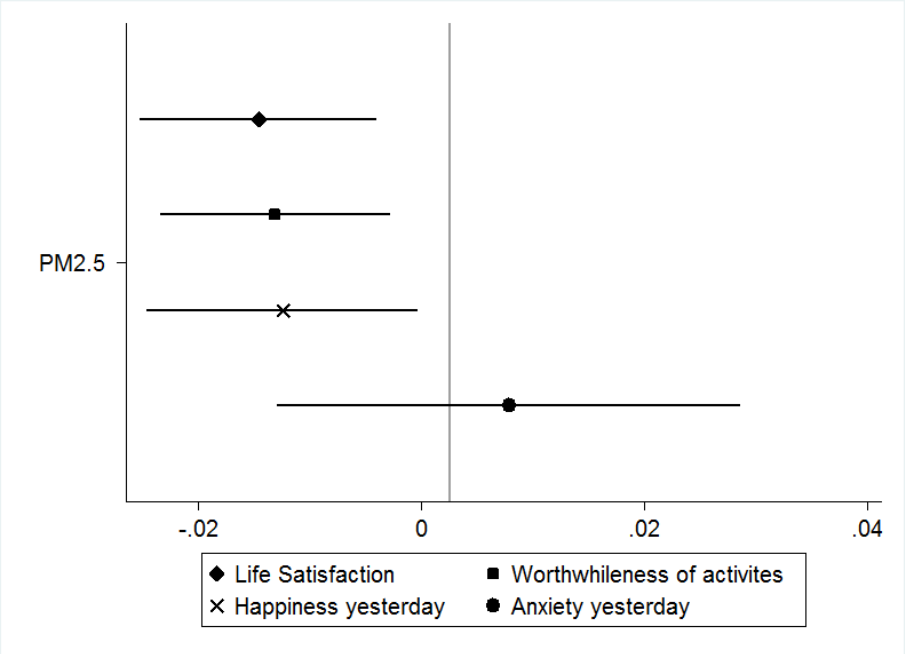


FIGURE 4.1: $PM_{2.5}$ AND THE RANGE OF SWB MEASURES

Note: The symbols represent the point estimates from Model IV, and the bars indicate the 95% confidence intervals. Please see the Table 4.3 and appendices 4 B-E for the related regression tables.

Table 4.3: Various model specifications for Life satisfaction and $PM_{2.5}$

	Model I Satisfaction	Model II Satisfaction	Model III Satisfaction	Model IV Satisfaction	Model V Satisfaction
$PM_{2.5}$	-0.0269***	-0.0206***	-0.0206***	-0.0146***	-0.0155***
	(0.00398)	(0.00418)	(0.00419)	(0.00539)	(0.00534)
Health		Reference category: Very bad health			
Bad		0.937***	0.937***	0.937***	
		(0.0886)	(0.0886)	(0.0884)	
Fair		1.868***	1.868***	1.870***	
		(0.0832)	(0.0831)	(0.0828)	
Good		2.450***	2.451***	2.453***	
		(0.0824)	(0.0824)	(0.0820)	
Very good		2.861***	2.862***	2.864***	
		(0.0849)	(0.0850)	(0.0843)	
July temperature				-0.00816	-0.00380
				(0.0155)	(0.0163)
January temperature				-0.00174	-0.00434
				(0.0170)	(0.0175)
July rain				-0.000473	-0.000488
				(0.000488)	(0.000468)
January rain				-0.00358	-0.000185
				(0.00716)	(0.00782)
July sun				-0.0278	-0.0149
				(0.0340)	(0.0340)
Jan sunshine				0.00682	-0.0183
				(0.0604)	(0.0708)
				(0.0340)	(0.0341)
Population density				0.000769*	0.000621*
				(0.000395)	(0.000366)
Local area mean income				5.94e-06**	7.64e-06***
				(2.51e-06)	(2.75e-06)
Local area median income				-8.99e-06*	-1.08e-05**
				(5.19e-06)	(5.38e-06)
Individual controls	No	Yes	Yes	Yes	Yes
Interview mode	No	Yes	Yes	Yes	Yes
Month and Year	No	No	Yes	Yes	Yes
Constant	7.674***	7.225***	7.245***	7.612***	10.64***
	(0.0450)	(0.237)	(0.238)	(0.372)	(0.389)
N	126,686	126,686	126,686	126,686	126,686
R-squared	0.002	0.178	0.178	0.178	0.124

*Standard errors clustered at local authority level appear in parentheses. *** p<0.01, ** p<0.05, * p<0.1*

4.32 Health effects

Air pollution may act to reduce individuals' SWB indirectly through its impact on their health and also directly. By incorporating self-reported health status into the model, the estimates represent the effect of air pollution on SWB over and above its effect through health. Figure 4.2 and Model IV and V of appendices 4B-E present the regression estimates for the association between air pollution and SWB with and without controlling for self-reported health status. Note that association between $PM_{2.5}$ and satisfaction decreases by approximately 6% when health is controlled for in the model, compared to the same coefficient when health controls are removed. Similarly, the coefficients are reduced by nearly 7% and 5% in the worthwhile model and happiness yesterday models when health is controlled for. These results suggest that health is one mechanism through which air pollution influences SWB, but that it does not fully explain the relationship. In contrast to this, there is no evidence of an association between anxiety yesterday and $PM_{2.5}$ concentrations, either when health controls are present or absent from the model.

FIGURE 4.2: A COMPARISON OF THE COEFFICIENTS FROM MODEL IV AND MODEL V

Note: The larger (smaller) symbols represent the point estimates from Model IV with health controls (Model V without health controls), and the bars indicate the 95% confidence intervals. Please see the Table 4.3 and appendices 4B-E for the related regression tables.

4.33 Income subsample analysis

Ideally, income would be included as a control variable, but household income was not included in the main models as it is not available for the whole sample. Only a subsample, which represents those who were either employees or under government employment at the time of interview, responded to income related questions about gross weekly pay in their main and second job (n = 62,988). Income is excluded from the primary analysis in order to maintain the representativeness of the sample and local area mean and median income, socio-economic status and housing tenure are all included as proxies instead. Dolan and Kavetsos (2016) take the same approach in their work on the APS dataset, which investigates the relationship between mode of interview and reports of SWB, as does Connolly (2013) in her work using the Princeton Affect and Time Survey, which looks at the relationship between climate and SWB.

Secondary analysis is carried out in order to investigate the degree to which the absence of income may influence the results of the main analysis. Model V is estimated again but this time also controlling for income (by including the log of gross weekly pay in the individuals' main and second jobs) using the subsample for which income data are available (See Table 4.4). Income is found to have a significant relationship with life satisfaction and anxiety yesterday, but not happiness yesterday or how worthwhile the respondents consider their activities to be. Qualitatively equivalent results are found between both $PM_{2.5}$ and all measures of satisfaction, worthwhileness and happiness in the regressions that control for income as are found in the main analysis. However, once income is controlled for the magnitudes of the associations do increase, for example, a 1 $\mu g\ m^{-3}$ increase in $PM_{2.5}$ is associated with a -0.0228 point drop in life satisfaction when income is controlled for as compared to a -0.0146 drop in the main analysis. Similar patterns are observed for reports of happiness yesterday and worthwhileness. The coefficient on anxiety remains statistically insignificant at conventional levels.

Looking at the subsample for which income data are available, it is evident that, without controlling for income, very similar coefficients as those that are obtained when income is incorporated, are found for satisfaction, happiness and worthwhileness. The change, therefore, is arguably largely due to the subsample

analysis and not, for the most part, a result of bias being introduced in the main analysis from the omission of income. Although the point estimates presented in the main analysis almost certainly suffer from some omitted variable bias due the inability to control for income, the results from the main analysis appear to present reliable evidence of a negative relationship between $PM_{2.5}$ and the three positive measures of SWB in the ONS for the UK population.

The model fit is better in the main analysis than it is in the income subsample. This is somewhat surprising, in particular in the case of both the life satisfaction and anxiety models given that income (which is included in the subsample analysis) is found to be a significant predictor these wellbeing outcomes. The weaker fit in the subsample may relate to the different size of the samples. The main analysis is carried out on a sample of 126,686 individuals, while the subsample is made up of 62,988 individuals. Alternatively, the different make-up of the sample may be behind the higher R^2 in the main analysis. It may be that the variation in the wellbeing of those who are in full-time employment only is less well explained than is the variation in the wellbeing of the whole sample which also includes those who are unemployed, inactive and self-employed. In other work using the ONS APS the author has found that the standard determinants do a better job of explaining low wellbeing than they do high wellbeing. As the mean levels of SWB are lower across the main sample than they are when the sample is restricted to the income subsample, the different makeup of the two samples, and the different levels of wellbeing reported by the two samples in particular, provides some evidence that the makeup of the sample contributes to differences across the model fit statistics.

Table 4.4: Income subsample analysis using Model IV specification

Main Analysis Model IV				
	Satisfaction	Worthwhile	Happiness	Anxiety
$PM_{2.5}$	-0.0146***	-0.0131**	-0.0125**	0.00784
	(0.00539)	(0.00526)	(0.00619)	(0.0106)
Constant	7.612***	6.229***	5.836***	3.623***
	(0.372)	(0.399)	(0.460)	(0.622)
N	126,686	126,686	126,686	126,686
R-squared	0.178	0.125	0.098	0.061
Income subsample with income control				
	Satisfaction	Worthwhile	Happiness	Anxiety
$PM_{2.5}$	-0.0228***	-0.0205***	-0.0197**	0.0194
	(0.00597)	(0.00612)	(0.00799)	(0.0121)
Log of total weekly income	0.101***	0.0212	-0.00557	-0.0804***
	(0.0134)	(0.0140)	(0.0170)	(0.0261)
Constant	8.582***	8.161***	7.224***	2.899***
	(0.558)	(0.565)	(0.805)	(0.932)
N	62,988	62,988	62,988	62,988
R-squared	0.108	0.066	0.050	0.038
Income subsample without income control				
	Satisfaction	Worthwhile	Happiness	Anxiety
$PM_{2.5}$	-0.0214***	-0.0202***	-0.0198**	0.0184
	(0.00593)	(0.00611)	(0.00800)	(0.0121)
Constant	8.941***	8.236***	7.204***	2.613***
	(0.555)	(0.560)	(0.804)	(0.936)
N	62,988	62,988	62,988	62,988
R-squared	0.107	0.066	0.050	0.038

*Standard errors clustered at local authority level appear in parentheses. *** p<0.01, ** p<0.05, * p<0.1*

4.34 Non-movers subsample analysis

The main analysis focuses on investigating the impact of annual average background concentrations of pollution and SWB assuming that where someone lives at the time of the interview affects them. Some people may have lived in their homes for many years and others only a few weeks, however. A robustness check is therefore carried out to see if the relationships suggested by the analysis reported in Model IV of appendices B-E hold when only those individuals who had lived at the same address for at least six months are included (n=126,399). All of the relationships relating to $PM_{2.5}$ do indeed hold, with slight increases in the magnitude of the effects relating to reports of both life satisfaction and happiness yesterday and a decrease in the relationship between worthwhile and fine particulate matter (see Table 4.5 below).

Table 4.5: Non-mover subsample analysis

Main Analysis Model IV				
	Satisfaction	Worthwhile	Happiness	Anxiety
$PM_{2.5}$	-0.0146***	-0.0131**	-0.0125**	0.00784
	(0.00539)	(0.00526)	(0.00619)	(0.0106)
Constant	7.612***	6.229***	5.836***	3.623***
	(0.372)	(0.399)	(0.460)	(0.622)
N	126,686	126,686	126,686	126,686
R-squared	0.178	0.125	0.098	0.061
Non-movers (over 6 months at their home)				
	Satisfaction	Worthwhile	Happiness	Anxiety
$PM_{2.5}$	-0.0147***	-0.0129**	-0.0130**	0.00819
	(0.00543)	(0.00530)	(0.00627)	(0.0106)
Constant	7.609***	6.265***	5.892***	3.638***
	(0.373)	(0.402)	(0.460)	(0.622)
N	126,399	126,399	126,399	126,399
R-squared	0.179	0.126	0.098	0.062

*Standard errors clustered at local authority level appear in parentheses. *** p<0.01, ** p<0.05, * p<0.1*

4.5 Discussion

To further enhance the evidence base on the determinants of SWB in ways that could ultimately help inform policy decisions, this paper considers the impact of a precise measure of air pollution on an expansive range of measures of SWB. The results based on responses to the question *'Overall, how satisfied are you with your life nowadays?'* are in line with existing literature relating to evaluative wellbeing and air pollution (Ferreira et al. 2013; Orru et al. 2016). On average, those exposed to higher air pollution in the UK report lower life satisfaction. The effect is considerable: living in a place with background pollution concentrations equivalent to that of Croydon in London compared to the Scottish Highlands is associated with a drop in life satisfaction greater than that which is associated with being disabled in the same sample. While there are challenges to using life satisfaction as a measure of wellbeing (discussed in Section 2, p.23), that this and other work consistently find negative associations between life satisfaction and air pollution at least suggests that life satisfaction ratings pick up more than just what is on a respondent's mind at the time of assessment. It is highly unlikely that particulate matter is thought about in a life satisfaction response yet it still seems to affect it: in much the same way as museum visits (Fujiwara 2013), fruit and vegetable consumption (Blanchflower, Oswald, and Stewart-Brown 2013) or proximity to the coast do (Brereton, Clinch, and Ferreira 2008).

In addition, there is also evidence of a significant relationship between background levels of $PM_{2.5}$ and individual responses to the question '*Overall, to what extent do you feel the things you do in your life are worthwhile?*'. One possible explanation for this result, and indeed the other significant relationships found, may be that individuals living in differently polluted areas engage in different activities. Speculatively, if individuals are less likely to engage in nature-related activities, such as walking through local parks or green spaces on the way to other places and doing unpaid voluntary work out of doors, in areas that are more polluted, then this could be one mechanism through which air pollution affects reports of the worthwhileness of their activities, as well as other dimensions of SWB. In the research presented in Paper 2 of this thesis data from Natural England's Monitor of Engagement with the Natural Environment survey is used to explore this possibility further.

There is also evidence of a link between positive hedonic wellbeing as captured by the question '*Overall, how happy did you feel yesterday*?' and the level of local air pollution individuals are exposed to. Holding constant other determinants of SWB, individuals living in more polluted unitary authorities report experiencing lower levels of happiness on the previous day. This is the first study to find a negative link between the levels of happiness people experience day to day and the air quality in their locality. The size of this effect is also meaningful: a one standard deviation change in the levels of $PM_{2.5}$ is negatively associated with a 0.039 drop in happiness, which is over a third of the effect of having a mortgage compared to owning one's own home outright in the same sample. This is an important result in the context of the recent emphasis on experiential measures of SWB (Stone and Mackie 2013) and the dearth of evidence linking air quality to experiential SWB. Importantly, the results from Paper 2 of this thesis, which are based on analysis using the same measures of hedonic wellbeing and particulate matter, but investigate the relationship in a smaller dataset (Natural England's Monitor for Engagement with the Natural Environment), do not demonstrate the same relationship. This result is, therefore, not conclusive and future research is required to build up an evidence base around the relationship between particulate matter and measures of positive hedonic wellbeing.

The results also suggest that air pollution influences life satisfaction, worthwhileness and happiness through its effect on health; all coefficients on $PM_{2.5}$ increase in magnitude when health status is not included in the models. However, a comparison of these coefficients with those from models incorporating health status reveals that much of the negative associations between $PM_{2.5}$ and all three positive measures from the ONS four are not mediated by self-reported health status. These results confirm the idea that air pollution negatively impacts SWB over and above health effects. The comparison across these models are imperfect as a result of the imprecise nature of the measure of health included in the dataset (a 0–5 scale of self-reported health) (Baker, Stabile, and Deri 2004). Having said that, self-reported health measures are more highly correlated with SWB than are objective health measures (Kahneman and Riis 2005), and so controlling for self-reported health is likely to produce lower estimates of the independent effect of air pollution on SWB, than would be produced if objective health measures were incorporated into the models. In order to better understand the relationship between SWB, air pollution and health, future

research should incorporate objective measures of health, e.g., by linking air pollution and health damages by locality to SWB. The current work provides the motivation for such research, presenting suggestive evidence that air quality valuation techniques which focus on health effects of air pollution exposure alone are likely to be underestimating the overall wellbeing costs of air pollution (US Environmental Protection Agency 2017; DEFRA 2011).

Interesting, and perhaps also surprising, is the fact that no relationship is found between the negatively framed measure of SWB – anxiety yesterday – and air pollution. The simple linear regression model finds evidence of the expected positive association between $PM_{2.5}$ and anxiety, and this remains the case when individual characteristics are controlled for. Once local are characteristics are controlled for, however, no significant relationship is found between $PM_{2.5}$ and anxiety. If, as some have argued (Lelkes 2013; Kahneman 2011), policymakers should prioritise the minimisation of misery over the maximisation of happiness, then these results suggest that pollution abatement may not be as important a policy priority. That the measure matters complicate matters for policy appraisal, but it also highlights that different measures of SWB are affected by different determinants and in so doing vindicates the use of multiple measures of SWB in the APS. The difference between the positive and negative measures of affect, in particular, highlight that they are different constructs (Larsen and McGraw 2011) that, in the very least, have different determinants. It would be interesting for future research to investigate if negatively framed evaluative and eudemonic measures are similarly unaffected by air pollution, or if they share the same determinants as their positive counterparts.

This study is not without its limitations, which create lines for future enquiry. There are four main caveats. First, although a great number of control variables are incorporated into the models, the cross-sectional nature of the data means that drawing causal inferences about the impact of air pollution on SWB is problematic. However, given that previous studies, across a wide range of different contexts and at different levels of spatial and temporal detail, have provided consistent evidence of a negative association between air pollution and evaluative wellbeing, the overall body of evidence is suggestive of an underlying causal relationship. Future research should look to reproduce the findings in relation to experiential and eudemonic wellbeing in order to establish similar levels of evidence for the other measures of SWB used here.

To be more confident about causality, researchers should look to use natural experiments where possible (Luechinger 2009; Chay and Greenstone 2005).

Second, the responses to the happiness and anxiety yesterday questions are treated as experiential measures of SWB. These measures are, however, somewhat imperfect experiential measures as the questions refer to yesterday, and so represent retrospective judgments rather than 'in the moment' experiences. More instantaneous measures of positive and negative affect could be obtained using the Experience Sampling Method (ESM), which involves prompting individuals through portable technology at various points over the course of a day, and eliciting information from them about their physical location, the activities which they are engaged in, the people they are with, and how they are feeling. A study by MacKerron and Mourato (2013) finds evidence of a link between environmental quality and an ESM-based measure of SWB. The authors measure the happiness of self-selecting individuals at random points in the day via app technology and their location via global positioning systems (GPS), finding a positive link between happiness and being outdoors in a natural environment. Given the scale of the APS, however, an ESM would not have been feasible, and so the happiness and anxiety questions included represent attempts to capture experiential measures of SWB within a short recall period and for a nationally representative sample of individuals. Future research should capitalise on the ability for modern technologies to track where individuals are via GPS and look to investigate the relationship between air quality and other elements of environmental quality and ESM-based data on representative samples.

Third, considerable evidence exists that SWB responses adapt to changes in circumstances over time. Previous studies have documented this phenomenon in relation to many significant life events using longitudinal analysis. For example, adaptation to the positive effect of marriage was found to be complete after two years on average, and life satisfaction almost totally rebounds after the loss of a spouse eight years after the event (Lucas et al. 2003). It is also important to note, however, that adaptation it is not inevitable for everyone and for every event. Many studies document significant differences in the rate and extent of adaptation across individuals, and adaptation to some life events such as disability and unemployment would appear to be only partial (Lucas 2005, 2007). There is also some evidence to suggest that individuals may even become sensitised to some stimuli, such as

unpredictable noise, over time (Luz and Nykaza 2009). These issues are complicated further by the possibility that adaptation processes may vary across measures of SWB. Luhmann et al. (2012) carried out a meta-analysis of studies relating to ten key life events including marriage and unemployment, in order to investigate the difference in adaptation processes in relation to evaluative and experiential SWB. They find evidence that the extent and rate of adaptation vary across measures, and that it is not the case that one measure adapts quicker or more fully across all life events.

Against this background, and given the cross-sectional nature of the data, it is difficult to say what role adaptation may play in the relationships documented between air pollution and the different measures of SWB. A longitudinal macro –level study carried out by Menz (2011) finds evidence that past levels of coarse particulate matter influences future life satisfaction, suggesting that people do not habituate to air pollution in terms of their evaluative wellbeing. It is not clear, however, if this would also be the case at a micro level, or whether the rate of adaptation (if any) to air pollution and environmental quality more generally differs across different levels and types of SWB. That the significant negative relationships found in the main analysis all hold when looking at the subsample of people who have lived in the area for over six months suggests that the results are not solely driven by individuals who are being newly exposed to the local levels of pollution and that adaptation amongst these non-movers is not complete. Yet the results only represent a snap-shot at one period of the association between local air pollution and measures of SWB. As such, the estimates represent the average associations between these SWB measures and background concentrations of particulate matter but do not get at individual differences in sensitivity to air pollution levels or estimate different effect sizes for individuals who are accustomed to different levels of air pollution. These are important research gaps which should be addressed in future. Moreover, the differences in the magnitude of the effects, with the association between pollution and the measures of evaluative wellbeing being larger than that of happiness levels may reflect different propensities to adapt to air pollution across these different dimensions of wellbeing. Longitudinal research examining adaptation in response to shocks to local pollution levels is required in order to investigate whether this is the case or if those differences reflect something more permanent.

Overall, the results reported in this paper lend weight to the idea that the various measures incorporated in the APS are capturing different but related characteristics of SWB. A spatially detailed approach to modelling the determinants of SWB including features of the physical environment such as local climate and air pollution is adopted. Drawing on best practice from a number of sources (Brereton, Clinch, and Ferreira 2008; Levinson 2012; DEFRA 2014; Met Office 2014) the analysis uses modelled concentrations of $PM_{2.5}$ and PWCs from the UK census to link individuals to air pollution levels in a precise manner. A wide range of controls relating to the physical environment and other local area characteristics which previous literature suggests may affect SWB are also incorporated. The results from this work indicate that background particulate matter concentrations are negatively associated with all positive measures of SWB investigated, even when controlling for health, but that reports of anxiety yesterday are unrelated.

Taken together these results build on existing evidence from the SWB literature based on evaluative measures to show the links between air quality and a range of different dimensions of SWB. The results pose a challenge to policymakers to think more carefully about the full range of impacts of air pollution, beyond its health effects. The findings also demonstrate that conclusions about the relationship between wellbeing and environmental quality can vary according to the richness of the left-hand side (the measure of SWB used) and the rigour of the right-hand side (the environmental quality and control variables). By being alert to how pollution relates to individuals' reports of their own SWB and how these associations vary across different measures of SWB, we can obtain a clearer and more complete picture of the wellbeing costs to society of bad air days.

Appendices 4

Appendix 4A: Descriptive statistics

	N	Mean	St. Dev	Min	Max
Dependent					
Satisfaction	126,686	7.390856	1.862775	0	10
Worthwhileness	126,686	7.696746	1.748481	0	10
Happiness	126,686	7.245576	2.205514	0	10
Anxiety	126,686	3.103461	2.881478	0	10
Independent					
$PM_{2.5}$	126,686	10.52174	2.684239	5.155429	16.94733
Controls					
Gender	126,686	100%			
Male	71,719	56.61		0	1
Female	54,967	43.39		0	1
Interview mode	128,932	100%			
Phone	67,492	53.28		0	1
In person	59,194	46.72		0	1
Age	126,686	45.95111	13.77148	16	99
Health	126,686	100%			
Very bad	1,915	1.51		0	1
Bad	6,701	5.29		0	1
Fair	20,893	16.49		0	1
Good	50,574	39.92		0	1
Very good	46,603	36.79		0	1
Ethnicity	126,686	100%			
White	116,069	91.62		0	1
Mixed	829	0.65		0	1
Indian	2,390	1.89		0	1
Pakistani	1,450	1.14		0	1
Bangladeshi	520	0.41		0	1
Chinese	540	0.43		0	1
Other Asian	963	0.76		0	1
Black	2,633	2.08		0	1
Other ethnicity	1,292	1.02		0	1
Disability status	126,686	100%			
Non-disabled	93,112	73.5		0	1
Disabled	33,574	26.5		0	1
Education	126,686	100%			
No education	152	0.12		0	1
Degree	30,611	24.16		0	1
Higher education	14,010	11.06		0	1
GCE, A-level	28,773	22.71		0	1
GCSE grades A*-C	27,156	21.44		0	1
Other qualifications	11,750	9.27		0	1
Work status	126,686	100%			
Employed	83,883	66.21		0	1

Unemployed	6,801	5.37		0	1
Inactive	36,002	28.42		0	1
Housing Tenure	126,686	100%			
Owner occupier	32,879	25.95		0	1
Mortgage	51,140	40.37		0	1
Part renting	569	0.45		0	1
Renting	41,156	32.49		0	1
Rent free	942	0.74		0	1
Marital Status	126,686	100%			
Single	37,974	29.97		0	1
Married	64,693	51.07		0	1
Separated	5,032	3.97		0	1
Divorced	14,966	11.81		0	1
Widowed	4,021	3.17		0	1
Socio-economic group	126,686	100%			
Higher managerial	15,493	12.23		0	1
Lower managerial	29,046	22.93		0	1
Intermediate	15,867	12.52		0	1
Small employers	9,661	7.63		0	1
Lower supervisory	6,904	5.45		0	1
Semi-routine	15,895	12.55		0	1
Routine operations	10,694	8.44		0	1
Never worked	23,126	18.25		0	1
July temperature	126,686	20.89656	1.446856	15.6	23.33
January temperature	126,686	7.194389	0.747889	5.04	9.54
July rain	126,686	62.45663	18.12096	37.19	157.8
January rain	126,686	9.833066	1.699241	6.98	17.41
July sun	126,686	6.110272	0.660394	4.24	8.01
January sun	126,686	1.725363	0.237265	0.87	2.21
Population density	126,686	16.87651	25.76908	0.09	138.7
Local area mean income	126,686	25355.77	5466.846	17289	68426
Local area median	126,686	21248.87	3308.871	15046	39940

Appendix 4B: Life satisfaction and PM2.5

	Model I	Model II	Model III	Model IV	Model V
	Satisfaction	Satisfaction	Satisfaction	Satisfaction	Satisfaction
$PM_{2.5}$	-0.0269***	-0.0206***	-0.0206***	-0.0146***	-0.0155***
	(0.00398)	(0.00418)	(0.00419)	(0.00539)	(0.00534)
Male		-0.136***	-0.136***	-0.136***	-0.168***
		(0.0134)	(0.0133)	(0.0134)	(0.0134)
Phone Interview		0.0557***	0.0551***	0.0595***	0.0710***
		(0.0163)	(0.0164)	(0.0143)	(0.0145)
Age		-0.106***	-0.106***	-0.106***	-0.128***
		(0.00336)	(0.00334)	(0.00334)	(0.00354)
Age2		0.00116***	0.00116***	0.00116***	0.00136***
		(3.74e-05)	(3.73e-05)	(3.73e-05)	(3.94e-05)
Health		Reference category: Very bad health			
Bad health		0.937***	0.937***	0.937***	
		(0.0886)	(0.0886)	(0.0884)	
Fair health		1.868***	1.868***	1.870***	
		(0.0832)	(0.0831)	(0.0828)	
Good health		2.450***	2.451***	2.453***	
		(0.0824)	(0.0824)	(0.0820)	
Very good health		2.861***	2.862***	2.864***	
		(0.0849)	(0.0850)	(0.0843)	
Ethnicity:		Reference category: White			
Mixed		-0.367***	-0.367***	-0.368***	-0.384***
		(0.0776)	(0.0776)	(0.0780)	(0.0775)
Indian		-0.0125	-0.0134	-0.0174	-0.0600
		(0.0469)	(0.0471)	(0.0469)	(0.0508)
Pakistani		-0.0964	-0.0971	-0.104	-0.166**
		(0.0641)	(0.0647)	(0.0640)	(0.0669)
Bangladeshi		-0.190*	-0.192*	-0.198**	-0.197*
		(0.0987)	(0.0990)	(0.0975)	(0.110)
Chinese		-0.176**	-0.177**	-0.176**	-0.125
		(0.0840)	(0.0845)	(0.0843)	(0.0873)
Other Asian		0.0169	0.0168	0.0168	0.0382
		(0.0749)	(0.0748)	(0.0752)	(0.0755)
Black		-0.383***	-0.384***	-0.385***	-0.336***
		(0.0504)	(0.0504)	(0.0501)	(0.0509)
Other ethnicity		-0.124*	-0.125*	-0.128*	-0.0922
		(0.0673)	(0.0670)	(0.0669)	(0.0682)
Disabled		-0.122***	-0.122***	-0.122***	-0.759***
		(0.0185)	(0.0185)	(0.0183)	(0.0178)
Education		Reference category: No qualifications			
Degree		0.335*	0.337*	0.336*	0.416**

	(0.190)	(0.189)	(0.188)	(0.187)
Higher education	0.398**	0.400**	0.399**	0.461**
	(0.190)	(0.190)	(0.189)	(0.189)
GCE, A-level	0.386**	0.388**	0.389**	0.433**
	(0.190)	(0.190)	(0.189)	(0.188)
GCSE grades A*-C	0.366*	0.368*	0.369*	0.393**
	(0.189)	(0.189)	(0.188)	(0.187)
Other qualifications	0.417**	0.420**	0.420**	0.430**
	(0.191)	(0.191)	(0.190)	(0.189)
Employment status	Reference category: Employed			
Unemployed	-0.720***	-0.720***	-0.720***	-0.752***
	(0.0376)	(0.0376)	(0.0376)	(0.0376)
Inactive	-0.0184	-0.0179	-0.0179	-0.176***
	(0.0174)	(0.0174)	(0.0174)	(0.0187)
Housing tenure	Reference category: Home owned outright			
Mortgage holder	-0.155***	-0.154***	-0.153***	-0.194***
	(0.0178)	(0.0178)	(0.0175)	(0.0175)
Part renting	-0.237***	-0.237***	-0.233***	-0.347***
	(0.0825)	(0.0825)	(0.0824)	(0.0836)
Renting	-0.312***	-0.312***	-0.310***	-0.421***
	(0.0210)	(0.0210)	(0.0207)	(0.0212)
Rent free	0.00900	0.00901	0.00779	-0.0955
	(0.0742)	(0.0742)	(0.0741)	(0.0816)
Marital Status	Reference category: Single			
Married	0.507***	0.507***	0.507***	0.550***
	(0.0154)	(0.0154)	(0.0153)	(0.0161)
Separated	-0.176***	-0.176***	-0.177***	-0.191***
	(0.0360)	(0.0360)	(0.0358)	(0.0373)
Divorced	-0.0143	-0.0142	-0.0119	-0.0394*
	(0.0230)	(0.0230)	(0.0231)	(0.0238)
Widowed	-0.274***	-0.274***	-0.274***	-0.270***
	(0.0452)	(0.0450)	(0.0450)	(0.0457)
Socio-economic status	Reference category: Higher managerial and professional			
Lower managerial	-0.0699***	-0.0710***	-0.0702***	-0.0802***
	(0.0178)	(0.0177)	(0.0178)	(0.0180)
Intermediate occupations	-0.156***	-0.157***	-0.157***	-0.180***
	(0.0230)	(0.0230)	(0.0231)	(0.0242)
Small employers	-0.193***	-0.194***	-0.194***	-0.202***
	(0.0274)	(0.0274)	(0.0274)	(0.0279)
Lower supervisory	-0.126***	-0.131***	-0.132***	-0.168***
	(0.0298)	(0.0297)	(0.0296)	(0.0306)
Semi-routine operations	-0.228***	-0.229***	-0.229***	-0.265***
	(0.0263)	(0.0263)	(0.0263)	(0.0270)
Routine operations	-0.221***	-0.222***	-0.224***	-0.243***

		(0.0300)	(0.0299)	(0.0300)	(0.0303)
Never worked unemployed		-0.149***	-0.150***	-0.151***	-0.226***
		(0.0263)	(0.0262)	(0.0264)	(0.0272)
July temperature				-0.00816	-0.00380
				(0.0155)	(0.0163)
January temperature				-0.00174	-0.00434
				(0.0170)	(0.0175)
July rain				-0.00358	-0.000185
				(0.00716)	(0.00782)
January rain				-0.000473	-0.000488
				(0.000488)	(0.000468)
Population density				-0.0278	-0.0149
				(0.0340)	(0.0340)
Local area mean income				0.00682	-0.0183
				(0.0604)	(0.0708)
Local area median				0.000769*	0.000621*
				(0.000395)	(0.000366)
Month Controls	NO	NO	YES	YES	YES
Constant	7.674***	7.225***	7.245***	7.612***	10.64***
	(0.0450)	(0.237)	(0.238)	(0.372)	(0.389)
N	126,686	126,686	126,686	126,686	126,686
R-squared	0.002	0.178	0.178	0.178	0.124

*Standard errors clustered at local authority level in parentheses. *** p<0.01, ** p<0.05, * p<0.1*

Appendix 4C: The worthwhileness of activities and $PM_{2.5}$

	Model I	Model II	Model III	Model IV	Model V
	Worthwhile	Worthwhile	Worthwhile	Worthwhile	Worthwhile
$PM_{2.5}$	-0.0208***	-0.0162***	-0.0162***	-0.0131**	-0.0138***
	(0.00320)	(0.00379)	(0.00381)	(0.00526)	(0.00532)
Male		-0.317***	-0.317***	-0.317***	-0.346***
		(0.0136)	(0.0136)	(0.0136)	(0.0134)
Phone		0.0582***	0.0577***	0.0614***	0.0712***
		(0.0154)	(0.0154)	(0.0137)	(0.0136)
Age		-0.0578***	-0.0577***	-0.0578***	-0.0765***
		(0.00305)	(0.00306)	(0.00307)	(0.00329)
Age2		0.000707***	0.000706***	0.000707***	0.000887***
		(3.36e-05)	(3.36e-05)	(3.36e-05)	(3.60e-05)
Health		Reference category: Very bad health			
Bad health		0.810***	0.811***	0.811***	
		(0.0902)	(0.0903)	(0.0903)	
Fair health		1.713***	1.714***	1.715***	
		(0.0903)	(0.0902)	(0.0899)	
Good health		2.150***	2.151***	2.152***	
		(0.0914)	(0.0913)	(0.0911)	
Very good		2.502***	2.503***	2.505***	
		(0.0931)	(0.0930)	(0.0927)	
Ethnicity:		Reference category: White			
Mixed		-0.151*	-0.151*	-0.151*	-0.164*
		(0.0854)	(0.0854)	(0.0852)	(0.0845)
Indian		0.0173	0.0165	0.0120	-0.0238
		(0.0487)	(0.0487)	(0.0492)	(0.0504)
Pakistani		-0.0361	-0.0363	-0.0398	-0.0900
		(0.0737)	(0.0740)	(0.0742)	(0.0760)
Bangladeshi		-0.0962	-0.0979	-0.101	-0.0979
		(0.127)	(0.127)	(0.127)	(0.143)
Chinese		-0.283**	-0.284**	-0.282**	-0.235*
		(0.124)	(0.123)	(0.123)	(0.125)
Other Asian		-0.0568	-0.0563	-0.0562	-0.0372
		(0.0704)	(0.0703)	(0.0702)	(0.0705)
Black		-0.0173	-0.0172	-0.0180	0.0252
		(0.0476)	(0.0478)	(0.0478)	(0.0494)
Other		-0.172***	-0.173***	-0.174***	-0.143**
		(0.0570)	(0.0570)	(0.0570)	(0.0587)
Disabled		-0.0316*	-0.0315*	-0.0314*	-0.568***
		(0.0183)	(0.0183)	(0.0184)	(0.0173)
Education		Reference category: No qualifications			
Degree		0.533**	0.532**	0.534***	0.604***

	(0.207)	(0.207)	(0.206)	(0.216)
Higher	0.584***	0.583***	0.584***	0.640***
	(0.208)	(0.207)	(0.207)	(0.217)
GCE, A-	0.555***	0.556***	0.556***	0.597***
	(0.207)	(0.206)	(0.206)	(0.216)
GCSE grades	0.528**	0.528**	0.528**	0.552**
	(0.208)	(0.207)	(0.207)	(0.217)
Other	0.521**	0.522**	0.522**	0.534**
	(0.209)	(0.209)	(0.208)	(0.218)
Employment	Reference category: Employed			
Unemployed	-0.551***	-0.551***	-0.551***	-0.576***
	(0.0351)	(0.0351)	(0.0349)	(0.0359)
Inactive	-0.0422**	-0.0417**	-0.0417**	-0.182***
	(0.0194)	(0.0193)	(0.0193)	(0.0198)
Housing	Reference category: Home owned outright			
Mortgage	-0.0452***	-0.0452***	-0.0444***	-0.0798***
	(0.0171)	(0.0171)	(0.0169)	(0.0171)
Part renting	-0.102	-0.102	-0.0989	-0.197**
	(0.0917)	(0.0915)	(0.0914)	(0.0918)
Renting	-0.111***	-0.111***	-0.109***	-0.204***
	(0.0210)	(0.0210)	(0.0206)	(0.0210)
Rent free	0.210***	0.210***	0.210***	0.122
	(0.0753)	(0.0753)	(0.0752)	(0.0822)
Marital	Reference category: Single			
Married	0.379***	0.379***	0.379***	0.415***
	(0.0165)	(0.0164)	(0.0164)	(0.0172)
Separated	0.0551	0.0550	0.0542	0.0412
	(0.0351)	(0.0351)	(0.0351)	(0.0373)
Divorced	0.0485**	0.0486**	0.0495**	0.0244
	(0.0245)	(0.0245)	(0.0247)	(0.0254)
Widowed	-0.0643	-0.0642	-0.0643	-0.0613
	(0.0466)	(0.0465)	(0.0464)	(0.0475)
Socio	Reference category: Higher managerial and professional			
Lower	0.0358**	0.0350*	0.0349*	0.0266
	(0.0181)	(0.0181)	(0.0181)	(0.0185)
Intermediate	-0.151***	-0.153***	-0.153***	-0.173***
	(0.0233)	(0.0233)	(0.0234)	(0.0238)
Small	-0.0111	-0.0119	-0.0124	-0.0183
	(0.0258)	(0.0259)	(0.0259)	(0.0263)
Lower	-0.0952***	-0.0994***	-0.101***	-0.131***
	(0.0298)	(0.0299)	(0.0299)	(0.0301)
Semi-routine	-0.145***	-0.146***	-0.148***	-0.176***
	(0.0270)	(0.0271)	(0.0273)	(0.0278)
Routine	-0.161***	-0.163***	-0.165***	-0.180***
	(0.0285)	(0.0286)	(0.0287)	(0.0287)

Never		-0.115***	-0.116***	-0.118***	-0.183***
		(0.0278)	(0.0279)	(0.0280)	(0.0285)
July				0.00905	0.0134
				(0.0177)	(0.0180)
January				0.000556	-0.00193
				(0.0156)	(0.0158)
July rain				0.000259	0.000250
				(0.000561)	(0.000475)
January rain				0.00444	0.00745
				(0.00775)	(0.00778)
July sun				-0.0349	-0.0241
				(0.0337)	(0.0328)
January sun				0.0578	0.0360
				(0.0597)	(0.0582)
Population				0.000678*	0.000549
				(0.000361)	(0.000342)
Local area				3.73e-06	5.14e-06
				(3.76e-06)	(3.99e-06)
Local area				-7.61e-06	-9.17e-06
				(6.35e-06)	(6.66e-06)
Month	NO	NO	YES	YES	YES
Constant	7.916***	6.351***	6.350***	6.229***	8.879***
	(0.0350)	(0.248)	(0.249)	(0.399)	(0.413)
N	126,686	126,686	126,686	126,686	126,686
R-squared	0.001	0.125	0.125	0.125	0.081

*Standard errors clustered at local authority level in parentheses. *** p<0.01, ** p<0.05, * p<0.1*

Appendix 4D: Happiness and $PM_{2.5}$

	Model I	Model II	Model III	Model IV	Model V
	Happiness	Happiness	Happiness	Happiness	Happiness
$PM_{2.5}$	-0.0177***	-0.0121**	-0.0121**	-0.0125**	-0.0134**
	(0.00448)	(0.00558)	(0.00554)	(0.00619)	(0.00612)
Male		-0.0932***	-0.0929***	-0.0926***	-0.125***
		(0.0151)	(0.0151)	(0.0151)	(0.0153)
Phone Interview		0.0495**	0.0486**	0.0566***	0.0686***
		(0.0235)	(0.0234)	(0.0192)	(0.0195)
Age		-0.0792***	-0.0791***	-0.0792***	-0.101***
		(0.00413)	(0.00410)	(0.00403)	(0.00417)
Age2		0.000943***	0.000941***	0.000943***	0.00115***
		(4.59e-05)	(4.56e-05)	(4.45e-05)	(4.58e-05)
Health		Reference category: Very bad health			
Bad health		0.933***	0.931***	0.933***	
		(0.0955)	(0.0955)	(0.0954)	
Fair health		1.862***	1.862***	1.866***	
		(0.0908)	(0.0909)	(0.0906)	
Good health		2.477***	2.478***	2.481***	
		(0.0918)	(0.0919)	(0.0917)	
Very good health		2.913***	2.913***	2.917***	
		(0.0929)	(0.0931)	(0.0925)	
Ethnicity:		Reference category: White			
Mixed		-0.184**	-0.184**	-0.187**	-0.204**
		(0.0886)	(0.0884)	(0.0880)	(0.0891)
Indian		0.151**	0.151**	0.146**	0.101
		(0.0612)	(0.0609)	(0.0621)	(0.0648)
Pakistani		-0.0327	-0.0336	-0.0334	-0.0985
		(0.0814)	(0.0818)	(0.0800)	(0.0834)
Bangladeshi		0.0631	0.0621	0.0534	0.0536
		(0.161)	(0.161)	(0.158)	(0.178)
Chinese		0.0257	0.0238	0.0261	0.0769
		(0.129)	(0.129)	(0.129)	(0.132)
Other Asian		0.0639	0.0596	0.0563	0.0777
		(0.0788)	(0.0790)	(0.0793)	(0.0831)
Black		-0.0262	-0.0272	-0.0309	0.0194
		(0.0549)	(0.0549)	(0.0542)	(0.0561)
Other ethnicity		-0.0860	-0.0886	-0.0935	-0.0570
		(0.0804)	(0.0801)	(0.0804)	(0.0828)
Disabled		-0.0723***	-0.0723***	-0.0716***	-0.733***
		(0.0225)	(0.0225)	(0.0226)	(0.0206)
Education		Reference category: No qualifications			
Degree		0.390*	0.400*	0.398*	0.479*

	(0.225)	(0.225)	(0.225)	(0.259)
Higher education	0.407*	0.416*	0.415*	0.477*
	(0.224)	(0.224)	(0.224)	(0.259)
GCE, A-level	0.398*	0.407*	0.407*	0.450*
	(0.224)	(0.224)	(0.224)	(0.259)
GCSE grades A*-	0.392*	0.401*	0.400*	0.422
	(0.225)	(0.225)	(0.226)	(0.259)
Other	0.412*	0.423*	0.422*	0.429*
	(0.225)	(0.225)	(0.226)	(0.260)
Employment	Reference category: Employed			
Unemployed	-0.241***	-0.241***	-0.240***	-0.275***
	(0.0440)	(0.0441)	(0.0438)	(0.0458)
Inactive	0.0651***	0.0665***	0.0667***	-0.0946***
	(0.0224)	(0.0223)	(0.0222)	(0.0230)
Housing tenure	Reference category: Home owned outright			
Mortgage holder	-0.101***	-0.100***	-0.0986***	-0.140***
	(0.0245)	(0.0244)	(0.0239)	(0.0240)
Part renting	-0.161	-0.158	-0.155	-0.272**
	(0.124)	(0.123)	(0.123)	(0.125)
Renting	-0.201***	-0.200***	-0.197***	-0.311***
	(0.0281)	(0.0280)	(0.0272)	(0.0279)
Rent free	0.118	0.120	0.122	0.0151
	(0.0841)	(0.0847)	(0.0849)	(0.0925)
Marital Status	Reference category: Single			
Married	0.428***	0.427***	0.426***	0.470***
	(0.0220)	(0.0219)	(0.0217)	(0.0223)
Separated	-0.0346	-0.0352	-0.0372	-0.0512
	(0.0472)	(0.0472)	(0.0466)	(0.0473)
Divorced	0.0187	0.0179	0.0201	-0.00733
	(0.0290)	(0.0290)	(0.0294)	(0.0306)
Widowed	-0.107**	-0.109**	-0.109**	-0.104*
	(0.0534)	(0.0533)	(0.0532)	(0.0534)
Socio economic	Reference category: Higher managerial and professional			
Lower managerial	-0.0209	-0.0209	-0.0197	-0.0301
	(0.0244)	(0.0244)	(0.0244)	(0.0249)
Intermediate	-0.0620**	-0.0630**	-0.0624**	-0.0868***
	(0.0300)	(0.0300)	(0.0300)	(0.0309)
Small employers	-0.0225	-0.0225	-0.0220	-0.0305
	(0.0321)	(0.0321)	(0.0320)	(0.0321)
Lower	-0.0597	-0.0626	-0.0634	-0.102**
	(0.0408)	(0.0408)	(0.0407)	(0.0406)
Semi-routine	-0.0861**	-0.0860**	-0.0853**	-0.122***
	(0.0335)	(0.0334)	(0.0333)	(0.0341)
Routine	-0.0921**	-0.0930**	-0.0933**	-0.114***
	(0.0394)	(0.0394)	(0.0397)	(0.0401)

Never worked		-0.0940***	-0.0924***	-0.0926***	-0.169***
		(0.0328)	(0.0327)	(0.0323)	(0.0331)
July temperature				0.0167	0.0210
				(0.0194)	(0.0204)
January				0.0131	0.0105
				(0.0180)	(0.0177)
July rain				0.000255	0.000242
				(0.000791)	(0.000793)
January rain				0.00106	0.00455
				(0.00853)	(0.00928)
July sun				-0.0801**	-0.0668*
				(0.0395)	(0.0385)
January sun				0.120	0.0942
				(0.0796)	(0.0946)
Population				0.00138**	0.00123**
				(0.000538)	(0.000525)
Local area mean				4.26e-06	6.03e-06
				(3.78e-06)	(3.89e-06)
Month Controls	NO	NO	YES	YES	YES
Constant	7.432***	6.000***	6.035***	5.836***	8.924***
	(0.0517)	(0.276)	(0.276)	(0.460)	(0.494)
N	126,686	126,686	126,686	126,686	126,686
R-squared	0.000	0.097	0.097	0.098	0.057

*Standard errors clustered at local authority level in parentheses. *** p<0.01, ** p<0.05, * p<0.1*

Appendix 4E: Anxiety and $PM_{2.5}$

	Model I	Model II	Model III	Model IV	Model V
	Anxiety	Anxiety	Anxiety	Anxiety	Anxiety
$PM_{2.5}$	0.0234***	0.0192***	0.0193***	0.00784	0.00897
	(0.00642)	(0.00640)	(0.00639)	(0.0106)	(0.0107)
Male		-0.193***	-0.192***	-0.190***	-0.160***
		(0.0235)	(0.0235)	(0.0235)	(0.0236)
Phone Interview		0.116***	0.118***	0.118***	0.106***
		(0.0287)	(0.0287)	(0.0292)	(0.0296)
Age		0.0699***	0.0698***	0.0698***	0.0915***
		(0.00587)	(0.00587)	(0.00586)	(0.00602)
Age2		-0.000828***	-0.000826***	-0.000828***	-0.00103***
		(6.64e-05)	(6.64e-05)	(6.65e-05)	(6.81e-05)
Health			Reference category: Very bad health		
Bad health		-0.931***	-0.929***	-0.926***	
		(0.110)	(0.110)	(0.110)	
Fair health		-1.750***	-1.750***	-1.748***	
		(0.109)	(0.109)	(0.109)	
Good health		-2.364***	-2.365***	-2.364***	
		(0.106)	(0.106)	(0.106)	
Very good health		-2.883***	-2.883***	-2.884***	
		(0.111)	(0.111)	(0.112)	
Ethnicity:			Reference category: White		
Mixed		0.186	0.184	0.175	0.197
		(0.118)	(0.118)	(0.118)	(0.120)
Indian		0.169*	0.169*	0.188**	0.238***
		(0.0904)	(0.0905)	(0.0892)	(0.0917)
Pakistani		0.0747	0.0768	0.108	0.181
		(0.109)	(0.109)	(0.109)	(0.112)
Bangladeshi		0.0419	0.0482	0.0302	0.0357
		(0.152)	(0.153)	(0.168)	(0.180)
Chinese		0.0183	0.0214	0.0158	-0.0306
		(0.165)	(0.165)	(0.164)	(0.165)
Other Asian		0.160	0.165	0.152	0.135
		(0.121)	(0.121)	(0.121)	(0.122)
Black		-0.0642	-0.0639	-0.0648	-0.116*
		(0.0657)	(0.0660)	(0.0663)	(0.0672)
Other ethnicity		0.214**	0.213**	0.202**	0.168*
		(0.0950)	(0.0949)	(0.0945)	(0.0949)
Disabled		0.262***	0.262***	0.263***	0.935***
		(0.0303)	(0.0303)	(0.0301)	(0.0275)
Education			Reference category: No qualifications		
Degree		-0.0177	-0.0192	-0.0549	-0.135

	(0.252)	(0.253)	(0.250)	(0.286)
Higher education	-0.171	-0.173	-0.199	-0.256
	(0.250)	(0.251)	(0.249)	(0.285)
GCE, A-level	-0.187	-0.190	-0.214	-0.252
	(0.248)	(0.248)	(0.246)	(0.282)
GCSE grades	-0.258	-0.261	-0.283	-0.297
	(0.253)	(0.254)	(0.252)	(0.288)
Other	-0.243	-0.246	-0.267	-0.267
	(0.251)	(0.252)	(0.250)	(0.287)
Employment	Reference category: Employed			
Unemployed	0.199***	0.200***	0.207***	0.248***
	(0.0529)	(0.0529)	(0.0527)	(0.0533)
Inactive	-0.0655*	-0.0667**	-0.0660**	0.0870***
	(0.0337)	(0.0336)	(0.0334)	(0.0335)
Housing tenure	Reference category: Home owned outright			
Mortgage holder	0.162***	0.162***	0.163***	0.202***
	(0.0275)	(0.0274)	(0.0275)	(0.0274)
Part renting	0.409***	0.411***	0.386**	0.506***
	(0.154)	(0.153)	(0.154)	(0.156)
Renting	0.275***	0.275***	0.270***	0.383***
	(0.0342)	(0.0341)	(0.0340)	(0.0336)
Rent free	-0.106	-0.108	-0.107	0.00201
	(0.121)	(0.121)	(0.121)	(0.125)
Marital Status	Reference category: Single			
Married	-0.145***	-0.145***	-0.144***	-0.190***
	(0.0307)	(0.0306)	(0.0308)	(0.0313)
Separated	0.116*	0.117*	0.119*	0.130**
	(0.0612)	(0.0612)	(0.0615)	(0.0608)
Divorced	0.0421	0.0418	0.0442	0.0673
	(0.0396)	(0.0395)	(0.0399)	(0.0411)
Widowed	0.0452	0.0464	0.0496	0.0405
	(0.0627)	(0.0629)	(0.0628)	(0.0642)
Socio economic	Reference category: Higher managerial and professional			
Lower managerial	0.0375	0.0407	0.0462	0.0571*
	(0.0322)	(0.0321)	(0.0322)	(0.0322)
Intermediate	-0.0396	-0.0353	-0.0271	-0.00163
	(0.0412)	(0.0416)	(0.0416)	(0.0426)
Small employers	0.0416	0.0447	0.0474	0.0569
	(0.0460)	(0.0463)	(0.0465)	(0.0459)
Lower	-0.0575	-0.0453	-0.0359	0.00635
	(0.0527)	(0.0532)	(0.0532)	(0.0533)
Semi-routine	-0.0549	-0.0515	-0.0384	0.00113
	(0.0441)	(0.0444)	(0.0444)	(0.0456)
Routine	-0.0587	-0.0543	-0.0381	-0.0137
	(0.0465)	(0.0463)	(0.0466)	(0.0467)

Never worked		0.152***	0.154***	0.163***	0.236***
		(0.0482)	(0.0482)	(0.0484)	(0.0487)
July temperature				-0.0235	-0.0272
				(0.0324)	(0.0336)
January				0.0533**	0.0558**
				(0.0251)	(0.0257)
July rain				0.000779	0.000773
				(0.00115)	(0.00121)
January rain				-0.00442	-0.00792
				(0.0133)	(0.0135)
July sun				0.0651	0.0521
				(0.0496)	(0.0502)
January sun				-0.0860	-0.0602
				(0.143)	(0.156)
Population				0.000214	0.000382
				(0.000436)	(0.000457)
Local area				5.69e-06	3.93e-06
				(5.83e-06)	(5.91e-06)
Month Controls	NO	NO	YES	YES	YES
Constant	2.858***	3.969***	3.924***	3.623***	0.597
	(0.0666)	(0.318)	(0.326)	(0.622)	(0.665)
N	126,686	126,686	126,686	126,686	126,686
R-squared	0.000	0.060	0.061	0.061	0.037

*Standard errors clustered at local authority level in parentheses. *** p<0.01, ** p<0.05, * p<0.1*

5. Every breath you take, every move you make

Visits to the outdoors and physical activity

help to explain the relationship between SWB and air pollution

(Paper 2)

5.1 Introduction

There is a growing body of literature which investigates how individuals' subjective wellbeing (SWB) relates to the quality of their surrounding environments (EQ). In particular, many studies document negative associations between air pollution individuals' life satisfaction (Luechinger 2010; Orru et al. 2016; Welsch 2006; Levinson 2012; MacKerron and Mourato 2009). MacKerron and Mourato (2009), for example, find that local nitrogen dioxide concentrations are negatively associated with the life satisfaction of a sample of London residents. Paper 1 of this thesis also presents evidence of links between air quality and how worthwhile individuals consider their activities to be and how happy they report feeling on the previous day (Dolan and Laffan 2016). Although identifying these relationships is an important first step, the insights gained from the existing body of evidence are limited by the fact that the mechanisms underlying these associations have rarely been explored and are not well understood.

It is interesting that the level of air pollution in a local area is negatively linked to the life satisfaction of residents (MacKerron and Mourato 2009), for example, but it does not provide insights into what it is about living under these conditions that makes people less satisfied. MacKerron and Mourato (2013) highlight a number of potential pathways from EQ to SWB: environmental 'bads' may impact wellbeing via their effect on individuals' health; environmental quality may shape individuals' perceptions of safety and social cohesion in an area; or, finally, environmental conditions may influence the activities the individuals engage in. Apart from a couple of studies which explore the relationship between air pollution and SWB with and without health controls, no other work exists which empirically investigates the pathways from air pollution to SWB (Schmitt 2013; Dolan and Laffan 2016). The results of these studies suggest that while health appears to be one pathway, it is not the whole story. We presently, therefore, have only a limited understanding of the production process that converts air pollution into ill-being.

The current work seeks to address this gap. This paper looks to behavioural factors to provide further explanation, hypothesising that living in a polluted environment might negatively influence SWB by discouraging behaviours that are positively linked to wellbeing. The two types of behaviour investigated in this study

are 1) visits to the outdoors and 2) physical activity. Existing research, further detailed below in Sections 5.12 and 5.13, links the quality of individuals' environments to both of these activities (Foster, Hillsdon, and Thorogood 2004; Roberts, Voss, and Knight 2014), and separate work has found these activities to be related to SWB (MacKerron and Mourato 2013; Dolan, Kavetsos, and Vlaev 2014). Together this literature highlights these behaviours as potential mediators of the relationship between air pollution and SWB. Understanding whether they play a role will expand our theoretical understanding of the relationship between EQ and human wellbeing, as well as contributing to scholarship on the determinants of SWB.

Exploring the pathways from EQ to SWB may also yield important policy insights. First, from an efficiency perspective, policymakers might, on the basis of the findings of Mackerron and Mourato (2009), for example, take measures to decrease air pollution with the goal of enhancing life satisfaction. If, however, the air pollution–wellbeing relationship arises from the behaviours being discouraged by high air pollution levels, more cost-effective policies options involving the facilitation and encouragement of those behaviours may exist. Second, and relating to equity concerns, if the wellbeing benefits of improvements in air quality are conditional on individuals changing their behaviour in reaction to these improvements, then they are likely to have heterogeneous effects across populations. Individuals who are less able to engage in the mediating activities, for example, those who have less leisure time, would stand to benefit less from the air quality improvements. Gaining a better idea of not only how, but also why, environmental goods and 'bads' are related to wellbeing can help to inform policies on how best to promote it.

The following sections of the introduction detail the literature which motivates the exploration of both visits to the outdoors and physical activity as potential mediators of the relationship between SWB and air pollution. Section 5.11 considers work which has investigated links between EQ and these activities. Section 5.12 discusses existing research which has focused on the relationships between these activities and measures of SWB. Finally, Section 5.13 outlines the current work and the epidemiological research it draws on for its methodological approach.

5.11 The relationship between EQ, spending time outdoors and physical activity

There is a growing body of evidence which suggests that the conditions of individuals' local environments are related to how they spend their time. The majority of this work focuses on green space. How green individuals' local areas are is predictive of their engagement in a wide range of activities related to the outdoors. Sugiyama et al. (2008), for example, find that individuals' perception of the greenness of their local environments is significantly positively associated with recreational walking and social interaction within neighbourhoods. Other studies find that visits to open public spaces and walking are both positively related to the proximity and attractiveness of public open spaces (Foster, Hillsdon, and Thorogood 2004; Giles-Corti et al. 2005; Tilt, Unfried, and Roca 2007). Thompson, Roe, and Aspinall (2013) have also shown that improvements in EQ can lead people to visit the outdoors more frequently. They found that self-reported visits to the outdoors and perceived EQ significantly increased in areas which were targeted by a Scottish environmental improvement programme called 'Woods in and around Town', compared to those that were not.

Relatedly, there is some emerging evidence that green space is related to individuals' levels of exercise. Mytton et al. (2012) find that living in the greenest quintile in England, compared to the least green quintile, was associated with 27% higher odds of achieving recommended physical activity levels. Similar work in New Zealand also found that the greener a neighbourhood is, the more physical activity the residents report engaging in (Richardson et al. 2013). Importantly, the research is not conclusive, and there has also been some work which has failed to find an association between green space and exercise (Ord, Mitchell, and Pearce 2013).

Although the literature is less well developed, some studies also link environmental 'bads' to individuals' activities. Much of this research explores short-run behavioural adjustments in response to air pollution alerts on high pollution days. Zivin and Neidell (2009), for example, find evidence that fewer people visit outdoor attractions in California on alert days, and Noonan (2014) documents evidence of lower park use amongst joggers and the elderly in response to these warnings. These alerts are also linked to reduced time spent on vigorous outdoor activity (Ward and Beatty 2016), and cycling for leisure purposes (Saberian, Heyes, and Rivers 2017). We know less about the long-run adjustments people make to negative environmental

conditions, but a small number of studies exist which suggest that they the normal levels of environmental 'bads' are also linked to how people spend their time. In a Swiss study, Foraster et al. (2016) find that long-term noise annoyance is associated with reduced physical activity. Roberts, Voss, and Knight (2014) find that higher community level air pollution is associated with lower levels of leisure-time physical activity in a nationally representative US sample.

Taken together this literature suggests that the worse the quality of individuals' environments the less they tend to visits to the outdoors and and engage in physical activity.

5.12 The relationship between spending time outdoors, physical activity and SWB

There is also a substantial amount of evidence that spending time in nature and engaging in physical activity is linked to wellbeing (Ulrich et al. 1991; Berman et al. 2012; Mayer et al. 2008; MacKerron and Mourato 2013; Takayama et al. 2014; Bratman, Daily, et al. 2015; Bratman, Hamilton, et al. 2015; Tyrväinen et al. 2014). This body of literature differs from most SWB research in that it has a lot more to say about experiential wellbeing than it does evaluative wellbeing. The only existing finding which is suggestive of a link between spending time outdoors and life satisfaction, for example, is one that finds that gardeners report higher satisfaction with life than non-gardeners (Ferrer-i-Carbonell and Gowdy 2007).

By comparison, there is much more literature documenting links between nature exposure and experiential wellbeing. Experimental work suggests that there are a wide range of benefits from engaging in nature-based activities. Walking in nature compared to in urban environments has been shown to significantly lower individuals' stress levels and enhance their moods (Tyrväinen et al. 2014; Bratman, Hamilton, et al. 2015; Bratman, Daily, et al. 2015; Takayama et al. 2014). Exposure to nature also enhances vitality, autonomy and the ability to reflect (Mayer et al. 2008; Ryan et al. 2010; Nisbet and Zelenski 2014; Zelenski and Nisbet 2014).

Other work has linked voluntarily spending time in nature with experiential wellbeing. Korpela et al. (2014), for example, find that individuals in their Finnish sample who reported spending more of their free time in nature reported higher levels

of emotional wellbeing. MacKerron and Mourato (2013) use an experience sampling method to geographically locate individuals and collect real-time data on their experiential wellbeing. They find that people reported being happier when they were in natural, relative to urban environments. In relation to negative experiential wellbeing, Lottrup, Grahn, and Stigsdotter (2013) find a negative relationship between the having access to open green space and levels of workplace stress. A small number of non-experimental studies by Hinds and colleagues also document links between visiting the outdoors and eudemonic wellbeing (Hinds and Sparks 2011; Hinds 2015).

By contrast, the evidence on the relationship between physical activity and SWB is mixed. A number of studies link exercise to higher life satisfaction (Elavsky et al. 2005; Dolan, Kavetsos, and Vlaev 2014; Downward and Rasciute 2011), while other have not (for example Dolan and Testoni, 2017). Dolan and Testoni (2017) attribute this mixed evidence to some papers failure including health controls. Their results suggest that physical activity affects life satisfaction through its impact on health, but not over and above that. Similarly, it is unclear whether physical activity is linked to eudemonic wellbeing; Yemiscigil (Unpublished), for example, documents a positive association between purpose in life and engagement in rigorous physical activity in a middle-aged US sample, but Ferguson et al. (2012) does not find physical activity to be a significant predictor of eudemonia in a sample of female undergraduate students in Canada.

On the basis that both exposure to nature and physical activity have been found to be related to SWB, a line of research has emerged which specifically focuses on investigating the benefits exercising outdoors. A systematic review of the literature on green exercise and wellbeing find that physical activity undertaken outdoors, compared to indoors, is associated with greater feelings of revitalisation and positive engagement, decreases in tension, confusion, anger, and depression, and increased energy (Thompson Coon et al. 2011). The study also finds evidence that individuals report being more satisfied when they undertake physical activity outdoors and express greater intentions to repeat the activity.

Overall, this literature suggests that visiting the outdoors and engaging in physical activity are both linked to at least some dimensions of SWB.

5.13 The current work

To date the EQ-SWB literature has provided little insight why individuals who live in more polluted environments report lower SWB. In contrast, it is common within epidemiological research to investigate the pathways from EQ to health outcomes. In particular, a number of studies have explored behavioural mediators of the relationship between green space and health using mediation analysis. This type of analysis is concerned with understanding the association between an independent variable and an outcome of interest through a third variable or variables. Richardson et al. (2013) and de Vries et al. (2013), for example, both use this approach and find that physical activity partially explains the positive relationship between green space and health in samples from the New Zealand and Holland respectively. As individuals' engagement in both visits to the outdoors and physical activity are linked to the quality of their environment (see Section 5.12), and such activities have themselves are associated with SWB (see Section 5.13), they may potentially play a role in the relationship between air pollution and wellbeing.

This paper presents the first empirical work to investigate behavioural pathways between SWB and air pollution. It also contributes to both the EQ-SWB literature and behaviour-SWB research by comparing and contrasting the associations between the determinants of interest and SWB across a range of different measures of SWB which reflect evaluative, eudemonic and experiential SWB. In doing so, the work offers a more comprehensive picture of how and why this element of environmental quality and these activities relate to wellbeing than has been available to date.

The paper considers and formally tests whether associations between SWB and air pollution are explained by visits to the outdoors and physical activity in four stages. A path diagram representing the relationships of interest appears in Figure 5.1 below (Frith and Mackinnon, 2008). First, the relationship between SWB and air pollution is considered (represented by the letter C in the upper section of Figure 5.1). Both reports of life satisfaction and the worthwhileness of activities are found to be significantly negatively associated with local levels of particulate matter controlling for individual and local area characteristics, but reports of happiness and anxiety yesterday are not. Second, the relationships between these activities and SWB are modelled (represented

by the letters B and E in the lower section of Figure 5.1). Frequency of visits to the outdoors is found to be significantly associated with all of the measures of SWB investigated in the expected ways. Physical activity is found to be unrelated to life satisfaction and anxiety yesterday but significantly related to reports of the worthwhileness of activities and happiness yesterday. Third, the relationship between the activities and air pollution is investigated (represented by the letters A and D in the lower section of Figure 5.1). Higher local levels of pollution are found to be associated with lower odds of visiting the outdoors more frequently as opposed to less over the previous twelve months and lower engagement in physical activity. Finally, formal mediation analyses are carried out (this involves estimating the difference between C in the upper section of Figure 5.1 and C' in the lower section). The results indicate that frequency of visits to the outdoors and physical activity totally mediate the link between air pollution and the worthwhileness of activities, and that frequency of visits to the outdoors partially mediates the association between air pollution and life satisfaction.

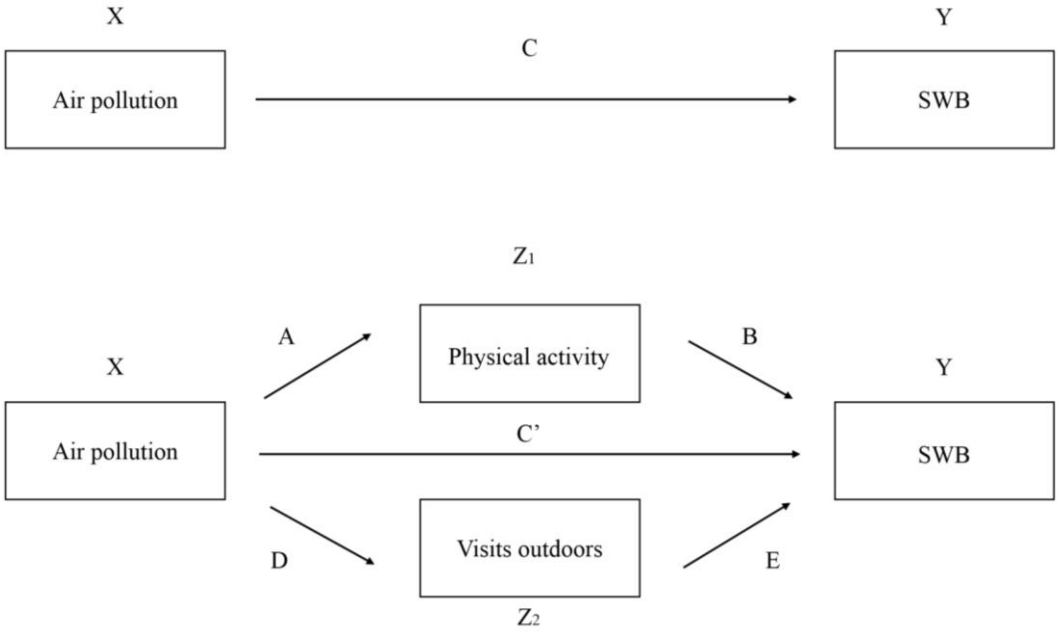


FIGURE 5.1: INVESTIGATING THE PATHWAYS FROM AIR POLLUTION TO WELLBEING

Overall the evidence presented here suggests that the negative relationships between air pollution and SWB can be explained, at least in part, by individuals living in more polluted environments visiting the outdoors and engaging in physical activity less frequently. The paper proceeds as follows: Section 2 describes the data, Section 3 details the methods, Section 4 presents the results and Section 5 discusses the findings and concludes.

5.2 Data

The data required to carry out the analysis including data on SWB, activities air pollution and other relevant control variables were drawn from a number of sources and merged using QGIS and Stata 14 (discussed in detail in Section 3.2, p.32). Descriptive statistics of all of the variables included in the analysis are documented in Appendix 5A. Data on SWB, the frequency of visits to the outdoors, physical activity, socio-demographics and whether the respondent lives in a rural or an urban setting are all drawn from the four cross-sectional waves of the Monitor of Engagement with the Natural Environment survey (MENE) spanning 2012-2015 and pooled (Natural England 2016). The data are downloaded under the Open Government License from the MENE website in Microsoft Excel format and loaded into STATA 14. Complete case analysis is carried out on data from 4,277 respondents from across the survey waves 2012-2015. The tables below show summary statistics for the four SWB variables of interest and report the correlations between the measures.

Table 5.1: SWB Summary Statistics

Variable	N	Mean	Std. Dev
Satisfaction	4,277	7.482815	2.00607
Worthwhile	4,277	7.631284	1.91124
Happiness	4,277	7.463409	2.251988
Anxiety	4,277	2.465513	2.853213

Table 5.2: SWB correlation matrix

	Satisfaction	Worthwhile	Happy	Anxious
Satisfaction	1			
Worthwhile	0.6512	1		
Happiness	0.5870	0.5332	1	
Anxiety	-0.2959	-0.2562	-0.3954	1

Behavioural measures relating to the frequency of visits to the outdoors and level of physical activity are also taken from the responses to MENE survey questions. A measure of frequency of visits to the outdoors is constructed from responses to the following question: '*Now thinking about the last 12 months, how often, on average, have you spent your leisure time out of doors, away from your home? By out of doors, we mean open spaces in and around towns and cities, the coast and the countryside. This could be anything from a few minutes to all day. It may include time spent close*

to your home, further afield or while on holiday in England. However, this does not include routine shopping trips or time spent in your own garden'. In order to reduce ensure sufficent sample in all categories responses are grouped to form a five-category variable in the following way; Daily (More than once per day, every day), Weekly (Several times a week, Once a week); Monthly (Once or twice a month, Once every 2- 3 months); Once or twice (Once or twice); Never (Never). Individuals' physical activity levels are captured by the question: '*In the past week, on how many days have you done a total of 30 minutes or more of physical activity, which was enough to raise your breathing rate? This may include sport, exercise, and brisk walking or cycling for recreation or to get to and from places, but should not include housework or physical activity that may be part of your job'*. Responses range from zero to seven. That the measures are limited to leisure time activities, i.e. do not include physical activity carried out for work purposes, means that they are imperfect measures of overall time spent outdoors and doing physical activity. However, as the current work is interested in the relationship between environmental quality and these behaviours, it is arguably more important to assess the extent to which individuals engage in these activities voluntarily and the MENE variables do exactly that. Measures of socio-demographic characteristics relating to health, disability, gender, age group, marital status, housing tenure, employment status and socio-economic status are all drawn from the MENE and individuals are classified as living in an urban if their area has over 10,000 residents.

Data on air pollution and other local area characteristics are obtained from the sources described in Section 2 and are linked to the MENE using matching techniques described in the data matching section on page 39. The MENE itself classifies individuals as living in an urban are if their local area has over 10,000 inhabitants and an urban/rural dummy was included in the analysis based on that information. A measure of local authority green land cover is also obtained from the Generalised Land Use Database for England and is included in a robustness check. This measure is based on England Communities and Local Government land classification system and is produced using an automated methodology which classifies land use from the Ordnance Survey Maps into the following nine categories; domestic buildings, domestic gardens, non-domestic buildings, roads, paths; rail, green space, water, and other land uses. The same green land cover variable is used in epidemiological work

carried out by Seresinhe, Preis, and Moat (2015) which explores the relationship between green space and health.

5.3 Methods

The overarching aim of the analysis is to investigate whether self-reported frequency of visits to the outdoors and physical activity explain the association between local air pollution and SWB reports. In order to do this, unadjusted and adjusted ordinary least squares regression (OLS) and ordinal logistic regression models are estimated to investigate the links between air pollution and SWB (Section 5.31), between visits outdoor and physical activity and SWB (Section 5.32), and between air pollution and those behaviours (Section 5.33). The Karlson, Holm and Breen method (KHB) is then used to formally test for mediation on the basis of the findings from the first three steps (Breen, Karlson, and Holm 2013) (Section 5.34).

5.31 SWB and air pollution

First, models investigating potential associations between the different measures of SWB and local levels of air pollution are estimated.

EQ_1 below provides the specification.

$$EQ_1: SWB_{ijt} = \beta_0 + \beta_1 P_j + \beta_2 X_{ijt+} \beta_3 Z_j + \varepsilon_{ijt}$$

Where SWB_{ijt} is the SWB rating of the respondent i in location j at date t. P_j is the annual average background particulate matter concentration at location j in 2012. X_{ijt} represents socio-demographic characteristics, Z_j are local area characteristics in location j and ε_{ijt} represents the error term.

5.32 SWB and behaviours

Second, how physical activity and visits to the outdoors separately and in combination relate to all four measures of SWB is explored. EQ_2 presents the specification of the combined model.

$$EQ_2: SWB_{ijt} = \beta_4 + \beta_5 V_{ijt} + \beta_6 E_{ijt} + \beta_7 Xijt + \beta_8 Z_j + \varepsilon_{ijt}$$

SWB_{ijt}, X_{ijt}, and Z_j and ε_{ijt} are as above. V_{ijt} is the reported frequency of visits to the outdoors of respondent i in location j at date t and E_{ijt} is the level of physical activity respondent i in location j at date t. In the combined specification, in which physical activity is included alongside frequency of visits to the outdoors, the measure of physical activity can be considered a proxy measure for indoor physical activity. Visits to the outdoors implicitly includes leisure time spent outdoors exercising and controlling for this, therefore, limits the physical activity variable to activity undertaken indoors.

5.33 Activities and air pollution

Third, ordinal logistic regression models are used to test for an association between frequency of visits to the outdoors and local levels of air pollution in three models: the first is a bivariate model, the second includes individual and local area characteristics and the third includes a physical activity control. EQ_3 provides the specification of the second version of this model.

$$EQ_3: V_{ijt} = \beta_9 + \beta_{10} P_j + \beta_{11} Xijt + \beta_{12} Z_j + \varepsilon_{ijt}$$

All variables are defined as above. The equivalent regression models for physical activity are also estimated using OLS.

5.34 Mediation analysis

Finally, in order to formally test the potential pathways between air pollution and SWB, separate mediation analyses are undertaken. The KHB method is used to do this. Although this method was developed to compare estimated coefficients of nested nonlinear probability models it represents a general decomposition method that can be applied to both discrete and continuous variables. Importantly, it allows for the incorporation of multiple mediators. It calculates the proportion of total effect attributable to mediating effect as the indirect effect divided by the total effect and estimates whether the mediating effects are statistically significant (for more details see Breen, Karlson and Holm 2013). The mediation analysis is carried out using the 'khb' command in STATA (Kohler and Holm 2011). The direct and indirect effects for the relationship between air pollution and life satisfaction, with visits to the outdoors acting as a mediator variable, are calculated using the following equation:

$$EQ_4: SWB_{ijt} = \beta_{13} + \beta_{14} P_j + \beta_{15} V_{ijt} + \beta_{16} X_{ijt+} \beta_{17} Z_j + \varepsilon_{ijt}$$

All variables are defined as above.

5.4 Results

The results for the first two stages of the analysis relating to the SWB-air pollution relationships and the SWB-activities relationships appear in the appendices Tables 5B-F. The results tables for stages three and four, the air pollution - activities relationships and the mediation analysis respectively, appear within the text below.

5.41 Is air pollution related to the different measures of SWB?

The analysis begins by investigating the relationship between SWB and air pollution using both unadjusted (Appendix 5B: Model I), and multiple linear regression models adjusting for individual and local area characteristics (Appendix 5B: Model II). These relationships are depicted in Figure 5.2 below. In what follows the results from the adjusted version of the models which include individual and local area characteristics are presented. Appendix 5B reports the results for both the unadjusted and adjusted models across all four SWB measures. The results present evidence of negative linear association between background concentrations of particulate matter and life satisfaction and the worthwhileness of activities. In contrast, both happiness anxiety yesterday are unrelated. While magnitudes of the coefficients for the relationship between particulate matter and life satisfaction and separately how worthwhile individuals consider their activities to be may appear to be small there are meaningful. Within the SWB literature a change in any single characteristic is not usually associated with large movements in SWB (OECD, 2013). In this dataset, being out of work, which is commonly identified as being one of the strongest negative predictors of SWB, is associated with a reduction in life satisfaction which is just over ten times the size of the drop associated with a 1 unit increase in local levels of particulate matter. While there is clearly a difference in importance across these two predictors, the fact that the coefficients are at all comparable is testament to the substantive nature of the relationship between of the particulate matter and life satisfaction.

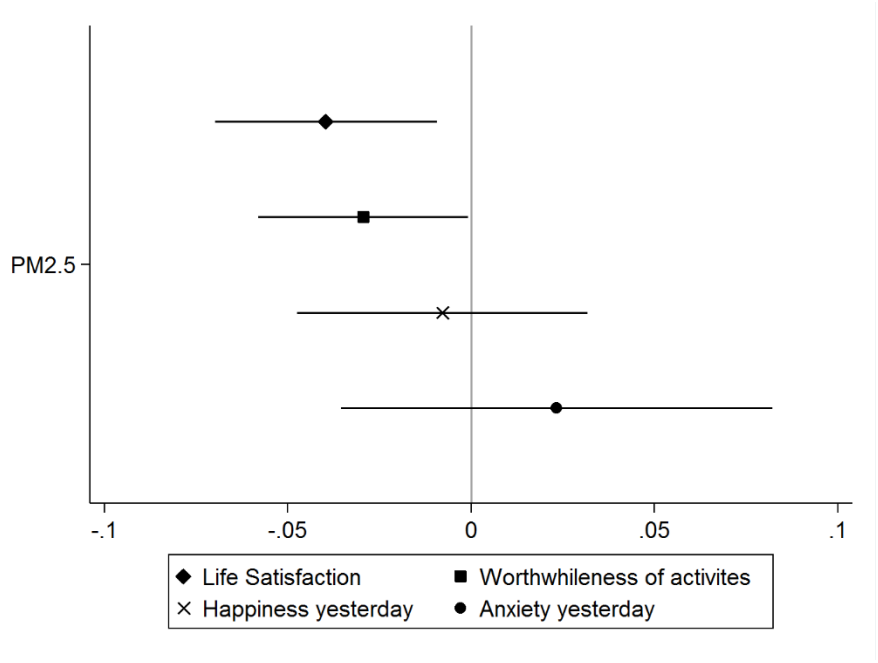


FIGURE 5.2: $PM_{2.5}$ AND THE RANGE OF SWB MEASURES

Note: The symbols represent the point estimates from Model II, and the bars indicate the 95% confidence intervals. Please see the Appendix 5B for the related regression tables.

5.42 Are frequency of visits to the outdoors and engagement in physical activity related to the different measures of SWB?

How visits to the outdoors and physical activity relate to the four measures of SWB is investigated both separately (see appendices 5C-F: Models I-IV) and in combination (see appendices 5C-F: Model V). Model IV explores the relationship between physical activity and SWB controlling or individual and local area characteristics. Model V adds frequency of visits to the outdoors to Model IV. The results of both models are described in detail and depicted in Figures 5.3 and 5.4 below.

Life satisfaction is significantly positively associated with visiting nature at least weekly compared to never. Physical activity, on the other hand, is unrelated to life satisfaction in both Model IV and V. The worthwhileness of activities is also positively linked with visiting the outdoors; all frequencies of visits are positively associated with worthwhileness compared to never visiting. Physical activity is found to be significantly associated with the worthwhileness of activities in Model IV. However, the positive association is no longer significant once the frequency of visits to the

outdoors is incorporated into the model, rendering physical activity a proxy measure of indoor physical activity (Appendix 5D: Model V).

Visiting the outdoors weekly and daily, compared to never, are both positively associated with happiness yesterday. The analysis also finds that frequency of exercise in the past seven days is weakly positively associated with happiness yesterday in Model IV but that the relationship no longer holds in the model controlling for visits to the outdoors i.e. when physical activity represents indoor physical activity alone (Appendix 5E: Model V). Lastly, in relation to anxiety yesterday only visiting the outdoors weekly compared to never is significantly negatively associated with anxiety. Physical activity is not found to be related to anxiety yesterday in either Model IV or V.

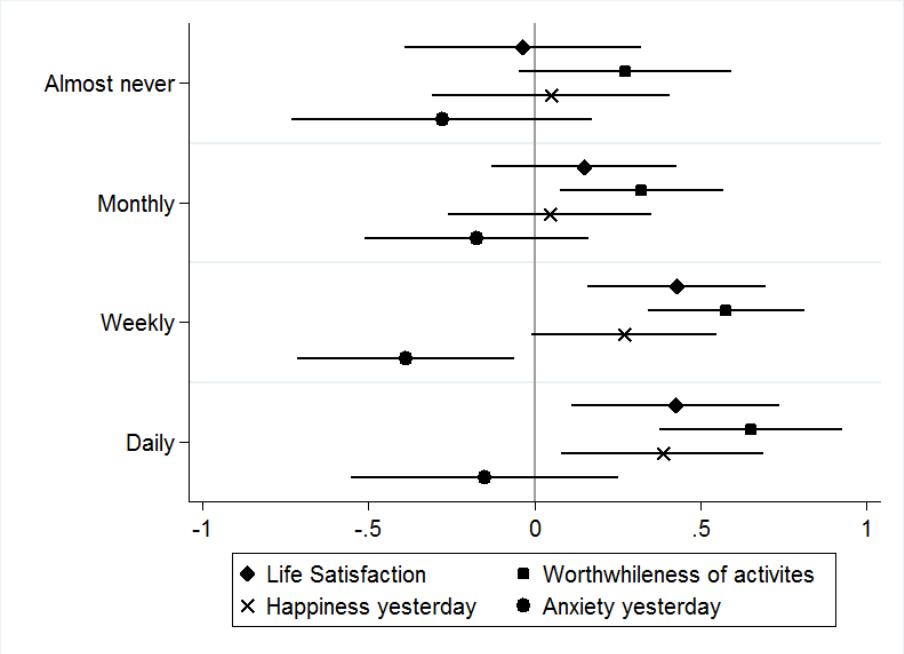


FIGURE 5.3: VISITS TO THE OUTDOORS AND THE RANGE OF SWB MEASURES

Note: The symbols represent the point estimates from Model V, and the bars indicate the 95% confidence intervals.

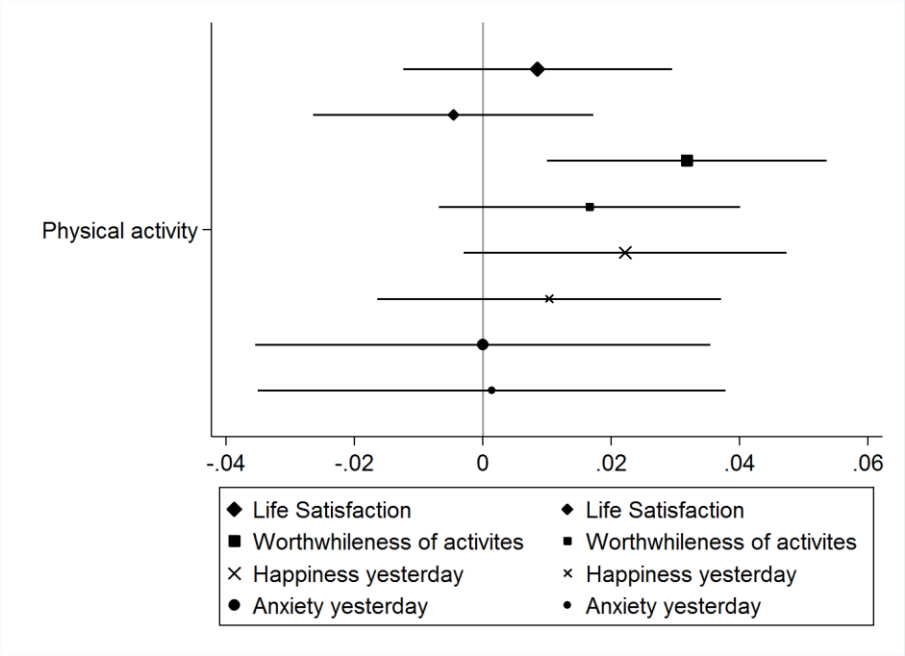


FIGURE 5.4: PHYSICAL ACTIVITY AND THE RANGE OF SWB MEASURES

Note: The larger (smaller) symbols represent the point estimates from Model IV (V) without (with) frequency of visits to the outdoors controls and the bars indicate the 95% confidence intervals.

5.43. Are frequency of visits to the outdoors and engagement in physical activity related to local levels of air pollution?

Regarding the relationship between air pollution and visits to the outdoors and physical activity, higher levels of local $PM_{2.5}$ are found to be associated with lower odds of visiting the outdoors more frequently as opposed to less over the previous twelve months with lower physical activity levels in the preferred specification of both those models (see Table 5.3: Models II & V). A one unit increase in the background concentrations of fine particulate matter is associated with an approximately 8% decrease in the odds of more frequent visits to the outdoors compared to less (significant at the 1% level). A one unit increase in particulate matter is associated with a 0.0707 unit decrease in physical activity (significant at the 1% level) (Table 5.3: Model V). Also of interest is the relationship between the two behaviours of interest (Table 5.3: Models III & VI): physical activity is significantly positively associated with visiting the outdoors, suggesting that people visit the outdoors to exercise.

Table 5.3: Physical activity, visits to the outdoors and local air pollution

			Visits		Physical		
Variables	Model I	Model II	Model III	Model III	Model IV	Model V	Model VI
				Odds ratios			
$PM_{2.5}$	-0.0823***	-0.0932***	-0.0826***	.9208***	-0.0481**	-0.0707**	-0.0424
	(0.0226)	(0.0277)	(0.0276)	(0.0254)	(0.0222)	(0.0304)	(0.0297)
	Reference category: Never						
Almost never							0.0702
							(0.200)
Monthly							0.272*
							(0.146)
Weekly							0.824***
							(0.158)
Daily							2.340***
							(0.193)
Physical			0.200***	1.221***			
			(0.0156)	(0.0191)			
Individual Characteristics	No	Yes	Yes	Yes	No	Yes	Yes
Local area characteristics	No	Yes	Yes	Yes	No	Yes	Yes
Constant cut 1	-3.149***	-2.165	-0.532	-0.532			
	(0.258)	(3.034)	(2.996)	(2.996)			
Constant cut 2	-2.524***	-1.494	0.153	0.153			
	(0.265)	(3.030)	(2.992)	(2.992)			
Constant cut 3	-1.310***	-0.172	1.518	1.518			
	(0.267)	(3.031)	(2.994)	(2.994)			
Constant cut 4	1.004***	2.283	4.101	4.101			
	(0.267)	(3.032)	(2.993)	(2.993)			
Constant					2.955***	7.180**	5.894*
					(0.267)	(3.312)	(3.104)
N	4,277	4,277	4,277	4,277	4,277	4,277	4,277
R^2/Pseudo R^2	0.0052	0.0433	0.0659	0.0659	0.003	0.073	0.137

*Standard errors clustered at local authority level. *** p<0.01, ** p<0.05, * p<0.1*

5.44 Mediation analysis

The above results suggest the relationship between life satisfaction and air pollution may be mediated by visits to the outdoors but not by engagement in physical activity. Physical activity is unrelated to life satisfaction once individual and local area characteristics controls are included. On this basis, a KHB mediation analysis is carried out to assess whether and to what extent frequency of visits to the outdoors mediates the relationship between life satisfaction and air pollution. Bootstrapping methods are used to calculate the 95% confidence intervals around the estimate of the indirect effect. This approach is recommended when assessing the significance of the difference in the indirect effect (Friedman et al. 2015; Preacher and Hayes 2008; MacKinnon et al. 2007). The results presented in Table 5.4 show that visits to the outdoors mediate a significant proportion of the relationship between life satisfaction and particulate matter: the coefficient on $PM_{2.5}$ is reduced by ~17 % in the full model, which incorporates visits to the outdoors, compared to the reduced model, which does not. Importantly, however, the coefficient in the full form of the model is still significant at the 5% level suggesting that the mediation is only partial.

Lastly, the first stages of the analysis suggest that both physical activity and visits to the outdoors may explain the relationship between reports of worthwhileness and level of local pollution. Both activities are found to be significantly associated with this measure of SWB and separately with air pollution. KHB analysis is used to formally test this idea. The results are shown in Table 5.5. They indicate that two behavioural variables totally mediate the relationship between eudemonic wellbeing and air pollution documented here. While the $PM_{2.5}$ coefficient in the reduced form of the model is negative and significant at the 5%, it is reduced by ~36 % in the full form of the model that contains both a measure of frequency of visits to the outdoors and physical activity levels, and is no longer significant. The difference between the coefficients across the two models is highly significant. The breakdown the mediating effect suggests that change is largely due to the visits to the outdoors, but that physical activity also accounts for approximately 11% of the change.

Table 5.4: Mediation analysis: Life satisfaction

KHB test of mediation: Life satisfaction (DV), $PM_{2.5}$ (IV), Frequency of visits to the outdoors (MV)			
	Life Satisfaction	95% Confidence Interval	
$PM_{2.5}$ Reduced	-0.039596**	-0.07	-0.00919
	(0.0155)		
$PM_{2.5}$ Full	-0.03296**	-0.0637	0.0022
	(0.05694)		
$PM_{2.5}$ Diff	-.0068598 **	-.0128666	-.000853
	(0.0031)†		
	Ratio	Percentage	
$PM_{2.5}$	1.201	16.75%	

*Standard errors clustered at local authority level in parentheses. *** p<0.01**p<0.05 * p<0.01, (n=4,277). All models include individual level, local area controls. †Bootstrapped standard error of the difference 100 reps.*

Table 5.5: Mediation analysis: The worthwhileness of activities

KHB test of mediation: Worthwhileness of activities (DV), $PM_{2.5}$ (IV), Frequency of visits to the outdoors & Physical activity (MV)			
	Worthwhileness	95% Confidence Interval	
$PM_{2.5}$ Reduced	-0.0295**	-0.0580846	-0.0008473
	(0.0146)		
$PM_{2.5}$ Full	-0.0188	-0.048144	0.0105402
	(0.0149)		
$PM_{2.5}$ Difference	-0.0106**	-.0169569	-.0043712
	(0.0032)†		
	Ratio	Percentage	
$PM_{2.5}$	1.567	36.19 %	

Breakdown	Coefficient	Std. Error	% difference	%
$PM_{2.5}$				
Weekly	0.0003729	0.0006398	-3.56	-1.26
Monthly	0.0011503	0.0012331	-10.99	-3.89
Once or twice	-0.0047904	0.0025666	45.78	16.22
Never	-0.0060811	0.0022192	58.12	20.59
Physical Activity	-0.0011149	0.0009019	10.66	3.77

*Standard errors clustered at local authority level in parentheses. *** p<0.01**p<0.05 * p<0.01, (n=4,277). All models include individual level, local area controls. †Bootstrapped standard error of the difference 100 reps.*

5.45 Further analyses

Interactions between visiting the outdoors and $PM_{2.5}$ levels and physical activity are also specified, but no evidence is found to support the idea that the associations between life satisfaction or worthwhileness of activities and either behavioural variable vary at different levels of particulate matter (Appendix 5G: Models I-IV). In other words, air pollution does not appear to moderate the effect of the behaviours on SWB. Additionally, the question of whether individuals visit the outdoors less in polluted areas as a result of having less opportunity to do so is investigated by incorporating a local authority green space coverage measure as a proxy for individuals' opportunity to visit the outdoors. The point estimates of the association between air pollution and visits to the outdoors become smaller when the measure of green space coverage is included, but the results remain substantively the same (Appendix 5H). The relationship between $PM_{2.5}$ and physical activity also decreases but the adjusted model presents evidence of a weak but significant association between the two controlling for green space.

5.5 Discussion

The current paper goes beyond this existing work which documents evidence of negative relationships between SWB and air pollution by exploring the production process through which air quality is converted into SWB.

5.51 The relationship between air pollution and the different measures of SWB

The paper starts by establishing links between air pollution at the English local authority level and two of the four measures of SWB measures investigated. Background concentrations of particulate matter are found to be negatively related to reports of both life satisfaction and the worthwhileness of activities, but no such relationship is documented with the two experiential measures of wellbeing - reports of happiness and anxiety yesterday.

The relationship between air pollution and life satisfaction reported here is both significant and substantive: living in an area with background concentrations of $PM_{2.5}$ equivalent to that of South Lakeland compared to Bristol city is associated with higher levels of life satisfaction equivalent to being married compared to belonging to the category separated, divorced or widowed. Similarly, the association between the worthwhileness of activities and air pollution is important: an increase of one standard deviation in particulate matter is negatively associated with the worthwhileness of activities to equivalent to approximately a third of the association between eudemonic wellbeing and having a mortgage, compared to owning your own home in the same sample.

That air pollution is associated with the evaluative measures, but unrelated to the experiential reports of wellbeing may be related to adaptation. Although the existing SWB literature does not explore whether individuals adapt, or become sensitised, to elements of EQ across different dimensions of wellbeing, research into the impact of other life circumstances has found that their effect to be stronger and more persistent on evaluative measures of wellbeing than experiential ones (Luhmann et al. 2012). Individuals may withdraw attention from the normal average air pollution levels in their area to the point where they do not affect how they feel day to day, while

still consciously or unconsciously taking them into account when they stand back and think about their lives and their activities (Welsch 2006).

It is important to note that other work, in Paper 1 of this thesis, which is based on analysis using the same measures of hedonic wellbeing and particulate matter, but investigate the relationship in a larger dataset (The UK's Annual Population Survey), does document a significant negative relationship between happiness yesterday and local particulate matter. The large nature of the APS would contribute to the analysis' power and as a result Paper 1 may picked up on a relationship between happiness and particulate matter which this study did not. Future research is required to further explore whether a relationship between particulate matter and positive hedonic wellbeing is supported in other datasets. If it is, the results of the rest of the analysis suggest that both visits to the outdoors and physical activity may act as mediators.

5.52 The relationship between frequency of visits to the outdoors and engagement in physical activity to the different measures of SWB

The results indicate that the wellbeing levels of individuals who visit the outdoors more frequently than monthly have higher levels life satisfaction, consider their activities to be less worthwhile and report feeling happier on the previous day. This echoes existing evidence that spending time in nature is positively related to experiential wellbeing (MacKerron and Mourato 2013; Bratman, Daily, et al. 2015) and contributes to an underdeveloped body of research which links individuals' nature-based activities to their evaluative and eudemonic wellbeing.

Interestingly, visiting weekly compared to never is also associated with lower anxiety levels. All other frequencies including daily visits are not found to be linked to lower anxiety. This result somewhat contrasts with existing work from the restorative environment literature that finds that between spending time reduces negative feelings (Tyrväinen et al. 2014). Typically, the restorative environment research measures experiential wellbeing during or directly after nature-based experiences and finds these activities reduce individuals' stress levels (Collado et al. 2017). The difference between the results of this work and the null finding in the current work may be attributable to the temporal mismatch between the variables –

anxiety is measured in relation to yesterday, and frequency of visits to the outdoors refers to the past 12 months. However, the same mismatch is present in the happiness-related analysis and a positive relationship is found. Although the findings in the current work suggest that visiting the outdoors is linked to positive experiences and not negative ones, the overall picture from the analysis is that visiting the outdoors is positively related to SWB across evaluative and experiential dimensions of wellbeing.

The relationship between physical activity and SWB varies to a greater extent across the range of SWB measures. Physical activity is unrelated to life satisfaction and anxiety yesterday, but positively associated with both the worthwhileness of activities and happiness yesterday. The results reported here are strikingly similar to those documented by Dolan and Testoni (2017). These authors use three separate datasets from the UK, a sample of residents in Berlin, London and Paris and an American sample, focusing their analysis on young people aged 16-25. Their work explores the relationship between SWB and physical exercise across a number of dimensions of wellbeing. The UK data contain responses to questions about of life satisfaction and physical activity and their analysis finds no evidence of a direct link between life satisfaction and physical activity. The European and American samples provide the opportunity to explore the links between physical activity and experiences of happiness, anxiety and stress, alongside experiences of purpose. The results indicate that physical activity is linked to both happiness and purpose, but not anxiety nor stress.

One explanation for the differences in the relationship between physical activity and across the two experiential measures of wellbeing is suggested by the results of another recent study. Lathia et al. (2017) explore the link between physical activity and hedonic SWB using smartphone-based mood data and activity tracking measures from both self-reported and electronically tracked activity (using accelerometers on participants' phones). They find that physical activity is related to high-arousal positive affect, which is the measure that most closely relates to the happiness measure explored in the current work, but not high-arousal negative affect, which relates to anxiety. Interestingly, they do find that physical activity is related to low arousal negative experiences. Other studies, including a recent one by Doré et al. (2016) document links between psychical activity and reduced depressive symptoms. Together this work suggests that physical activity may reduce the negative experiences

individuals have, but not their experiences of anxiety specifically. In general, SWB research finds that negative experiences tend to be more differentiated than positive ones and that the assessment of a range of negative feelings provides deeper insights into the determinants of negative experienced wellbeing (Stone and Mackie 2013).

Finally, this paper finds evidence to suggest that, over and above its effects through health, engaging in physical activity is predictive of both eudemonic and hedonic wellbeing. This contributes new evidence to a small body of literature on this topic that has to date yielded mixed results (Ferguson et al. 2012; Yemiscigil Unpublished). Importantly, once visits to the outdoors are controlled for, and physical activity, therefore, represents a measure of indoor physical activity, the relationship between both the worthwhileness of activities and happiness yesterday and physical activity no longer holds. This suggests that outdoor physical activity is driving the links between SWB and physical activity documented here. These findings echo evidence from the green exercise literature which indicates that physical activity which is undertaken outdoors is more beneficial to individuals than the equivalent activities carried out in an indoor setting (Thompson Coon et al. 2011).

5.53 The relationship between frequency of visits to the outdoors and engagement in physical activity and local levels of air pollution

This paper presents the first evidence that specifically relates visits to the outdoors to local levels of air pollution. It also, presents the first UK-based evidence of a link between air pollution and phsyical activty. An individual has lower odds of visiting the outdoors more frequently if they live in a polluted environment (every one unit increase in $PM_{2.5}$ is associated with 8% lower odds). Additionally, physical activity is found to be negatively related to $PM_{2.5}$ levels. This contributes new evidence to a wider literature that has linked features of individuals' physical environments to the behaviours they engage in (Foster, Hillsdon, and Thorogood 2004; Tilt, Unfried, and Roca 2007; Giles-Corti et al. 2005; Roberts, Voss, and Knight 2014).

5.53 Why do people who live in polluted environments visit the outdoors less frequently?

As existing work has found that air pollution appears to be weakly negatively associated with tree and other green element coverage (Nowak, Crane, and Stevens 2006; Tiwary et al. 2009), the frequency of visits to the outdoors and physical activity may actually be related to the availability of green space and the opportunity this provides to engage in these activities, rather than air pollution. If this were the case, then the relationship between air pollution and time spent outdoors would be spurious, with the actual link being between the availability of natural outdoor space and the associated time spent outdoors. However, the results of the robustness check, which includes a control variable representing the percentage of green space coverage in the local authority, suggest that this is not the case: once green space cover is controlled for the relationship between particulate matter and frequency of visits to the outdoors remains statistically significant and qualitatively the same. The association between, physical activity and air pollution, in contrast, becomes substantially smaller, although it remains significant.

Beyond the availability of green space, therefore, the explanation for the link between air pollution and these behaviours may lie either in the lower appeal of engaging in those activities in different quality environments or in individuals who do not like spending time outdoors selecting into more polluted environments. The first explanation relates to the idea that visiting the outdoors and doing physical activity may simply be less appealing in polluted areas; pollution affects visibility, degrades vegetation and can cause discomfort when breathing (DEFRA 2007b; US Environmental Protection Agency 2011) all of which could influence individuals' decisions to spend time outdoors and to exercise there. Importantly, previous research has shows that indivduals' perceptions of air pollution are positively correlated with objective air pollution levels (Day 2007). Given that people are aware of pollution levels, worries about the health consequences of spending time outdoors may also decrease its appeal. The second potential explanation for the relationship between these activities and air pollution levels relates to selection effects: if individuals who value visiting the outdoors less select into more polluted environments, benefiting from cheaper housing, then it may not be the case that the pollution in an area affects the desirability of spending time outdoors but rather that polluted areas attract individuals who value such activities less. Beyond controlling for the opportunity to

spend time outdoors in the green space robustness check, this paper cannot test the merits of these other potential explanations.

Interestingly, the models containing interactions find that the relationship between either life satisfaction or the worthwhileness of activities and time spent outdoors and physical activity are not different at different levels of air pollution. These non-significant interactions of pollution and the frequency of visits to outdoors and physical activity in both the life satisfaction and worthwhile activities models, suggest that although individuals visit the outdoors less frequently and engage in less physical activity, the more polluted their local area is, doing so does not appear to be differently related to wellbeing. Further research is required to tease out why people are engaging in these activities less frequently in polluted environments, but this work suggests that it would be wellbeing enhancing for them to do so regardless of the local levels of air pollution.

5.56 The evidence of mediation

The results of the mediation analysis present evidence of a partial mediating effect of visits to the outdoors on the widely documented relationship between air pollution and life satisfaction. That the mediation is only partial, explaining ~17% of the relationship between life satisfaction and background concentrations of particulate matter leaves much unaccounted for. Finally, the mediation analysis identifies visits to outdoors and physical activity as the whole explanation for the relationship documented between reports of the worthwhileness of activities and air pollution. Air pollution appears to be solely related to eudemonic wellbeing through individuals' engagement in activities relating to the natural world. These results represent the first empirical evidence in the air pollution- SWB literature, and in the EQ-SWB literature more broadly, which indicates that the condition of individuals' environments influences their SWB via their behaviour. While the current work only considers air pollution and investigates the role of two overlapping activities, future research should look to explore other possible pathways from EQ to SWB.

5.57 Limitations

This paper is not without limitations; in particular, the use of cross-sectional data means that causal claims about the nature of these relationships cannot be made, and the temporal mismatch between likely affects the precision of the estimates.

Although living in a more polluted environment predicts spending less time outdoors and exercising less, and both of these activities are positively associated with a range of SWB measures, it is unclear whether these relationships are causal. Reverse causality may afflict the estimates presented throughout the hypothesised causal chain. It is possible, for example, that individuals with higher levels of SWB are more likely to visit the outdoors and engage in physical activity, or indeed that in locations where individuals visit the outdoors or exercise for leisure more frequently there is lower air pollution as a result of individuals engaging in more pollution generating leisure activities. It is also possible that individuals who have higher wellbeing may select into less polluted environments.

Problems of omitted variable bias also cannot be ruled out. Although care was taken to control for a wide range of individual, interview and local area characteristics

in the analysis, the cross-sectional nature of the data does not allow for the inclusion of individual time-invariant characteristics such as optimism or other time-variant controls including behaviours which may be related to both the outcomes of interest and their predictors. The EQ-health literature has, for example, highlighted social interactions as a potential pathway through which locals environment might influence wellbeing (Maas et al. 2009). Due to data availability, the current work does not explore this as a potential pathway, nor does it investigate other nature-related activities such as gardening.

Despite these issues, a number of the papers presented in the literature review contain data and identification strategies which allow the authors to better assess causality than it is possible to do so in the current work. Luechinger (2009), for example, uses the mandated installation of scrubbers at power plants and wind patterns to instrument estimates of the relationship between life satisfaction and sulphur dioxide and finds that the instrumented estimates are larger in magnitude than conventional estimates. There are also experimental studies which have randomised individuals into spending time outdoors and physical activity and demonstrated that these activities impact individuals' wellbeing positively (Takayama et al. 2014; Bratman, Daily, et al. 2015; Bratman, Hamilton, et al. 2015). While these studies do not speak to all the relationships of interest in the current work, they are suggestive of a causal chain from air pollution, and the activities of interest, to SWB.

The link in the chain for which there is the least reliable causal evidence in the existing literature is air pollution causing lower engagement in outdoor visits and physical activity. The averting behaviours literature provides difference-and-difference based estimates of the short-run behavioural responses to air pollution alerts which include fewer visits to outdoor attractions and physical activity. While this suggest that air pollution does influence people's behaviour, no research exists which provides causal evidence of normal levels of air pollution affecting the activities an individual engages in the long –run. In an attempt to somewhat address this a robustness check involving the inclusion of a variable which represents the percentage of the local authority covered by green space, was carried out in the current work. That the relationship between air pollution and these visits to the outdoors and physical activity hold suggests that this relationship cannot be explained by this other element of environmental quality, but it is still not possible to claim it is causal. Future work

could seek to further address these causality issues by taking advantage of matching strategies or natural experiments in order to gain further insight into why individuals living in polluted environments engage in these activities less frequently.

Another issue is that the variables of interest relate to a range of different time periods with some being global or long-term and some relating to the recent past. Two of the four SWB questions ask questions about individuals' lives and activities overall, and the activity measure relating to the frequency of visits to the outdoors refers to the past twelve months. In contrast, the experiential SWB measures discussed above relates to yesterday, and the physical activity question asks about the past seven days. Additionally, although the survey responses were collected from 2012-2015, the air pollution data represent the average background concentration of air pollution in the local authority level in 2012 only. Due to these differences in time-frame, these variables are not optimally matched. While some of the differences arise out of the nature of the multidimensional analysis of SWB, or from relating measures that are global by definition to activity-based measures, others are down to data availability. Importantly, mediation analysis, which represents the central contribution of this work, is only carried out in relation to life satisfaction and separately how worthwhile individuals consider their activities to be. The first analysis examines the frequency of visits to the outdoors, and the second both frequency of visits to the outdoors and physical activity. The temporal incongruities are therefore somewhat, though not entirely, minimised in the relationships explored in the mediation analysis.

Some temporal mismatch is commonly the case in the exploration of behavioural mediators in epidemiological research (see for example de Vries et al. (2013). This undoubtedly, however, affects the precision of the estimates produced, and the results should, therefore, be interpreted as providing evidence of relationships without overemphasising the precise magnitude of the coefficients. It is also important to highlight that the current work does not shed light on the relationship between daily fluctuations in air pollution and reports of SWB and activities. Its parallel is how climate relates to how people feel and what they do, rather than the weather. The current work suggests that living in a more polluted environment predicts lower SWB and lower engagement in the activities of interest. It does not, however, speak to the question of whether on more polluted days people feel worse or do fewer of these activities. There is currently only limited research on the second question (Zivin and

Neidell 2009; Saberian, Heyes, and Rivers 2017), and future work should look to build on this using measures which relate to the recent past or the moment itself.

5.57 Policy insights

Despite the limitations discussed above, the paper makes significant contributions to our understanding of the relationship between air pollution and SWB, in particular by establishing, for the first time, the mediating role individuals' activities play in this relationship. The results provides valuable insights for policymakers concerned with the distribution of wellbeing across society. Although the results suggest that policies which improve air quality are attractive from a wellbeing perspective they also highlight that there may be other more efficient and equitable ways of improving wellbeing. First, from an efficiency perspective these results highlight that it may be more feasible or cost-effective to promote wellbeing by targeting visits to the outdoors and physical activity directly rather than indirectly via air quality improvements. This could involve subsidising trips to outdoor attractions, or building local outdoor exercise facilities, for example. That the wellbeing effects of these activities do not appear to be dependent on the level of pollution in their environment, suggest that policymakers should look to encourage these activities regardless of where the target individuals live.

Second, the results highlight equity related considerations by informing our understanding of the conditions under which, and the populations for whom, improvements in air quality may bring about enhanced wellbeing. The findings suggest that policies which contribute to air quality will better benefit those who have the capacity to react by engaging in these activities. Individuals who have low mobility or who face other restrictions such as leisure time scarcity, for example, might be expected to benefit less from improvements in air quality and to have their relative disadvantage compounded. Policymakers concerned with equitable impacts may wish to consider compensating those individuals who benefit less from these policies due to a lack of capacity to engage in these activities.

As visits to the outdoors and physical activity appear to be important elements of the production process that converts environmental quality into SWB, policymakers

should be alert to the relationships between environmental quality and individual behaviour, and, with the goal of enhancing wellbeing, explore the effectiveness of policies which look to decrease local pollution levels or encouraging nature-related activities, or both. More generally these findings highlight the need for SWB research to consider not just whether, but also why, the circumstances of people's lives influence how they feel.

Appendices 5

Appendix 5A: Descriptive statistics

	N	Mean	St. Dev	Min	Max
Dependent					
Satisfaction	4,277	7.485896	2.007548	0	10
Worthwhileness	4,277	7.634227	1.912921	0	10
Happiness	4,277	7.465914	2.253746	0	10
Anxiety	4,277	2.461213	2.851572	0	10
Independent					
$PM_{2.5}$	4,277	12.112	2.705	5.733	16.947
Mediators					
Frequency of Visits	4,277	1.0			
Daily	516	.1206		0	1
Weekly	1,948	.4555		0	1
Monthly	1,040	.2432		0	1
Almost never	320	.748		0	1
Never	453	.1059			
Physical activity	4,277	2.371	2.566	0	7
Controls					
Gender	4,277	1.0			
Male	2,043	.4777		0	1
Female	2,234	.5223		0	1
Health	4,277	1.0			
Very bad	37	.087		0	1
Bad	255	.596		0	1
Fair	875	.2046		0	1
Good	1,895	.4431		0	1
Very good	1,215	.2841		0	1
Disability status	4,277	1.0			
Non-disabled	3,295	.7704		0	1
Disabled	982	.2296		0	1
Age group	4,277	1.0			
16-24	565	.1321		0	1
25-34	762	.1782		0	1
35-44	634	.1482		0	1
45-54	632	.1478		0	1
55-64	554	.1295		0	1
65+	1,130	.2642			
Socio-economic group	4,277	1.0			
AB	762	17.82		0	1
C1	1,086	25.39		0	1
C2	869	20.32		0	1
DE	1,560	36.47		0	1
Marital Status	4,277	1.0			
Married	2,375	55.53		0	1
Separate/divorce/widow	746	17.44		0	1

Single	1,156	27.03		0	1
Work status	4,277	1.0			
In full -time work	1,416	33.11		0	1
In education	276	6.45		0	1
Not working	785	.1835		0	1
Part-time work	559	.1307		0	1
Retired	1,241	.2902		0	1
Housing Tenure	4,277	1.0			
Mortgage	916	.2142		0	1
Rent private	149	.348		0	1
Owned outright	1,358	.3175		0	1
Rent local authority	894	.2090		0	1
Other tenure	960	.2245		0	1
Ethnicity	4,277	1.0			
White	3,646	85.25		0	1
Non- white	631	14.78		0	1
Mean local income	4,277	500.50	109.12	327.2	1148.8
Median local income	4,277	419.23	71.73	295.5	701
Urban/Rural local authority	4,277	1.0			
Rural	560	.1309			
Urban	3,717	.8691			
January max temperature	4,277	7.018688	.6625097	5.71	7.84
July max temperature	4,277	21.23519	1.336335	18.8	22.97
January rain	4,277	2.548782	0.743879	1.71	3.95
July rain	4,277	1.918457	0.414556	1.48	2.77
Green space	4,277	.6270677	.2483844	.1237	.9728

Appendix 5B**:** Association between local air pollution and SWB

Variables	Satisfaction		Worthwhile		Happiness		Anxious	
	Model I	Model II	Model I	Model II	Model I	Model II	Model I	Model II
$PM_{2.5}$	-0.0298**	-0.0394**	-0.0212*	-0.0292**	-0.00416	-0.00762	0.0551**	0.0233
	(0.0134)	(0.0154)	(0.0124)	(0.0146)	(0.0146)	(0.0201)	(0.0217)	(0.0298)
White		0.0385		0.000999		0.00125		-0.280*
		(0.0769)		(0.0771)		(0.117)		(0.147)
Age				Reference group: 16-24				
25-34		-0.445***		-0.178		-0.141		-0.0176
		(0.109)		(0.110)		(0.131)		(0.161)
35-44		-0.663***		-0.266**		-0.285*		0.336*
		(0.137)		(0.124)		(0.150)		(0.188)
45-54		-0.707***		-0.320**		-0.224		-0.0188
		(0.131)		(0.128)		(0.149)		(0.188)
55-64		-0.499***		-0.0985		-0.238		0.0695
		(0.141)		(0.137)		(0.169)		(0.220)
65+		-0.274*		-0.0330		-0.0317		-0.0244
		(0.162)		(0.180)		(0.192)		(0.253)
Gender				Reference category: Female				
Male		-0.243***		-0.383***		-0.184***		-0.167*
		(0.0562)		(0.0585)		(0.0636)		(0.0872)
Disabled		-0.102		0.0245		-0.0986		0.231*
		(0.0891)		(0.0870)		(0.102)		(0.130)
Marital status				Reference category: Married				
Separated/ Divorced/ Widowed		-0.430***		-0.521***		-0.382***		0.102
		(0.0926)		(0.0844)		(0.112)		(0.129)
Single		-0.599***		-0.538***		-0.324***		-0.00846
		(0.0789)		(0.0786)		(0.0970)		(0.116)
Work status				Reference category: Working full-time				
In education		0.0252		0.110		-0.0948		0.389
		(0.141)		(0.136)		(0.165)		(0.236)
Not working		-0.422***		-0.307***		-0.362***		0.418***
		(0.0970)		(0.102)		(0.103)		(0.146)
Part-time		-0.130		-0.0720		-0.0372		0.0583
		(0.0862)		(0.0778)		(0.0958)		(0.147)
Retired		0.233**		0.0964		0.325**		-0.346*
		(0.114)		(0.124)		(0.154)		(0.206)
Socio-economic status				Reference category: AB				
C1		-0.113		-0.106		-0.0114		-0.0760
		(0.0859)		(0.0790)		(0.0996)		(0.127)
C2		-0.0673		-0.0836		0.0458		-0.0781
		(0.0806)		(0.0780)		(0.0953)		(0.131)
DE		-0.210**		-0.289***		-0.153		-0.0186
		(0.0900)		(0.0928)		(0.109)		(0.138)
Tenure status				Reference category: Owned outright				
Mortgage		-0.251***		-0.199**		-0.251**		0.0983
		(0.0955)		(0.0897)		(0.106)		(0.132)
Rent private		-0.138		-0.233***		-0.174		0.139
		(0.0857)		(0.0884)		(0.108)		(0.141)
Rent local authority		-0.0295		-0.00894		-0.0258		0.0591
		(0.0982)		(0.0873)		(0.110)		(0.145)
Other		-0.129		-0.0950		-0.127		-0.00575
		(0.175)		(0.166)		(0.232)		(0.258)
July		-0.0417		0.130		0.122		-0.182

temperature								
		(0.157)		(0.161)		(0.184)		(0.315)
January temperature		0.0486		-0.113		-0.00712		0.170
		(0.110)		(0.107)		(0.124)		(0.171)
July rain		-0.0660		-0.223		-0.397**		0.191
		(0.157)		(0.156)		(0.194)		(0.297)
January rain		0.0771		-0.00706		0.638**		-0.0487
		(0.257)		(0.257)		(0.319)		(0.469)
Urban		-0.000989		0.0241		-0.0826		0.154
		(0.0847)		(0.0779)		(0.0914)		(0.143)
Local area mean income		-0.0023***		-0.002***		-0.000919		-0.00103
		(0.000551)		(0.00056)		(0.00077)		(0.0011)
Local area median		0.00343***		0.0025**		0.00132		0.00117
		(0.00105)		(0.00099)		(0.00138)		(0.002)
Constant	7.844***	4.756**	7.888***	8.629***	7.514***	4.879**	1.798***	1.737
	(0.164)	(1.938)	(0.156)	(1.795)	(0.182)	(1.986)	(0.249)	(2.529)
N								
R-squared	0.002	0.194	0.001	0.140	0.000	0.126	0.003	0.078

*Standard errors clustered at local authority level in parentheses. *** p<0.01, ** p<0.05, * p<0.1*

Appendix 5C: Life satisfaction and physical activity and visits to the outdoors.

	Satisfaction				
Variables	Model I	Model II	Model III	Model IV	Model V
Reference category: Never					
Almost never	0.198	-0.0317			-0.0313
	(0.190)	(0.181)			(0.181)
Monthly	0.517***	0.152			0.154
	(0.153)	(0.141)			(0.141)
Weekly	0.924***	0.428***			0.432***
	(0.143)	(0.135)			(0.136)
Daily	1.015***	0.416***			0.427***
	(0.164)	(0.154)			(0.158)
Physical			0.0651***	0.00763	-0.00502
			(0.0118)	(0.0106)	(0.0111)
Individual controls	No	Yes	No	Yes	Yes
Local area controls	No	Yes	No	Yes	Yes
Constant	6.799***	4.473**	7.329***	4.662**	4.502**
	(0.140)	(1.920)	(0.0478)	(1.920)	(1.917)
N	4,277	4,277	4,277	4,277	4,277
R-squared	0.028	0.208	0.007	0.201	0.208

*Standard errors clustered at local authority level in parentheses. *** p<0.01, ** p<0.05, * p<0.1*

Appendix 5D: The worthwhileness of activities and physical activity and visits to the outdoors.

	Worthwhile				
Variables	Model I	Model II	Model III	Model IV	Model V
Reference category: Never					
Almost never	0.425**	0.281*			0.279*
	(0.166)	(0.164)			(0.163)
Monthly	0.612***	0.336***			0.332***
	(0.137)	(0.125)			(0.125)
Weekly	0.966***	0.597***			0.584***
	(0.127)	(0.119)			(0.120)
Daily	1.151***	0.694***			0.657***
	(0.147)	(0.135)			(0.139)
Physical			0.0753***	0.0308***	0.0157
			(0.0113)	(0.0110)	(0.0119)
Individual controls	No	Yes	No	Yes	Yes
Local area controls	No	Yes	No	Yes	Yes
Constant	6.872***	8.386***	7.453***	8.380***	8.294***
	(0.123)	(1.776)	(0.0459)	(1.798)	(1.784)
N	4,277	4,277	4,277	4,277	4,277
R-squared	0.031	0.158	0.010	0.149	0.159

*Standard errors clustered at local authority level. *** p<0.01, ** p<0.05, * p<0.1*

Appendix 5E: Happiness yesterday and physical activity and visits to the outdoors.

	Happiness				
Variables	Model I	Model II	Model III	Model IV	Model V
Reference category: Never					
Almost never	0.229	0.0541			0.0533
	(0.192)	(0.182)			(0.182)
Monthly	0.371**	0.0539			0.0511
	(0.172)	(0.155)			(0.155)
Weekly	0.714***	0.284**			0.276*
	(0.154)	(0.141)			(0.141)
Daily	0.932***	0.411***			0.388**
	(0.166)	(0.151)			(0.155)
Physical			0.0730***	0.0216*	0.00978
			(0.0129)	(0.0128)	(0.0136)
Individual controls	No	Yes	No	Yes	Yes
Local area controls	No	Yes	No	Yes	Yes
Constant	6.918***	4.652**	7.290***	4.717**	4.595**
	(0.144)	(2.032)	(0.0526)	(2.008)	(2.039)
N	4,277	4,277	4,277	4,277	4,277
R-squared	0.015	0.129	0.007	0.126	0.129

*Standard errors clustered at local authority level. *** p<0.01, ** p<0.05, * p<0.1*

Appendix 5F: Anxiety yesterday and physical activity and visits to the outdoors.

	Anxiety				
Variables	Model I	Model II	Model III	Model IV	Model V
Reference category: Never					
Almost never	-0.435*	-0.280			-0.280
	(0.224)	(0.230)			(0.230)
Monthly	-0.461***	-0.179			-0.179
	(0.168)	(0.171)			(0.171)
Weekly	-0.841***	-0.389**			-0.391**
	(0.158)	(0.166)			(0.165)
Daily	-0.733***	-0.146			-0.150
	(0.198)	(0.202)			(0.204)
Physical			-0.0599***	0.000402	0.00181
			(0.0188)	(0.0180)	(0.0185)
Individual controls	No	Yes	No	Yes	Yes
Local area controls	No	Yes	No	Yes	Yes
Constant	3.082***	1.705	2.608***	1.758	1.694
	(0.157)	(2.522)	(0.0806)	(2.538)	(2.537)
N	4,277	4,277	4,277	4,277	4,277
R-squared	0.009	0.079	0.003	0.077	0.079

*Standard errors clustered at local authority level. *** p<0.01, ** p<0.05, * p<0.1*

Appendix 5G: Interaction models with $PM_{2.5}$ physical activity and frequency of visits to the outdoors

	Satisfaction			Worthwhile		
	Model I	Model II	Model III	Model IV	Model V	Model VI
$PM_{2.5}$	-0.00701	-0.0139	-0.0232	0.00741	0.00787	-0.0194
	(0.0442)	(0.0445)	(0.0175)	(0.0342)	(0.0338)	(0.0179)
Physical	0.0584	-0.00525	0.0421	0.0112	0.0154	0.0105
	(0.0492)	(0.0112)	(0.0474)	(0.0564)	(0.0119)	(0.0525)
$PM_{2.5}$XPhysical	-0.00531		-0.00400	0.000353		0.000399
	(0.00390)		(0.00378)	(0.00463)		(0.00433)
Reference category: Never						
Almost never	0.0943	0.111	-0.0422	0.667	0.665	0.273*
	(0.868)	(0.865)	(0.181)	(0.677)	(0.676)	(0.164)
Monthly	0.957	0.997	0.146	1.053**	1.050**	0.324**
	(0.653)	(0.649)	(0.142)	(0.522)	(0.524)	(0.127)
Weekly	0.370	0.460	0.421***	0.779	0.773	0.575***
	(0.624)	(0.619)	(0.137)	(0.498)	(0.490)	(0.121)
Daily	0.380	0.543	0.403**	1.103*	1.092*	0.646***
	(0.690)	(0.671)	(0.158)	(0.579)	(0.560)	(0.141)
Almost never X $PM_{2.5}$	-0.0105	-0.0117		-0.0309	-0.0308	
	(0.0674)	(0.0671)		(0.0501)	(0.0501)	
Monthly X $PM_{2.5}$	-0.0654	-0.0687		-0.0580	-0.0578	
	(0.0481)	(0.0477)		(0.0387)	(0.0389)	
Weekly X $PM_{2.5}$	0.00527	-0.00231		-0.0151	-0.0146	
	(0.0468)	(0.0463)		(0.0365)	(0.0358)	
Daily X $PM_{2.5}$	0.00369	-0.00949		-0.0367	-0.0358	
	(0.0517)	(0.0500)		(0.0439)	(0.0423)	
Individual controls						
Local area controls						
Constant	4.216**	4.308**	4.446**	8.069***	8.062***	8.328***
	(1.973)	(1.967)	(1.941)	(1.808)	(1.812)	(1.785)
N	4,277	4,277	4,277	4,277	4,277	4,277
R-squared	0.210	0.210	0.209	0.160	0.160	0.159

*Standard errors clustered at local authority level. *** p<0.01, ** p<0.05, * p<0.1*

Appendix 5H: Robustness checks of the relationship between PM2.5 visits to the outdoors and physical activity controlling for green space coverage.

	Visits				Physical		
Variables	Model I	Model II	Model III	Model III Odds ratio	Model IV	Model V	Model VI
$PM_{2.5}$	-0.0338	-0.0680**	-0.0602**	-0.9416**	-0.0163	-0.0524*	-0.0289
	(0.0233)	(0.0271)	(0.0276)	(0.02596)	(0.0244)	(0.0312)	(0.0303)
Green space	0.921***	0.550***	0.497**	1.64397**	0.596**	0.405	0.291
	(0.202)	(0.211)	(0.219)	(0.359)	(0.281)	(0.284)	(0.276)
Reference category: Never							
Almost never							0.0650
							(0.200)
Monthly							0.281*
							(0.145)
Weekly							0.830***
							(0.156)
Daily							2.349***
							(0.192)
Physical			0.200***	1.2213***			
			(0.0157)	(0.0191)			
Individual controls	No	Yes	Yes	Yes	No	Yes	Yes
Local area controls	No	Yes	Yes	Yes	No	Yes	Yes
Constant cut 1	-1.998***	-0.160	1.276	1.276			
	(0.348)	(3.068)	(3.044)	(3.044)			
Constant cut 2	-1.369***	0.509	1.959	1.959			
	(0.351)	(3.061)	(3.037)	(3.037)			
Constant cut 3	-0.145	1.830	3.322	3.322			
	(0.348)	(3.060)	(3.037)	(3.037)			
Constant cut 4	2.184***	4.283	5.903*	5.903*			
	(0.354)	(3.064)	(3.040)	(3.040)			
Constant					2.955***	3.645	3.144
					-0.267	-3.506	-3.284
N	4,277	4,277	4,277	4,277	4,277	4,277	4,277
R^2/Pseudo R^2	0.0089	0.0428	0.0653	0.0653	0.003	0.072	0.137

*Standard errors clustered at local authority level. *** p<0.01, ** p<0.05, * p<0.1*

6. Green without anxiety

The relationship between pro-environmental behaviour and different measures of subjective wellbeing

(Paper 3)

6.1 Introduction

There is little doubt that pro-environmental behaviour (PEB) on the part of individuals is imperative to the wellbeing of the planet and of future generations (Dietz et al. 2009; Stern 2007). However, our current understanding of how individuals' engagement in PEB relates to their own wellbeing is limited. While we are increasingly learning more about the positive and negative instigators of PEB (Priolo et al. 2016; Mallett 2012; Mallett, Melchiori, and Strickroth 2013; Rees, Klug, and Bamberg 2015; Allen and Ferrand 1999; Gosling and Williams 2010; Scannell and Gifford 2010), our picture of the consequences of PEB for individuals is unclear. This represents an important gap; understanding the wellbeing effects of PEB will inform both how it is conceptualised and the strategies used to promote it (Kasser 2009).

Pro-environmental behaviour has long been equated with sacrifice. This view of PEB has its basis in traditional ideas around what welfare itself constitutes. According to a narrow standard economic framework, utility is based on individuals' consumption (Binder and Blankenberg 2017). Within such a framework, income represent a proxy measure for utility, and PEB, which often involves costs and requires individuals to forgo consumption, reduces the utility of the individual engaging in it (Brown and Kasser 2005). Relatedly, much of environmental psychology has understood PEB as being costly to the individual, characterising it as altruistically motivated behaviour (Stern 2000; Schwartz 1977; Allen and Ferrand 1999; Geller 1995; Schultz 2001), where altruism is defined as a feeling or action that prioritises the wellbeing of others independent of one's own interests (Jencks 1990). Some existing empirical work supports this view of PEB; a number of research studies document evidence of individuals associating PEB engagement with inconvenience and discomfort and viewing it as costly both in terms of time and money (Lorenzoni, Nicholson-Cole, and Whitmarsh 2007; Stoll-Kleemann, O'Riordan, and Jaeger 2001). Such negative perceptions of the consequences of PEB are also thought to inhibit individuals' engagement in these activities; anticipated feelings of anger and frustration in relation to public transport and household recycling have been negatively linked to a desire to engage in those activities (Carrus, Passafaro, and Bonnes 2008). Together this theoretical and empirical literature presents PEB engagement as a

"*balance between self and society, and between luxury and morality*" (Bedford, Collingwood et al. 2010 p.3).

Over the past number of decades, however, utility theory has broadened to incorporate not just what people consume, but also what they do (Juster 1990). In line with this reconceptualisation, theoretical work in both economics and psychology has questioned the idea that there is a conflict between individual wellbeing and pro-social action. This work suggests that these behaviours can provide individuals with 'warm glow'– a positive emotional feeling – and contribute to their needs for autonomy, relatedness, and competence (Andreoni 1990; Ryan, Huta, and Deci 2013). A number of authors have linked these concepts to pro-environmental behaviour and have suggested that intrinsic benefits are underexplored motivators of PEB (Kasser 2009; Kaplan 2000; De Young 2000; Van Der Linden 2015). Recently, researchers have turned to non-economic measures of utility, and in particular to subjective wellbeing data (SWB), to explore these ideas empirically. A growing body of literature uses these data to examine how engaging in behaviours which promote the wellbeing of others affects the individual themselves (Dunn, Aknin, and Norton 2008; Meier and Stutzer 2008; Son and Wilson 2012).

Although the focus of most of the research has been charitable giving and volunteering, a growing number of studies, falling under what is referred to by Verdugo (2012) as the positive psychology of sustainability research, explore the relationship between SWB and PEB. This literature provides empirical support for the idea that PEB promotes individual wellbeing. In particular, it documents positive relationships between PEB and individuals' reports of their life satisfaction (Welsch and Kühling 2010; Kaida and Kaida 2016; Jacob, Jovic, and Brinkerhoff 2009; Corral-Verdugo et al. 2011; Brown and Kasser 2005). Related work has also found that individuals who engage in lifestyles based on voluntary simplicity (i.e. freely choosing to live frugally) also report higher levels of life satisfaction (Boujbel and d'Astous 2012; Jackson 2005) and that materialism is negatively associated with psychological wellbeing (Pandelaere 2016). In an example of a non-SWB based study Taufik, Bolderdijk, and Steg (2015) find that participants who receive feedback that they behaved environmentally friendly experience a literal warm glow – they perceive a higher temperature than people who learned they acted environmentally unfriendly one. The authors attribute this effect to the positive self-signal this feedback creates.

While this work is indicative of individuals' wellbeing being positively linked to PEB, the findings appear to be at odds with the theoretical and empirical work that highlights the negative consequences for the individual of engaging in PEB. The current work explores whether these seemingly conflicting ideas about the wellbeing consequences of PEB engagement may in part be explained by different ideas of what wellbeing is (Venhoeven, Steg, and Bolderdijk 2017). Within philosophical work around wellbeing, a distinction is commonly made between hedonic wellbeing and eudemonic wellbeing. Hedonic wellbeing, relates to the positive and negative emotions that individuals experience, and eudemonic wellbeing reflects their sentiments of purpose and purposelessness (Stone and Mackie 2013; Son and Wilson 2012). The existing positive psychology of sustainability literature has generally failed to recognise the distinction between these types of wellbeing (Venhoeven, Bolderdijk, and Steg 2013). In relying on life satisfaction, a combination measure of both hedonic and eudemonic wellbeing, as the sole measure of wellbeing, the existing research may be obscuring a more nuanced story about how acting in a pro-environmental way influences how people feel. To explore whether this is the case the current work directly compares how PEB engagement relates to SWB measures which assess these two types of wellbeing separately.

There are good reasons to think that the distinction between these different types of wellbeing matters. First, non-PEB activities produce different effects for hedonic and eudemonic wellbeing. Work which has used separate measures of subjective wellbeing to assess these different types of wellbeing directly finds them to be differently related to activities such as working, spending time with children and watching TV (White and Dolan 2009). Second, and specific to PEB, while some PEBs, such bike riding, could be construed as being pleasurable, many others are more readily associated with discomfort and sacrifice (Venhoeven, Steg, and Bolderdijk 2017). As pleasure is not an inherent characteristic of PEB, engagement may not be expected to yield consistent hedonic benefits. Moreover, depending on the characteristics of the behaviour it may come at a hedonic cost. While riding a bike might be considered more pleasurable than riding in a car, for example, waiting at a bus stop would, generally be considered less so. In contrast, to the extent that an individual feels that all PEB represents doing 'good', it may all feel purposeful and yield eudemonic wellbeing across the board. A better understanding of the

multidimensionality of SWB can provide insight into how PEB engagement might both contribute to and detract from individual wellbeing.

Beyond, the need for conceptual clarity around SWB, there is also the question of what PEB constitutes. Existing literature has largely focused on investigating single behaviours or groups of behaviours which have an environmental impact (Corral-Verdugo et al. 2011; Xiao and Li 2011; Binder and Blankenberg 2016; Verhofstadt et al. 2016). Within the environmental psychology literature, however, authors have argued that an examination of both general tendencies and individual PEBs is necessary (Kaiser and Wilson 2004; Stern 2000). Studies which investigate single PEBs are limited in a number of ways. Individuals arguably only have substantive positive ecological impacts through PEB when these behaviours are aggregated across many different activities (Markowitz et al. 2012), and so a single behaviour does not provide much insight into the extent to which they are helping the environment. Looking at any one behaviour may also misrepresent their overall levels of PEB engagement as individuals may license themselves to act in environmentally damaging ways as a result of engaging in a given PEB (Thøgersen and Ölander 2003; Tiefenbeck et al. 2013). Beyond that, previous research based on multivariate analysis of a range of PEB measures documents evidence of different clusters of PEB, such as private sphere PEB and environmental citizenship behaviours (Lynn 2014; Stern 2000; Larson et al. 2015). The investigation of single behaviours precludes a comparison of the relationships between the SWB measures and clusters of PEB which may have important shared characteristics. Costs, for example, might differ greatly across different clusters of PEBs and this characteristic might influence their relationship to SWB.

Additionally, it has also been suggested that it is important to investigate PEBs that the individual is aware are linked to benefits for the environment, not just those that have an impact. This is in order to understand the psychological processes that relate to conscious PEB engagement (Markowitz et al. 2012). Existing SWB-PEB work has focused largely on behaviour which impacts the environment by using measures of individuals' ecological footprints (Lenzen and Cummins 2013; Verhofstadt et al. 2016), or investigating PEBs which positively affects the environment, such as eating seasonal food, regardless of whether or not they are undertaken as a result of pro-environmental considerations (Corral-Verdugo et al.

2011). However, research based on intended PEB, as defined by the individuals themselves, is crucial to our understanding and targeting of pro-environmental activities (Stern 2000, Kaiser and Wilson 2004). The wellbeing benefits of PEB may be dependent, as research suggests is the case for pro-social spending, on the individuals awareness of the behaviour's positive impact (Aknin et al. 2013). The results of recent work by Binder and Blakenberg (2017) find that green identity mediates the relationship between green behaviour and life satisfaction, support this idea.

The current work seeks to address the issues mentioned above. It uses a range of measures of SWB to investigate how wellbeing relates to composite measures of PEBs explicitly linked to environmental goals. The data come from Natural England's Monitor of Engagement with the Natural Environment survey (MENE), which contains both SWB measures and self-reported measures of PEB. The analysis is carried out in two stages: first, multiple correspondence analysis is undertaken, both as a data reduction technique and in order to explore relationships between the different types of PEBs contained in the survey; second, regression analysis is used to investigate the relationship between the derived components and the SWB measures. This approach allows for the investigation of the relationship between a general measure of PEB and both eudemonic and hedonic SWB.

The results show that, on average, the more an individual engages in PEB, the more satisfied they are with their lives and the more worthwhile they consider their activities to be (a eudemonic measure of wellbeing). In contrast, no relationship is documented between the general measure of PEB and the purely hedonic measures of SWB in the analysis – happiness and anxiety yesterday. Additionally, whether different types of PEB are differently related to wellbeing is investigated. The results find that, for any given level of PEB engagement, undertaking relatively more common PEBs is positively associated with all the measures of wellbeing investigated. Possible explanations for these relationships may relate to the social norms or costs associated with these different types of PEB (Stern 2000; Kaiser and Wilson 2004). Finally, the whether the relationships between PEB and SWB depends on whether the individuals express concern over damage to the natural environment is explored. The relationships between life satisfaction, happiness and anxiety yesterday and PEB

engagement do not vary but the relationship to how worthwhile an individual considers their activities to be does.

Together, these findings represent the first empirical evidence to compare the wellbeing correlates of PEB engagement with a range of SWB measures. The results highlight a potential role for targeting eudemonic wellbeing in the encouragement of PEB and the importance of taking into account both the multidimensional nature of wellbeing and the different types of PEB when considering how they relate to one another. The study proceeds as follows; Section 2 describes the data, Section 3 presents the methods and results and Section 4 discusses the findings and concludes.

6.2 Data

All of the data used in the analysis comes from pooled cross-sections of the MENE for the years 2012-2015. The MENE survey consists of weekly waves of face-to-face interviews with a representative sample of the English adult population (aged 16 and over) (Natural England 2016). The ONS four were introduced to the MENE survey as a trial in 2012 and ran quarterly for a year starting in June 2012 (these measures are discussed in detail in Section 3.2, .p.32). From May 2014, the questions were formally adopted into the main survey, and the question frequency was increased to weekly. Complete case analysis is carried out on the sample of 5,206 respondents for whom SWB measures, demographic characteristics, PEBs and other individual characteristics such as self-reported work status are available. Descriptive statistics and a correlation matrix for the four SWB measures appear in Tables 6.1 and 6.2 below.

Table 6.1: SWB Summary Statistics

Variable	N	Mean	Std. Dev
Satisfaction	5,206	7.322897	2.033731
Worthwhile	5,206	7.559355	1.890324
Happiness	5,206	7.413561	2.259045
Anxiety	5,206	2.678832	2.883422

Table 6.2: SWB correlation matrix

	Satisfaction	Worthwhile	Happy	Anxious
Satisfaction	1			
Worthwhile	0.6234	1		
Happiness	0.5813	0.5194	1	
Anxiety	-0.2919	-0.2429	-0.4027	1

In order to investigate the relationship between wellbeing and PEB responses to all environment-related activity questions contained in the MENE for the years, 2012-2015 were considered. These questions asked individuals to reflect on the past 12 months and agree or disagree with the following statements: '*I usually recycle items rather than throw them away'; 'I usually buy seasonal or locally grown food'; 'I choose to walk or cycle instead of using my car when I can*'; '*I usually buy eco-friendly products and brands'; 'I encourage other people to protect the environment'; 'I am a member of an environmental or conservation organisation'; 'I volunteer to help care*

for the environment'. Five of the seven were then selected on the basis that they directly referred to the environment and therefore the respondent would have been aware of the links between the behaviour and the environmental impact. Responses relating to whether an individual bought seasonal or locally grown food and whether they chose to walk or cycle were excluded on the basis that these responses related to activities which individuals may engage in out of health or other concerns without being aware of their environmental impact. The descriptive statistics for the five measures used in the analysis appear in Table 6.3 below.

Table 6.3: Descriptive statistics for individual PEB measures

Variable	N	Mean	Min	Max
Recycle	5,206	0.745	0	1
Buy eco-friendly	5,206	0.238	0	1
Encourage others	5,206	0.242	0	1
Member	5,206	0.068	0	1
Volunteer	5,206	0.054	0	1

The analysis also incorporates a measure of concern about the natural environment, captured by the degree to which an individual agrees with the following statement; '*I am concerned about damage to the natural environment'*. Responses to this statement were measured on a five-point Likert scale from 'strongly disagree' to 'strongly agree' and were collapsed into dummy variables in the current analysis with strongly disagree, disagree and neither agree nor disagree being coded as 0 and agree and strongly agree being coded as 1 in order to ensure sufficient sample sizes for analysis.

6.3 Methods and Results

Multiple correspondence analysis (MCA) is first carried out as a data reduction technique and to explore patterns of relationship between the original PEB variables. MCA was chosen as a result of its suitability for the analysis of the binary PEB variables (Greenacre 2007; Greenacre and Blasius 2006). The predicted individual scores derived from MCA were then used in multivariate regression analysis to investigate the relationship between SWB and PEB.

6.31 Multiple correspondence analysis

MCA was carried out on the indicator matrix of the five measures of PEB using the 'mca' command in STATA 14 (See Table 6.4). The axes were then assessed using a number of common considerations in MCA (Costa et al. 2013; Canuel et al. 2014). First, the principal inertia scores were examined using the criterion of including MCA dimensions with inertia above 0.2 (Hair, Black, and Babin 2009). The first dimension meets this criterion with a principal inertia value of .34; the second component also does with a value of 0.21; all other components do not. Second, the scree-plot, which presents the proportions of variance explained, was examined. As can be seen in Figure 6.1 the elbow occurs at the second dimension indicating that the proportion of variance explained drops faster up to two dimensions and less rapidly after that (Johnson and Wichern 2002). Third, the cumulative variance explained was considered. The first two components together capture notably larger amounts of the variance in the data than the subsequent ones (See Table 6.4). The first dimension explains 34% of the total variation in the data while the first two in combination explain 55%, and the first three in combination explain over 71%. Lastly, retaining two dimensions allows for the construction of two-dimensional pictures of data which facilitates interpretation (See Figure 6.2). On the basis of the above considerations, two dimensions were retained for further analysis. It is, however, important to note that these two dimensions collectively explain just under 55% of the variance in the data, which suggests that the original variables are somewhat heterogeneous.

Table 6.4: Multiple correspondence analysis dimensions

	Principal Inertia	Percent	Cumulative Percent
Dimension 1	.3439	34.39	34.39
Dimensions 2	.2053	20.53	54.92
Dimensions 3	.1654	16.54	71.46
Dimensions 4	.1456	14.56	86.02
Dimensions 5	.1398	13.98	100.00
N	5,206		
Number of axes	4		

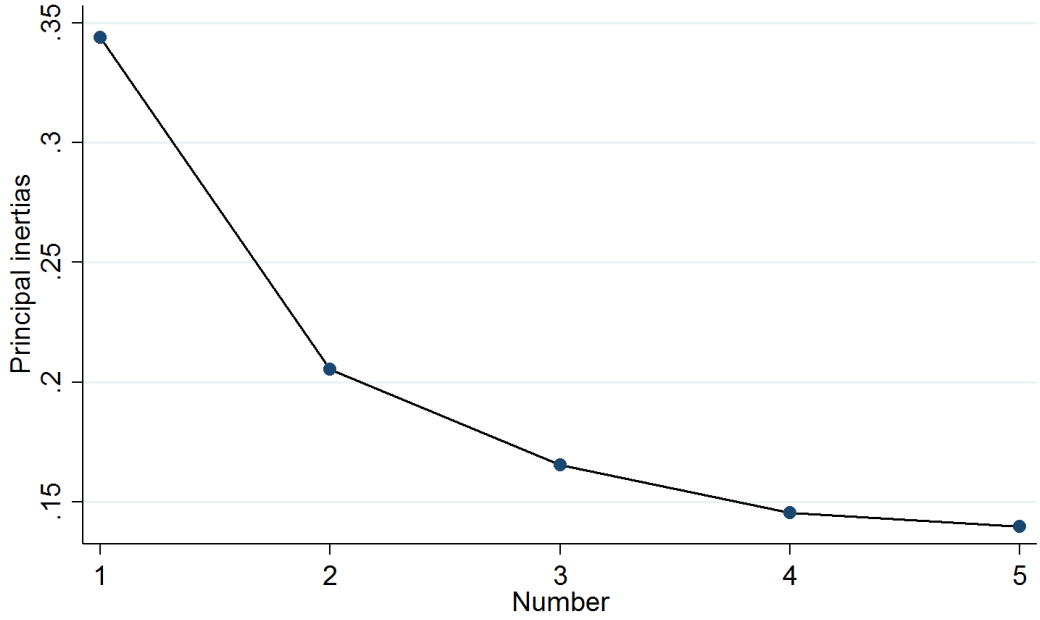


FIGURE 6.1: MULTIPLE CORRESPONDENCE ANALYSIS SCREEPLOT

The category coordinates were then plotted, and the resulting graph (Figure 6.2) was used to interpret the dimensions. The first dimension under MCA explains as much of the variance as possible and appears to group all of the PEBs. The first dimension, therefore, can be interpreted as a general measure of PEB. The second dimension is orthogonal to the first and displays as much of the remaining variance as possible. This dimension appears to contrast recycling, encouraging others to protect the environment and buying eco-friendly products with volunteering and being a member of an environmental organisation. Interestingly, when the prevalence of the behaviours which are contrasted in dimension two are compared (See Table 6.3), it is clear that this dimension contrasts relatively more common behaviour, to less common,

behaviours. Predicted values for both of the dimensions were calculated for each individual. The scores were then reverse coded so higher scores on the first dimension represent a higher level of engagement in PEB, and higher scores on the second dimensions represent a greater level of engagement in common relative to uncommon behaviours.

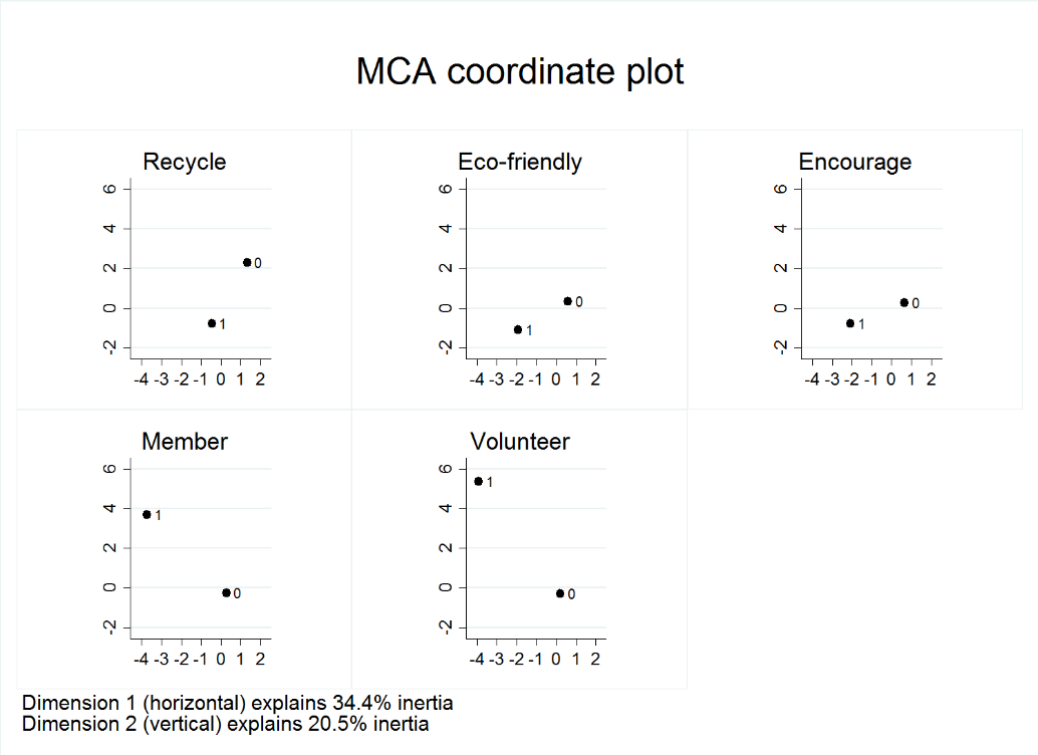


FIGURE 6.2: MULTIPLE CORRESPONDENCE ANALYSIS CATEGORY COMPONENT PLOT

6.32 Regression Analysis

Regression analysis was then carried out to explore the relationship between the measures of PEB constructed using the MCA analysis, environmental concern and the four measures of SWB. In the main analysis, six models were specified for each of the four wellbeing measures (See appendices B-E). Model I examines how the first and second dimension scores derived from the MCA above relate to each of the four measures of wellbeing. The first dimension represents a general measure of engagement in PEB with higher scores indicating higher levels of engagement. The second component represents the level of engagement in common relative to uncommon behaviours. Model II incorporates control variables relating gender, ethnicity, age group, whether the person has a long-standing illness, health problem or disability, work and marital status, tenure and socio-economic status (descriptive statistics can be found in Appendix 6.A). Importantly self-reported health is missing for 65% of the data and is therefore not controlled for in this specification (sensitivity analysis is presented in both in Figure 6.5 and Appendix 6G with imputed self-reported health). Model III builds on Model II by including a measure of concern for the environment. Model IV looks at how being concerned for the environment relates to wellbeing when PEB is not incorporated into the models. Model V includes interactions with the two measures of PEB and the measure of concern.

6.33 Results for the first dimension

The first dimension, which represents a general measure of engagement in PEB, is found to be significantly positively related to life satisfaction in Models I-II. Similarly, a general tendency to engage in PEB is found to be significantly positively related at to how worthwhile an individual considers their activities to be in Models I-II. In contrast, the relationship between the first component and happiness yesterday appears to be significant in Model I but is no longer so once individual level controls are included. Lastly, general tendency to engage in PEB is not found to be associated with levels of anxiety yesterday in Models I-II. The results of Model II for all four SWB measures and a general measure of PEB engagement are presented in the upper part of the coefficient plot in Figure 6.3 below.

6.34 Results for the second dimension

Holding constant overall levels of engagement, the second component can be interpreted as engaging in relatively more common compared to less common PEBs. This component is similarly related to all four measures of wellbeing in that it is significantly positively associated with life satisfaction, the worthwhileness of activities and happiness yesterday, and negatively associated with anxiety yesterday at the 5% level in Models I-III. The results of Model II for all four SWB measures and a measure which contrasts engaging in more common compared to less common PEBs are presented in the lower part of the coefficient plot in Figure 6.3 below.

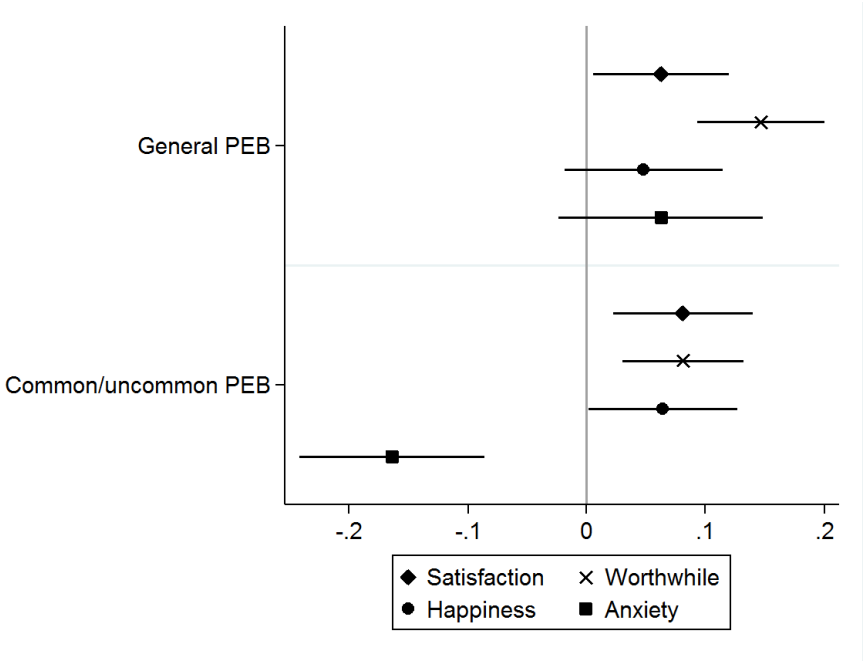


FIGURE 6.3: PRO-ENVIRONMENT BEHAVIOUR MEASURES AND THE RANGE OF SWB MEASURES

Note: The symbols represent the point estimates from Model II, and the bars indicate the 95% confidence intervals.

6.35 Results relating to environmental concern

Models II and III examine the relationship between the SWB measures and PEB when socio-demographics are controlled for and environmental concern is excluded or included in the model, respectively. The addition of the measure of concern does not alter substantively any of the relationships between the SWB measures and either of the PEB measures.

Models III and IV compare the relationship between environmental concern and the SWB measures with and without controlling for PEB with the two PEB variables. The results from these two models are contrasted in Figure 6.4 below (see also appendices 6B-E). Concern for the environment is found to be unrelated to life satisfaction in both models. In contrast, a significant association is documented between how worthwhile individuals consider their activities to be and their concern over damage to the natural environment when PEB is not controlled for (Model IV). This relationship is insignificant, however, in Model III when the two principal components representing PEB engagement are included. These findings suggest that PEB engagement is driving the relationship between environmental concern and this measure of eudemonic wellbeing. Finally, neither happiness yesterday nor anxiety yesterday are found to be significantly associated with concern in either Model III or Model IV.

Finally, Model V includes interactions with the two measures of PEB and concern over damage to the natural environment. The relationship between PEB, life saisfaction, happiness and anxiety is the same for those that stated that they were concerned and those that did not. There is, however, evidence of an interaction between PEB and concern in the case of reports of the worthwhileness of activities, with those who reported being unconcerned having a more positive relationship between PEB and how worthwhile they considered their activities to be.

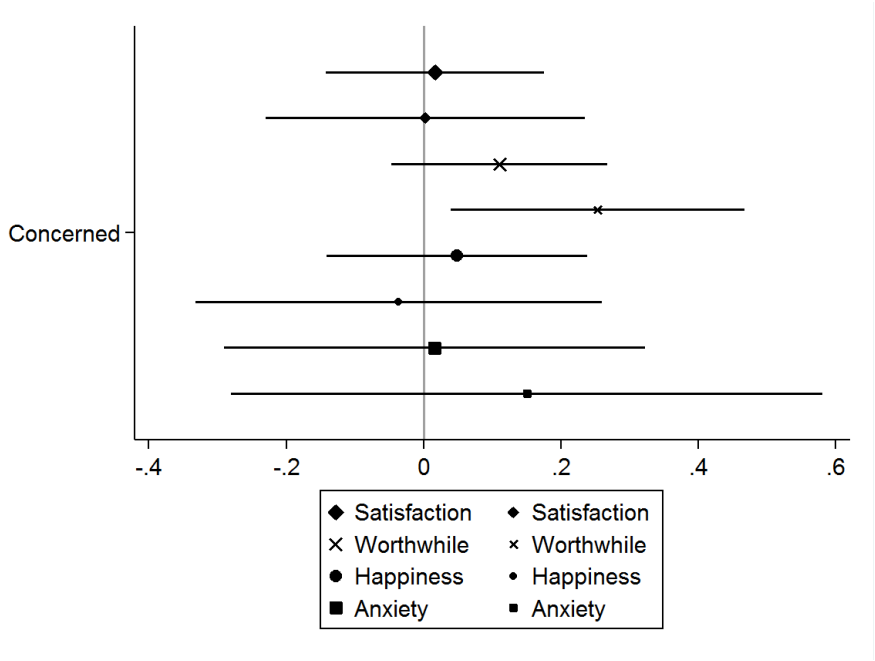


FIGURE 6.4: CONCERN OVER THE NATURAL ENVIRONMENT AND THE RANGE OF SWB MEASURES.

Note: The larger (smaller) symbols represent the point estimates from Model IV including (Model V excluding) the PEB controls, and the bars indicate the 95% confidence intervals.

6.36 Robustness check with imputed health controls.

Data on self-reported health was missing for 68% of the sample. As a result, health status was not controlled for in the main analysis. Instead, a proxy measure was included in the main analysis which reflects individuals' binary response to the following question: '*Do you have any long-standing illness, health problem or disability that limits your daily activities or the kind of work you can do?*'. In recognition of the importance of health as a predictor of SWB, however, a robustness check was carried out using imputed values for self-reported health status (based on 100 imputations as recommended by Graham, Olchowski and Gilreath 2007). Multiple imputation is a widely adopted statistical method for dealing with missing data. In the current work, the control variables were used to carry out a univariate imputation for the missing health data using an ordered logistic regression. The results shown in Appendix 6G demonstrate that the estimates remain substantively the same across all four measures of SWB for both measures for pro-environmental behaviours when health-controls are included.

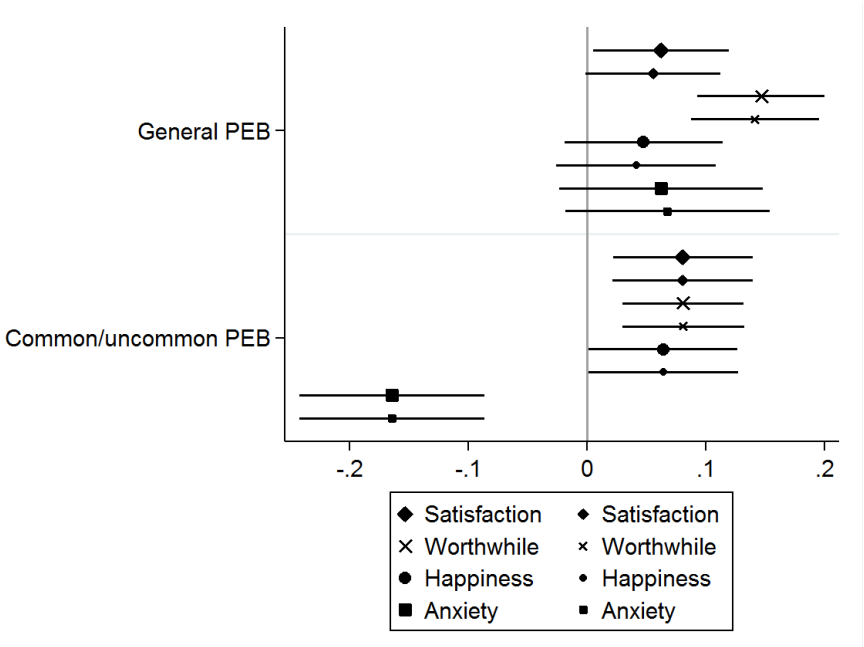


FIGURE 6.5: GENERAL PEB AND THE RANGE OF SWB MEASURES.

Note: The larger (smaller) symbols represent the point estimates from the models Model III excluding (Model VI including) the imputed health controls, and the bars indicate the 95% confidence intervals.

6.4 Discussion

By going beyond life satisfaction as the sole measure of SWB, focusing on PEBs that have explicit environmental goals, and using multiple correspondence analysis to explore patterns of relationships between these behaviours, the current work provides new insights into the relationship between individual wellbeing and PEB.

6.41 General PEB and the ONS four

The results indicate that PEB engagement is significantly associated with life satisfaction and how worthwhile individuals consider their activities to be, but not how happy or anxious they report feeling on the previous day. The findings to some degree echo ideas of the relationship between PEB and wellbeing contained in the positive psychology of sustainability literature. The key tenet of this literature is that PEB is a positive behaviour that is maintained through positive wellbeing consequences for the individual (Verdugo 2012). The results of the current work suggest that PEB may benefit people by making their lives more purposeful. The same does not appear to be true in terms of hedonic wellbeing, however. General levels of PEB engagement are not associated with happiness or anxiety yesterday. While this result suggests that individuals do not derive pleasure from engaging in PEB, it also indicates that these behaviours do not come at a hedonic cost. Similar results were documented in relation to volunteer work by Son and Wilson (2012). They find evidence that volunteering enhances eudemonic and social, but not hedonic wellbeing in the National Survey of Middle Age in the US. Interestingly, they do not find evidence of a dose-response to volunteering; in other words, volunteering appears to matter for wellbeing, but how much time they spend volunteering does not.

6.42 Common/uncommon PEBs and the ONS four

Different measures of SWB tell a different story about how wellbeing relates to general levels of engagement in PEB. Where the results do cohere across different dimensions of SWB, however, is in relation to the second dimension. This dimension contrasts engagement in relatively more common compared to less common PEBs.

Controlling for their overall level of PEB engagement, individuals' who report undertaking relatively more common, compared to less common, behaviours are significantly more satisfied with their lives, consider their activities to be more worthwhile, and report higher levels of happiness and lower levels of anxiety on the previous day. What this second component represents and what that means for the relationship between SWB and this component is open to interpretation.

A couple of the characteristics of these categories of behaviours are relevant from a theoretical perspective, namely social norms and costs. The descriptive social norms relating to the PEBs - the extent to which they are perceived as common - will likely be stronger for the common behaviours than for the relatively uncommon ones. The degree to which an individual perceives engaging in a given behaviour as being the 'done thing' may influence their perception of the 'goodness' of carrying out such behaviours and their moral responsibility to engage in it (Thøgersen 2006; Brekke, Kipperberg, and Nyborg 2010). Nyborg, (2006, p.353), for example, propose a theoretical model in which internal rewards for green consumption behaviours depend on "*the perception that the action in question is governed by an applicable norm that is recognized and observed in the subject's community"* . The results of the current work are in line with this view.

A second interpretation based on the relative prevalence of these behaviours is also possible. It has been argued elsewhere that the proportion of individuals engaging in an activity can act as a proxy measure of how costly it is (Diekmann and Preisendörfer 2003; Kaiser and Wilson 2004). Despite the fact that recycling, which is engaged in by over 70% of the individuals in the sample, could be more cost intensive for some individuals than volunteering, which is engaged in by only around 5% of the sample, in aggregate it is likely that a PEB engaged in by the majority of the population is less costly than one engaged in by a small minority of people. This argument is supported by research which suggests that the most popular PEBs tend to be those that require minimal effort and personal cost (Dunlap and Scarce 1991). Based on this line of reasoning, the results may reflect that engaging in relatively less costly PEB, as compared to more costly ones, is positively related to all measures of wellbeing investigated here.

While it is only possible to speculate about the reasons, and importantly these reasons may vary across the different dimensions of SWB, what is clear from the current work is that the relationship between PEB and SWB does vary across different types of PEB.

6.42 The role of environmental concern

The analysis also speaks to the small body of literature which has investigated how pro-environmental attitudes relate to wellbeing (Welsch and Kühling 2011; Ferrer-i-Carbonell and Gowdy 2007; Binder and Blankenberg 2016; Binder and Ward 2013). Concern about damage to the environment is not found to be related to any measure of SWB when investigated in the context of models which capture levels of PEB, but it is significantly positively associated with the worthwhileness of activities when the two PEB related components are not included. This result is similar to evidence from Binder and Blankenberg (2016) that suggests that environmental concerns impact positively on life satisfaction via concerned individuals volunteering to help the environment.

Another interesting result relating to the eudemonic measure of SWB emerges from the Model V that interacts environmental concern with PEB. The result of this specification indicates that the association between general PEB engagement and the measure of eudemonic wellbeing is stronger for the 16% of people who do not report being concerned over damage to the natural environment relative to those that do. On the face of it, this finding appears surprising. Existing research on pro-social spending has found that the relationship between pro-social spending and happiness is greatest for those individuals who report self-transcendent values (Hill and Howell, 2014), and we might expect that those who are concerned about damage to the natural environment might derive more purpose out of taking action to protect it. That the opposite is found to be the case may be explained by the benefits to individuals who are concerned about environmental being limited due to their awareness of seriousness of many environmental problems and the small contribution that their actions make towards mitigating them. By comparison, those that are not concerned may derive image and status benefits from being seen to behave pro-environmentally without their wellbeing depending on the environmental impact of their behaviour (Griskevicius,

Tybur, and Van den Bergh 2010; Binder and Blankenberg 2017). It would be interesting in future work to further explore how attitudes and values moderate the relationship between SWB and PEB.

6.43 Leveraging the wellbeing consequences of PEB to encourage more of it

The current work provides a wealth of new insights into the relationship between individual wellbeing and PEB which can help to inform PEB interventions. The traditional view of PEB as a sacrifice gives rise to PEB encouragement strategies of two main kinds; interventions either looked to encourage PEB by decreasing the sacrifices involved, for example by providing material incentives, or trying to encourage altruism by making moral appeals highlighting the impact of environmental issues on others or nature (De Young 2000; Allen and Ferrand 1999; Bolderdijk et al. 2013; Dietz 2015). While there is some evidence that these approaches can be effective in some situations, a number of authors have cautioned against them. Some researchers, for example, have questioned the sustainability of material incentives and have documented cases of them backfiring (Frederiks, Stenner, and Hobman 2015b; Frederiks, Stenner, and Hobman 2015a; De Young 2000). Others have suggested that, by emphasising sacrifice rather than wellbeing enhancing solutions, the altruism centred-approach contributes to helplessness and excludes self-interested individuals from PEB (Kaplan 2000; Stefano De Dominicis and Bonaiuto 2017). The results of the current work suggests alternative strategies to encourage PEB.

First, it is not clear that individuals are aware of the apparent wellbeing benefits from engaging in PEB. Existing research has demonstrated that individuals do not always accurately predict the future wellbeing consequences of circumstances or activities. Studies have found that individuals mispredict their future utility from taking pro-environmental action and engaging with the natural world; for example, car users experienced switching to public transport more positively than expected (Pedersen, Friman, and Kristensson 2011), and individuals underestimate the hedonic benefits of walking in nature (Nisbet and Zelenski 2011a). Other work, related to test feedback, found that individuals did not update their predictions about their own responses as a result of the experiences of the event (Wilson, Meyers, and Gilbert 2001). Together this work suggests that people may mispredict how they will feel

engaging in PEB, even when they have experience of doing so. One approach to encouraging PEB could, therefore, be to provide feedback that makes salient the feelings of worthwhileness associated with PEB engagement. This could involve, for example, prompting individuals to remember times when they engaged in PEB and it felt worthwhile, or informing people of the eudemonic wellbeing people tend to derive from PEB. Aknin, Dunn, and Norton (2012) find that reminding individuals of a time when they spent money on someone else, compared to themselves, enhances their mood and leads them to make further pro-social choices. Similar approaches may work to encourage PEB.

Another related strategy would be to enhance the sense of purpose individuals derive from engaging in PEB. This might be achieved, for example, by making people aware of the environmental impact of their PEB. Aknin et al. (2013) find that spending on others is most likely to lead to emotional benefits when the helper knows that their spending has had a positive impact. Other aspects of eudemonic wellbeing such as personal growth and feelings of competence could also be targeted (Ryff and Keyes 1995; Venhoeven, Steg, and Bolderdijk 2017; Kaplan 2000; Schultz and Zelezny 2003). As Binder and Blankenberg (2017) find that the relationship between PEB and life satisfaction is mostly attributable to self-image benefits and other work has found relationships between both pro-social spending and volunteering and SWB are independent of the amount of money and time given (Aknin, Dunn, and Norton 2012; Son and Wilson 2012), strategies which align the enhancement of self-image with actions that deliver substantial environmental benefits would appear to be particularly important.

Finally, engaging in common behaviours relative to uncommon behaviours appears to be more positively related to wellbeing is a significant finding. Some of the more common behaviours, such as recycling, are essential components of a sustainable lifestyle given that they have direct environmental consequences in the control of the individual. Less common behaviours, such as being a member of an environmental organisation, are also of great importance, particularly as they may influence policy and in doing so affect the behaviour of many individuals and organisations at once (Stern 2000; Clayton et al. 2015). The above result suggests that encouraging these less common behaviours may be less beneficial to wellbeing than the commonly undertaken PEBs. Future work to understand the drivers of this relationship in order

to know how best to promote both. Two key areas which merit further exploration are the norms and costs associated with these different clusters of PEBs. These two potential drivers would lead to different policy conclusions. PEBs for which there are low descriptive social norms, for example, could be targeted with injunctive social norm messaging (conveying social approval for the action) through advertisement or other means with a view to both encouraging PEB and increasing the wellbeing individuals derive from it (Nyborg, Howarth, and Brekke 2006; Schultz et al. 2007). In contrast, if costs were found to better explain the relatively weak relationship between uncommon behaviours and eudemonic wellbeing policymakers could explore micro-volunteering strategies whereby many people are encouraged to do small tasks as a way to achieve both environmental and wellbeing benefits (Brady 2015; Brady, Morris, and Bigham 2015).

6.44 Limitations and future research

Further work on the topic of SWB and PEB is imperative as a number of important caveats apply to the current research. As the analysis is based on cross-sectional data, it is unclear whether the links documented between SWB and PEB represent causal relationships. Individuals who engage in these PEBs may derive both a sense of purpose and feelings of satisfaction from doing so. It is also possible, however, that those who have higher levels of eudemonic wellbeing and life satisfaction are more likely to engage in PEB (Kasser 2017). Additionally, the results may suffer from omitted variable bias; nature connectedness, for example, has been found in separate studies to be significantly associated with meaning in life and PEB (Howell et al. 2011; Pereira and Forster 2015). Due to data limitations, this variable could not be included in the current analysis. Existing experimental and longitudinal work has found evidence of a bi-directional relationship between SWB and other pro-social behaviours, including volunteering and charitable giving (Son and Wilson 2012; Aknin, Dunn, and Norton 2012).While PEB shares many common characteristics with these behaviours, it is also different in a number of ways that may influence its relationship with wellbeing; for example, many PEBs typically involve less social interaction than is case with volunteering (Son and Wilson 2012), and the impact of pro-environmental actions may appear less salient than charitable donations elicited

to help identifiable victims, for example (Aknin et al. 2013). As such, it is important that future work establish the extent to which engaging in PEB actually causes SWB.

Beyond issues around causality, only five self-reported measures of PEB were incorporated into this analysis. Though the self-reported behaviour is used widely in environmental psychology, estimates of the validity of these measures vary widely (Steg and Vlek 2009). Furthermore, these measures do not cover all dimensions of PEB previously found in existing literature; for example, no measure relates to environmental policy support. This PEB has been recognised as an important PEB from an impact perspective and has been found in previous studies to represent a separate dimension of PEB engagement relative to consumer behaviours or environmental citizenship (Stern et al. 1999). Future work should look to incorporate experimental methods to establish causality and directly measure a more comprehensive range of PEBs in order to better understand whether and how various dimensions of actual PEB engagement affect wellbeing.

Despite these limitations, the results of the current work present valuable new insights into the nature of the relationship between SWB and PEB which challenge the view of PEB as entailing sacrifice. They suggest that individuals derive a eudemonic wellbeing gain from engaging in PEBs without paying a hedonic cost, and that they may be better off doing their bit by engaging in common PEBs compared to uncommon behaviours. Future research should build on these findings to establish whether the associations presented here reflect causal relationships from PEB to wellbeing. Policymakers should take these findings into account in the pursuit of the important goals of promoting both environmental protection and human wellbeing.

Appendices 6

Appendix 6A: Descriptive statistics

	N	Mean	St. Dev	Min	Max
Dependent					
Satisfaction	5,206	7.323	2.034	0	10
Worthwhile	5,206	7.559	1.890	0	10
Happiness	5,206	7.414	2.259	0	10
Anxiety	5,206	2.679	2.883	0	10
Independent					
General PEB	5,206	-1.51e-09	1.0001	-1.0489	4.1198
Common/Uncommon	5,206	5.92e-09	1.0001	-5.2664	1.4256
Concerned	5,206				
Not concerned	846	.16		0	1
Yes concerned	4,360	.84		0	1
Controls					
Gender	5,206	1.0			
Male	2,418	.48		0	1
Female	2,788	.52		0	1
Health (without	1,683	1.0			
Very bad	16	.01		0	1
Bad	106	.06		0	1
Fair	355	.21		0	1
Good	754	.45		0	1
Very good	452	.27		0	1
Health (first imputation)	5,206	1.0			
Very bad	47	.01		0	1
Bad	313	.06		0	1
Fair	1,134	.21		0	1
Good	2,372	0.46		0	1
Very good	1,340	0.26		0	1
Disability status	5,206	1.0			
Non-disabled	3,985	.77		0	1
Disabled	1,221	.23		0	1
Age group	5,206	1.0			
16-24	757	.15		0	1
25-34	894	.17		0	1
35-44	744	.14		0	1
45-54	778	.15		0	1
55-64	734	.14		0	1
65+	1,299	.25			
Socio-economic group	5,206	1.0			
AB	945	.18		0	1
C1	1,357	.26		0	1
C2	977	.19		0	1
DE	1,927	.37		0	1
Marital Status	5,206	1.0			

Married	2,862	.55	0	1
	1,415	.27	0	1
Single	929	.18	0	1
Work status	5,206	1.0		
In full -time work	1,725	.33	0	1
In education	661	.12	0	1
Not working	1,482	.28	0	1
Part-time work	362	.07	0	1
Retired	976	.19	0	1
Housing Tenure	5,206	1.0		
Mortgage	1,236	.24	0	1
Rent private	1,595	.31	0	1
Owned outright	999	.19	0	1
Rent local authority	1,153	.22	0	1
Other tenure	223	.4	0	1
Ethnicity	5,206	1.0		
White	4,431	.85	0	1
Non- white	775	.15	0	1

Appendix 6B: Life Satisfaction, pro-environmental behaviour and concern

VARIABLES	Satisfaction Model I	Satisfaction Model II	Satisfaction Model III	Satisfaction Model IV	Satisfaction Model V
General PEB	0.115***	0.0639**	0.0627**		0.00420
	(0.0291)	(0.0290)	(0.0290)		(0.0933)
Concerned			0.0167	0.0696	0.0465
			(0.0808)	(0.0805)	(0.0945)
General PEB X					0.0624
					(0.0998)
Common/Uncommon	0.104***	0.0816***	0.0810***		0.0758
	(0.0300)	(0.0299)	(0.0299)		(0.0785)
					0.00771
Common/Uncommon Concerned					(0.0830)
Constant	7.323***	7.549***	7.536***	7.470***	7.503***
	(0.0314)	(0.177)	(0.184)	(0.185)	(0.199)
Controls	NO	YES	YES	YES	YES
N	5,206	5,206	5,206	5,206	5,206
R-squared	0.006	0.097	0.097	0.095	0.097

*Standard errors clustered at local authority level in parentheses. *** p<0.01, ** p<0.05, * p<0.1.*

Appendix 6C: The worthwhileness of activities, pro-environmental behaviour and concern

VARIABLES	Worthwhile Model I	Worthwhile Model II	Worthwhile Model III	Worthwhile Model IV	Worthwhile Model V
General PEB	0.218***	0.155***	0.147***		0.354***
	(0.0279)	(0.0270)	(0.0272)		(0.100)
Concerned			0.111	0.205**	0.00777
			(0.0799)	(0.0806)	(0.0864)
General PEB X					-0.220**
					(0.0998)
Common/Uncommon	0.114***	0.0855***	0.0810***		0.0904
	(0.0265)	(0.0264)	(0.0260)		(0.0938)
Common/Uncommon Concerned					-0.0172 (0.0980)
Constant	7.559***	7.528***	7.441***	7.319***	7.554***
	(0.0311)	(0.151)	(0.163)	(0.165)	(0.164)
Controls	NO	YES	YES	YES	YES
N	5,206	5,206	5,206	5,206	5,206
R-squared	0.017	0.077	0.077	0.070	0.078

*Standard errors clustered at local authority level in parentheses. *** p<0.01, ** p<0.05, * p<0.1*

Appendix 6D: Happiness yesterday, pro-environmental behaviour and concern

VARIABLES	Happiness Model I	Happiness Model II	Happiness Model III	Happiness Model IV	Happiness Model V
General PEB	0.106***	0.0515	0.0480		-0.0273
	(0.0337)	(0.0332)	(0.0338)		(0.108)
Concerned			0.0488	0.0900	0.0909
			(0.0963)	(0.0939)	(0.108)
General PEB X					0.0808
					(0.112)
Common/Uncommon	0.0852***	0.0662**	0.0643**		0.0428
	(0.0316)	(0.0317)	(0.0319)		(0.0981)
Common/Uncommon X					0.0270
Concerned					(0.102)
Constant	7.414***	7.402***	7.364***	7.312***	7.316***
	(0.0351)	(0.174)	(0.179)	(0.177)	(0.188)
Controls	NO	YES	YES	YES	YES
N	5,206	5,206	5,206	5,206	5,206
R-squared	0.004	0.059	0.059	0.058	0.059

*Standard errors clustered at local authority level in parentheses. *** p<0.01, ** p<0.05, * p<0.1*

Appendix 6E: Anxiety yesterday, pro-environmental behaviour and concern

VARIABLES	Anxiety Model I	Anxiety Model II	Anxiety Model III	Anxiety Model IV	Anxiety Model V
General PEB	-0.000861	0.0635	0.0624		0.278*
	(0.0444)	(0.0456)	(0.0436)		(0.148)
Concerned			0.0159	0.000599	-0.0488
			(0.156)	(0.158)	(0.164)
General PEB X					-0.224
					(0.149)
Common/Uncommon	-0.194***	-0.163***	-0.164***		-0.322***
	(0.0387)	(0.0397)	(0.0396)		(0.116)
Common/Uncommon					0.176
Concerned					(0.126)
Constant	2.679***	3.297***	3.284***	3.294***	3.346***
	(0.0556)	(0.251)	(0.277)	(0.272)	(0.292)
Controls	NO	YES	YES	YES	YES
N	5,206	5,206	5,206	5,206	5,206
R-squared	0.005	0.043	0.043	0.040	0.044

*Standard errors clustered at local authority level in parentheses. *** p<0.01, ** p<0.05, * p<0.1*

Appendix 6F: Subjective wellbeing, pro-environmental behaviour and concern

VARIABLES	Model III Satisfaction	Model III Worthwhile	Model III Happiness	Model III Anxiety
General PEB	0.0627**	0.147***	0.0480	0.0624
	(0.0290)	(0.0272)	(0.0338)	(0.0436)
Common/Uncommon	0.0810***	0.0810***	0.0643**	-0.164***
	(0.0299)	(0.0260)	(0.0319)	(0.0396)
Concerned	0.0167	0.111	0.0488	0.0159
	(0.0808)	(0.0799)	(0.0963)	(0.156)
White	0.231***	0.216***	0.111	-0.590***
	(0.0814)	(0.0762)	(0.0898)	(0.124)
Age		Reference group: 16-24		
25-34	-0.703***	-0.340***	-0.389***	0.207
	(0.113)	(0.109)	(0.127)	(0.175)
35-44	-0.913***	-0.376***	-0.672***	0.522***
	(0.131)	(0.114)	(0.144)	(0.184)
45-54	-1.030***	-0.505***	-0.601***	0.399**
	(0.136)	(0.119)	(0.143)	(0.177)
55-64	-0.799***	-0.360***	-0.465***	0.427*
	(0.138)	(0.118)	(0.160)	(0.224)
65+	-0.479***	-0.0740	-0.0831	0.153
	(0.166)	(0.138)	(0.164)	(0.251)
Gender		Reference group: Male		
Female	0.101*	0.290***	0.0912	0.118
	(0.0527)	(0.0509)	(0.0643)	(0.0798)
Disabled	0.793***	0.520***	0.685***	-0.848***
	(0.0837)	(0.0743)	(0.0846)	(0.117)
Marital status		Reference group: Married		
Separated/ Divorced/ Widowed	-0.586***	-0.488***	-0.509***	0.320***
	(0.0763)	(0.0790)	(0.0895)	(0.119)
Single	-0.570***	-0.556***	-0.610***	0.146
	(0.0865)	(0.0781)	(0.0991)	(0.121)
Work status		Reference group: Married		
In education	-0.0673	-0.0924	0.103	-0.169
	(0.0770)	(0.0668)	(0.0975)	(0.125)
Not working	0.184	-0.0296	0.154	-0.286
	(0.123)	(0.108)	(0.135)	(0.186)
Part-time work	-0.0733	0.0769	-0.0494	0.186
	(0.120)	(0.113)	(0.153)	(0.204)
Retired	-0.538***	-0.459***	-0.428***	0.281**
	(0.0974)	(0.0818)	(0.0965)	(0.130)
Socio-economic status		Reference group: AB		
C1	-0.0823	-0.155**	-0.0269	0.0895
	(0.0767)	(0.0657)	(0.0803)	(0.119)
C2	-0.104	-0.0979	-0.0913	-0.0683

	(0.0885)	(0.0767)	(0.0949)	(0.118)
DE	-0.172*	-0.244***	-0.234**	0.0900
	(0.0912)	(0.0816)	(0.0993)	(0.130)
Tenure status		Reference group: Mortgage		
Rent private	0.0773	0.124	0.116	-0.0796
	(0.0801)	(0.0788)	(0.0888)	(0.121)
Owned outright	-0.118	0.0501	0.0726	0.208
	(0.114)	(0.104)	(0.111)	(0.157)
Rent local authority	-0.0930	-0.0778	0.0575	0.323***
	(0.0780)	(0.0788)	(0.0874)	(0.121)
Other tenure	-0.00689	-0.0765	0.0513	-0.132
	(0.152)	(0.139)	(0.166)	(0.215)
Constant	7.536***	7.441***	7.364***	3.284***
	(0.184)	(0.163)	(0.179)	(0.277)
N	5,206	5,206	5,206	5,206
R-squared	0.097	0.077	0.059	0.043

*Standard errors clustered at local authority level in parentheses. *** p<0.01, ** p<0.05, * p<0.1*

Appendix 6G: Robustness check- models with and without imputed health controls

VARIABLES	Satisfact Model	Satisfact Model	Worthw Model	Worthw Model	Happy Model	Happy Model	Anxio Model	Anxious Model VI
General PEB	0.0627*	0.0559*	0.147**	0.1418*	0.0480	0.0415	0.0624	0.068
	(0.0290)	(0.029)	(0.0272)	(0.0274)	(0.033	(0.034	(0.043	(0.0436)
Concerned	0.0167	0.0146	0.111	0.108	0.0488	0.0455	0.0159	0.0179
	(0.0808)	(0.0809)	(0.0799)	(0.0797)	(0.096	(0.096	(0.156	(0.156)
Common/Unco	0.0810*	0.0809*	0.0810*	0.0815*	0.0643	0.0646	-	-0.164***
	(0.0299)	(0.03)	(0.0260)	(0.0262)	(0.031	(0.032	(0.039	(0.0397)
Constant	7.536**	7.92819	7.441**	7.752**	7.364*	7.73**	3.284*	2.977***
	(0.184)	(0.198)	(0.163)	(0.178)	(0.179	.203	(0.277	(.306)
Controls	YES	YES	YES	YES	YES	YES	YES	YES
Health controls	NO	YES	NO	YES	NO	YES	NO	YES
N	5,206	5,206	5,206	5,206	5,206	5,206	5,206	5,206
R-squared	0.097	0.106	0.077	0.083	0.059	0.065	0.043	0.046

*Standard errors clustered at local authority level in parentheses. *** p<0.01, ** p<0.05, * p<0.1*

7. Converting good intentions into positive environmental impact

(Paper 4)

7.1 Introduction

Energy efficiency represents a major challenge to governments around the world (DECC 2014). A key domain in which this matters is the home. After transport, domestic energy use is the main source of energy consumption that private individuals have direct control over (Wang and Moriarty 2017). In Europe, for example, domestic energy use is responsible for approximately 25% of all direct energy consumption (Eurostat 2017). The corresponding figure for the UK alone is higher again at 29% (BEIS 2017a). The CO_2 emissions resulting from this sector are key contributors to issues of environmental degradation, including climate change, and achieving efficiency in this area is central to strategies to address these problems (Steg, Perlaviciute, and van der Werff 2015). In the UK, a number of reports have suggested that it will be impossible to achieve the 2050 target of 80% emission reductions laid out in the 2008 Climate Change Act without a substantial drop in household energy consumption (Palmer, Terry, and Pope 2012; Commitee on Climate Change 2012).

In this context, both researchers and policymakers are interested in interventions which can make households more energy efficient (Behavioural Insights Team 2011; Frederiks, Stenner, and Hobman 2015b; OECD 2011; Abrahamse et al. 2005; DECC 2014). These strategies can take on two forms: they can target the household's energy-related infrastructure or the behaviour of its members (Allcott and Mullainathan 2010). Infrastructure solutions, including those involving new technologies, are widely understood to have an important role to play (OFGEM 2017; Pacala and Socolow 2004). Non-technical solutions which target consumer behaviour are also appealing, however, as they have the potential to reduce energy consumption quickly without the need for infrastructural changes (OECD 2017; Behavioural Insights Team 2011; Dietz et al. 2009).

Strategies to target household behaviour explore both the effectiveness of price or information-based strategies (Wang and Moriarty 2017). Pricing strategies include taxation (Berkhout, Ferrer-i-Carbonell, and Muskens 2004) or dynamic pricing whereby prices vary based on temporal demand characteristics (Faruqui and Sergici 2010). While studies find that household consumption is affected by price, the overall message from the literature is that household energy consumption is relatively price inelastic, particularly in the short-run (Wang and Moriarty 2017; Advani et al. 2013; Azevedo, Morgan, and Lave 2011). Information-based strategies, in contrast, include everything from the provision of energy saving tips to personal feedback or peer-

comparison (Allcott 2011; Fischer 2008; Allcott and Mullainathan 2010). A meta-analysis of information-based strategies to reduce residential electricity consumption finds these programmes lead to an average reduction in energy consumption of 7.4%, though importantly they document a high level of heterogeneity in treatment effects across different types of information (Delmas, Fischlein, and Asensio 2013). Some recent work documents evidence to suggest that strategies that combine information and pricing may be particularly effective (Jessoe and Rapson, 2014).

While this work demonstrates that intervention strategies involving price and information can deliver real energy reductions, their applicability is not universal. The majority of the effective interventions falling under information-based strategies require information is about individuals' or peers' consumption to feedback to target populations (Allcott and Mullainathan 2010). Work on pricing has mostly considered situations in which individuals face the marginal unit cost of their electricity consumption (Wang and Moriarty 2017). While these conditions clearly apply to many people in the domestic sector, for others it does not; it is not commonly the case for people living in communal establishments such as residential care, halls of residence and army bases, for example (McMakin, Malone, and Lundgren 2002). According to the most recent census in the UK, one million people live in such communal living arrangements (Office for National Statistics 2015). The 2010 Census in the US estimated that the equivalent figure was over eight million (National Research Council 2012). The energy consumption of such establishments is often master metered and residents tend to pay a flat rate for their energy which is incorporated in an overall bill (Alberts et al. 2016; Tone 2010; Karp et al. 2016; Ministry of Defence 2017; McMakin, Malone, and Lundgren 2002).

To date, the behavioural science literature has contributed much less to our understanding of strategies which could be effective at reducing energy consumption in contexts where information on individual consumption is limited and price cannot be use a lever. Within these contexts efforts to reduce energy saving consumption are often limited to the provision of energy saving tips. This is despite the fact that there is evidence to suggest that such strategies are ineffective (Delmas, Fischlein, and Asensio 2013). The development of new approaches and the identification of ways to make energy-saving tips more effective in such contexts are, therefore, important goals.

Implementation intentions is a behaviour change technique from social psychology which may represent a promising intervention with which to target household energy consumption in this context. It is unrelated to price, has low information requirements, and has been shown to work to bring about behaviour change in relation to other relevant behaviours. Specifically, implementation intentions consist of 'if-then' plans for which individuals identify situations ('if') that when encountered should be met with specific behavioural responses ('then'), and that relate to an overall goal (Gollwitzer and Sheeran 2006). The technique is understood to work via mechanisms that strongly resemble habitual processes. Forming the implementation intention links the target behaviour to situational cues in the mind of the individual, and, as a result, the behaviour is thought to become automatically activated upon encountering these cues (Holland, Aarts, and Langendam 2006). Studies show that encouraging individuals to formulate implementation intentions is effective at helping people get to bed earlier, drink less alcohol, eat more healthily and vote (Cooke and Lowe 2016; Nauts et al. 2016; Verplanken and Faes 1999; Nickerson and Rogers 2010).

Existing research from the environmental domain also highlights implementation intentions as a potentially effective strategy with which to target domestic energy consumption. Some previous work looks at the effect of forming implementations on other PEBs such as taking public transport, making eco-friendly purchases, waste recycling, and reducing meat consumption, all with successful results (Holland, Aarts, and Langendam 2006; Bamberg 2002; Bell et al. 2016; Loy et al. 2016; Rise, Thompson, and Verplanken 2003). Perhaps, the best indication that implementation intentions can bring about energy savings is a recent work carried out by Bell et al. (2016). This study finds that teenagers who form implementation intentions self-report significantly higher energy saving behaviours both five days and six weeks later, compared to those who do not.

These studies highlight the potential for implementation intention interventions to yield energy savings in a residential context. However, they do not speak to whether and what extent real energy savings can be achieved using this strategy. Although the use of individual self-reports of PEBs is common within studies in environmental psychology, these measures may not reflect actual behaviour due to social desirability or recall bias, for example. A study by Gatersleben, Steg, and Vlek

(2002) finds that self-reported PEB is only marginally related to household energy use in two large-scale studies in the Netherlands. Behavioural experiments in environmental economics, in contrast, largely focus on impact-based measures, such as meter readings (Allcott 2011) and the refuse weight (Nigbur, Lyons, and Uzzell 2010). Without such objective measures, it is hard to judge the potential of a given behaviour change strategy, and the lessons which can be drawn for policy are limited (Mckenzie-Mohr 2000; Huddart Kennedy, Krahn, and Krogman 2015).

The current work addresses this gap. It investigates two interventions to encourage individuals to carry out impactful electricity saving behaviours using techniques relating to an implementation intentions based approach to behaviour change. The interventions are evaluated in two field experiments in a student hall of residence in London. Specifically, the studies involve either providing the opportunity for students to detail or detailing situations, in which to carry out electricity savings behaviours. Both interventions are evaluated based on their impact on consumption as measured by electricity meter readings. The residents at this field site all pay a flat rate for their energy consumption as part of their rent, and the existing infrastructure does not make individualised energy consumption information easily available.

Existing research on pro-environmental behaviours is often criticised for focusing on actions that do not have significant environmental benefits (Huddart Kennedy, Krahn et al. 2015). The use of electricity consumption to evaluate the interventions in the current work inherently emphasises the importance of targeting behaviours that, if undertaken, yield real energy savings. Three electricity saving behaviours are chosen based on their identification by the UK's Department of Energy and Climate Change as being among the most impactful energy-saving behaviours households can adopt. They are: switching off lights; only boiling as much water as is necessary; and using lids on saucepans (Palmer, Terry, and Peter 2012). The students in all conditions are made aware of the source of these tips.

Study 1 represents the first work to evaluate and provide direct estimates of the electricity and cost savings from an implementation intentions exercise in a residential setting. The results of the study indicate that encouraging residents to formulate implementation intentions around the above-mentioned behaviours leads to a ~21% reduction in energy consumption over the following four-week period,

compared to providing energy saving tips alone. The effect does not vary depending on whether the individual expresses concern over environmental issues. The second study strips back the intervention so that the contextual cues are passively delivered in the context of energy saving tips posted under the students' doors. This lighter touch version of the intervention does not achieve any energy savings.

In what follows the methods are described (Section 2), the results are presented (Section 3), and the findings are discussed (Section 4).

7.2 Methods

Both Study 1 and Study 2 consist of natural field experiments in a university hall of residence in South London. They took place in spring and autumn 2016. The major benefit of this approach is that the interventions were implemented in the real-world environment in which the participants live and consume electricity. In addition, as the students were unaware that their consumption is being monitored, their consumption patterns were unaffected by the observation (this effect is commonly referred to as a 'Hawthorne effect' and is described in detail in Harrison and List, 2011).

The leases on the residential units in the halls run from September to August, such that the two studies involve two different student bodies (Study 1 includes residents from the academic year 2015-16; Study 2's residents are from 2016-17). The hall consists of student accommodation for over a 1000 students, most of whom live in shared accommodation, sharing bedrooms, kitchen and bathrooms, or all three. A subset of these students live in studio rooms, which are dispersed throughout the halls across all of the 15 residential floors. In these rooms, students live alone and have their own shower room and kitchen. Both studies focus on the residents of these rooms in order to limit the potential for interference and to be able to attribute the effects of the interventions to a specifically targeted individual. 130 studio rooms were available for inclusion in the first study, and 140 at the time of the 2nd study. Each of these studio rooms has an electrical closet outside which houses the electricity meter for that room. Electricity readings, in kilowatt-hours, were taken manually every week for the duration of the studies.

7.21 Study 1

Study 1 examines whether or not the formation of implementation intentions, as compared to being given energy saving tips, leads to real electricity savings. The study took place in spring 2016. The private halls of residence opened for business in September 2015. The targeted student population were, therefore, the first residents of the hall. Their week 1 energy reading represents their whole electricity usage from the day they moved in up to the point of the survey.

Study 1 involved speaking with the student residents directly. Research assistants knocked on all of the 130 rooms available and a convenience sample consisting of the 93 that answered their doors was included in the study. The students were randomly assigned to a treatment or control group. In both groups, the assistants identified themselves as representatives from the LSE's Sustainability Team and wore t-shirts with the team's logo. All students were first asked whether they considered themselves to be a person who is concerned with environmental issues (they were verbally given the option to indicate either 'yes', 'no' or 'somewhat') and were then told about the top three tips for energy saving.

Individuals in the control group were then given a door hanger with energy saving tips in an imperative style (e.g. 'Switch off the lights!') as a reminder. The treatment group were also given a different version of the door hanger. The research assistants then asked the members of the treatment group to fill in the door hanger by ticking the boxes beside the tips they were planning on carrying out and to fill in the blanks to indicate the situational cue associated with each activity; for example, 'If I am leaving my room to go to…_____…then I will switch off the lights!'. See Appendix A for the layout of both versions of the door hanger used in Study 1.

7.22 Study 2

Study 2 tested whether exposing individuals to energy saving tips with an if-then format, as compared to normal 'do this' style tips, could encourage electricity savings. It was carried out on the halls' second cohort in autumn 2016. As this intervention did not require direct contact with the students all 140 rooms were included in the sample. As the initial reading at the beginning of the study no longer represented just the residents' consumption, a baseline measurement was taken for all rooms. In this study door hangers were posted under all doors of studio rooms. Those students who were randomly allocated to the control group were posted the same door hanger with imperative style energy saving tips, e.g. 'Switch off the lights!' that was used in Study 1. Those students who were allocated to the treatment group received the same tips but in an 'if-then' format, incorporating added situational cues; for example, 'If you are leaving your room to go to University then switch off the lights!'. See Appendix 7B for both versions of the door hanger used in Study 2.

7.3 Results

7.31 Study 1

In order to check for balance across the treatment and control groups in Study 1, the week 1 reading was used to perform a balance test. A two-sided t-test found no evidence to suggest that the treatment and control groups differed in their baseline consumption (see Appendix 7D). Additionally, no evidence was found to suggest that electricity consumption of those that answered their doors was significantly different from those that did not (see Appendix C). Lastly, the residents were asked whether they considered themselves to be concerned with environmental issues (and prompted with the options 'yes', 'no' or 'somewhat'). A chi^2 test finds no evidence to suggest that the distribution of concern is different across the two groups (see Appendix 7D).

The electricity consumption of the students in the treatment and control groups was then compared using a two-sided t-test of difference in means for electricity consumption across the four-week period following the intervention. The results of the study indicate that the formation of implementation intentions led to significant and substantial electricity savings over the course of the month. The average electricity consumption in the treatment group was of 20% lower than that of the control group (see Table 7.1 for a weekly breakdown testing differences in means). An OLS regression model was also specified in which the students' level of concern and the treatment variable were interacted. The results indicate that consumption decreased most for those who indicated that they were concerned, but the results of the interactions are insignificant at all conventional levels (see Appendix 7F). Overall, the results from Study 1 suggest that encouraging individuals to form implementation intentions around energy saving behaviours is an effective strategy to bring about reduced electricity consumption over a one-month period. The analysis presented in Table 7.2 provides estimates of both the CO_2 emissions and the costs savings achieved in the treatment group, compared to the control.

Table 7.1: Comparison of means across weeks 1-4 for Study 1

Study 1	Week 1	Week 2	Week 3	Week 4	Total
Control	206.35	211.78	196.09	199.8	814.02
Energy Saving Tips	(12.9)	(14.65)	(13.01)	(14.61)	(52.86)
Treatment	164.51	165.4	164.02	148.96	642.89
Implementation Intentions	(8.45)	(7.81)	(10.32)	(12.22)	(30.39)
Difference	41.84***	46.38***	32.07*	50.85***	171.13***
	(15.35)	(16.51)	(16.57)	(19.01)	(60.65)
Percentage reduction	20.28%	21.9%	16.35%	25.45%	21.02%

*Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1, N=93*

Table 7.2: Savings estimates from Study 1

Savings indicator	
Average 1 month electricity consumption Savings (kWh)	171.1281
Total 1-month electricity consumption Savings (kWh)	8043.02
Average CO_2 emissions savings (kgCO_2e)	71
- Source: National Energy foundation UK carbon calculator estimates of average grid electricity	
Total CO_2 emissions savings (kgCO_2e) for 47 treated rooms	3337
Average Electric Tumble Dryer cycle equivalent	69
- Source: CarbonFootprint.com estimate: 2.50 kWh per cycle Based on an average load capacity of 4.76 kg of dry laundry	
Total electric tumble dryer cycle equivalent	3217
Average cost savings estimate	£13.69
- Source: The National Union of Students estimate of Energy kWh unit price of £0.08.Excluding VAT	
Total cost savings for 47 treated rooms	£643.44

7.32 Study 2

As the initial reading at the beginning of Study 2 no longer represented just the residents' consumption, a 1-week baseline measurement was taken for all rooms. A two-sided t-test showed no significant difference in electricity in this baseline week across the two groups (see Appendix 7E).

The electricity consumption of the student in the treatment and control groups was then compared post-intervention using the same approach as was used to analyse the results of Study 1. A two-sided t-test of difference in means for electricity consumption over the four-week period showed no significant differences between the two groups. Analysis of each of the weeks in isolation also demonstrates no differences across the treatment and control groups. The results of this second study indicate that the presentation of the tips in an 'if-then' style did not lead to any significantly different electricity savings than the imperative style tips alone (see Table 7.3).

Table 7.3: Comparison of means across weeks 1-4 for Study 2

Study 1	Week 1	Week 2	Week 3	Week 4	Total
Control	169.7714	168.1	166.9857	167.3	672.1571
- Energy Saving Tips	(11.64)	(11.2)	(9.81)	(11.07)	(41.92)
Treatment	171.0571	179.5857	178.9429	175.9714	705.5571
- If-then tips	(10.63)	(18.31)	(18.71)	(19.21)	(65.1)
Difference	-1.285714	-11.48571	-11.95714	-8.671429	-33.4
	(15.77)	(21.47)	(21.13)	(22.17)	(77.43)

*Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1, N=140*

7.4 Discussion

The results of the studies present rigorous evaluations of two behaviour change interventions targeting domestic energy consumption in communal accommodation.

7.41 Study 1

Study 1 tests the effect of an implementation intention intervention on electricity consumption in a real-world residential setting. Evaluating this intervention using real-consumption data not only answers the question: did the encouragement of implementation intentions reduce electricity consumption? But also, by how much and what carbon and cost savings were achieved? Individuals who were encouraged to form implementation intentions across three impactful energy savings behaviours consumed approximately 21% less electricity in the week following the intervention and these savings were sustained over a subsequent four-week period. These savings are high in the context of the literature that measures residential energy consumption interventions via their impact (Abrahamse et al., 2005). They are, however, in line with other evidence from research on students in halls of residence which finds that information and norms bring about approximately 22% reductions (Alberts et al. 2016). Together these results suggest that student residential energy consumption may be particularly susceptible to intervention (Alberts et al., 2016). The effect of the intervention persisted for the four-week period for which electricity was monitored. This is in line with existing evidence from implementation intentions research which finds that the effects tend to be long-lasting, suggesting that they can help to create new habits (Holland et al. 2006).

Over the four-week period the members of the treatment group collectively saved approximately 3337 kilograms of CO_2 (Carbon Footprint Calculator 2017). This is the equivalent of over 3200 electric tumble dryer cycles. Based on estimates used by the UK's National Union of Students on the cost of electricity provision in UK halls of residences (£0.08/kilowatt hour), the per room savings over the month post-intervention are £13.69 and total savings across the 48 treated rooms amounted to £643.44 over the intervention period. If the interventions were to be scaled across all of the rooms in the hall and even to other halls of residence in the country (which were

home to a total of 397,000 residents in UK's 2011 Census (Office for National Statistics 2015)) the environmental and cost reductions could potentially be orders of magnitude higher. Having a precise metric on the savings means that the study produces numbers which can be used to feedback to policymakers, companies who wish to carry out a cost-benefit analysis, and the users themselves to inform them of the effectiveness of the implementation intention exercise.

7.42 Study 2

The second study represents an attempt to leverage the 'if-then' formula to make information tips more effective. Despite evidence to suggest that energy savings tips have limited, if any, effect (Delmas, Fischlein, and Asensio 2013; Steg and Vlek 2009), information campaigns are a commonly used behaviour change tactic in environmental campaigning. Little is known about the most effective way to present information about PEBs in order to encourage their uptake. Study 2 explored the extent to which furnishing tips with situational cues made them more effective. The approach towards this second intervention has some basis in existing literature. One study on alcohol consumption found that experimenter-provided implementation intentions were just as effective as self-generated ones at encouraging behavioural change (Armitage 2009). However, no study to date has tested whether the provision of information which incorporates situational cues around desirable behaviours is effective at promoting behavioural goals.

In Study 2 no difference was found in the electricity consumption of the treatment and control groups at any stage during the four-week follow-up. This null result suggests that the interaction with the targeted individuals may be necessary to achieve energy savings using if-then formatted plans. One potential explanation for why it did not work could be that the participants' choice of implementation intentions, regardless of whether it is their own or someone else's, acts as a commitment device. Commitment-based strategies have previously been shown to be effective at encouraging towel reuse in hotels (Baca-Motes et al. 2013). The current intervention did not involve the participants making active choices which might explain why it was unsuccessful. That the if-then style tips were no more effective than standard tips is

an important lesson for environmental information campaigns which often involve the passive delivery of pro-environmental tips with situational cues.

7.43 Strengths and limitations- whether and why?

Exploring the effectiveness of the interventions using natural field experiments such as those in Studies 1 and 2 has a number of benefits. First, the randomisation of participants into treatment and control setting provides causal estimates of the effects of the interventions in terms of electricity savings. Second, the evaluation of interventions using consumption outcomes inherently places emphasis on considering and targeting the most impactful PEBs possible, and allows for the conversion of the impact estimates into estimates of environmental benefits in terms of CO_2 emission reductions and cost savings. Finally, the fact that the participants are unaware of the trial and it takes place in a real-world setting means the results are not subject to Hawthorne effects (Levitt and List, 2011). In short, such an approach provides good and valuable evidence as to whether the interventions worked across a range of indicators.

However, both studies are not without limitations. In particular, interference between students in the treatment and control groups may have occurred. As the studio rooms are self-contained units spread across many floors, it is unlikely that this represents a major issue but it cannot be ruled out. A second limitation is that due to sample size restrictions, both studies do not allow for the comparison of energy consumption in the treatment group to a clean control group in which the residents received no information at all. Despite evidence to suggest that information campaigns alone are relatively ineffective in bringing about behaviour change in the energy consumption domain (Delmas, Fischlein, and Asensio 2013), it is important to highlight the fact that these studies can only speak to the effect of if-then style plans (Study 1) and if-then style information (Study 2) above and beyond the provision of energy tips.

A third limitation relates to the inability of the work to detect which PEBs lead to the reduction in energy saving in the first study. The implementation intentions intervention may have affected engagement in behaviours beyond those for which they

formed implementation intentions, just those or a subset. Given that implementation intentions have been found to effectively influence self-reports of energy saving behaviours in existing research (Bell et al. 2016), it is arguably a greater contribution to measure the actual environmental impact of these interventions. However, future studies would ideally include additional self-reported measures to better understand how this intervention relates to energy consumption through specific behaviours.

Finally, Study 2 evaluates a light-touch version of the intervention which was found to be successful in Study 1. Although, as previously mentioned, the setup of both studies provides good estimates of whether the interventions worked, it does not provide insights into why. Stripping back interventions in ways that reduce or nullify their effectiveness, as detailed in Study 2, is just one reason why this is problematic. Investigating the psychological mechanisms behind successful PEB behaviour interventions is also critical when considering whether an effect can be replicated in other circumstances and when looking to further develop the interventions to make them more effective. If the behavioural sciences are to encourage the adoption of impactful and sustained pro-environmental lifestyles, the 'why' matters too.

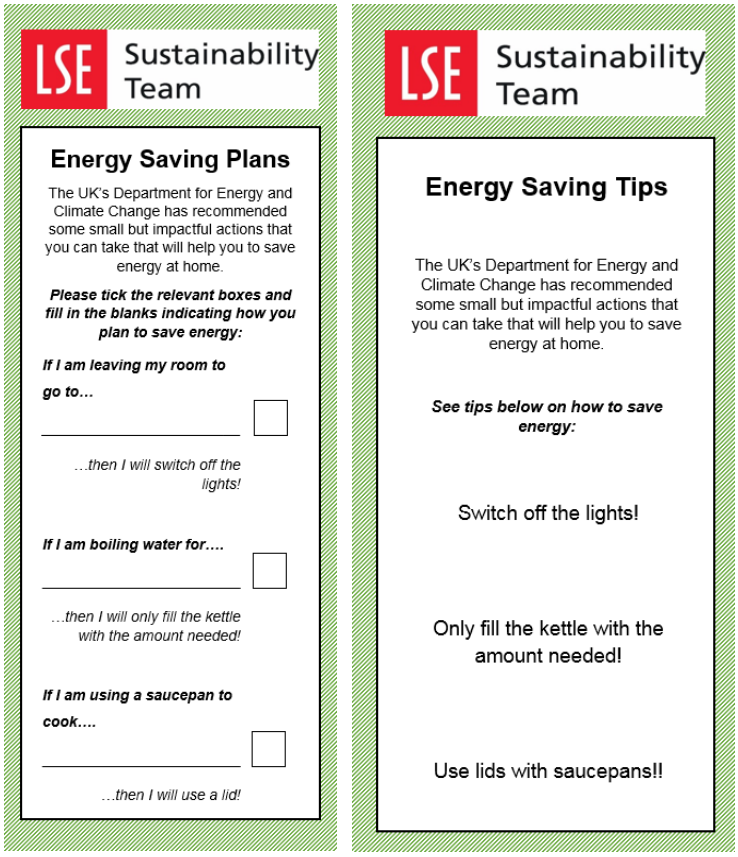
7.44 Conclusions

Price and consumption feedback, alongside advances in energy infrastructure and technological solutions, are likely to continue to dominate policy strategies to reduce household energy consumption (OECD 2017, 2011; OFGEM 2017; Department of Communications Energy and Natural Resources 2015). The widespread introduction of smart meters in the UK, for example, will make real-time feedback a reality for many households (BEIS 2017b). Despite this, the transition to smart meters will take time, and there are likely to be places like communal accommodation where it may not be feasible to charge individuals per unit of energy consumed or provide consumption feedback at an individualised level. With energy savings and the corresponding CO_2 emissions reductions "*a 1% gain today is worth more than a 1% gain tomorrow*" (Behavioural Insights Team 2001, p.3). It is, therefore, also important to identify effective strategies which can target energy consumption in environments where individuals are currently price indifferent, and consumption information is unavailable or costly to obtain.

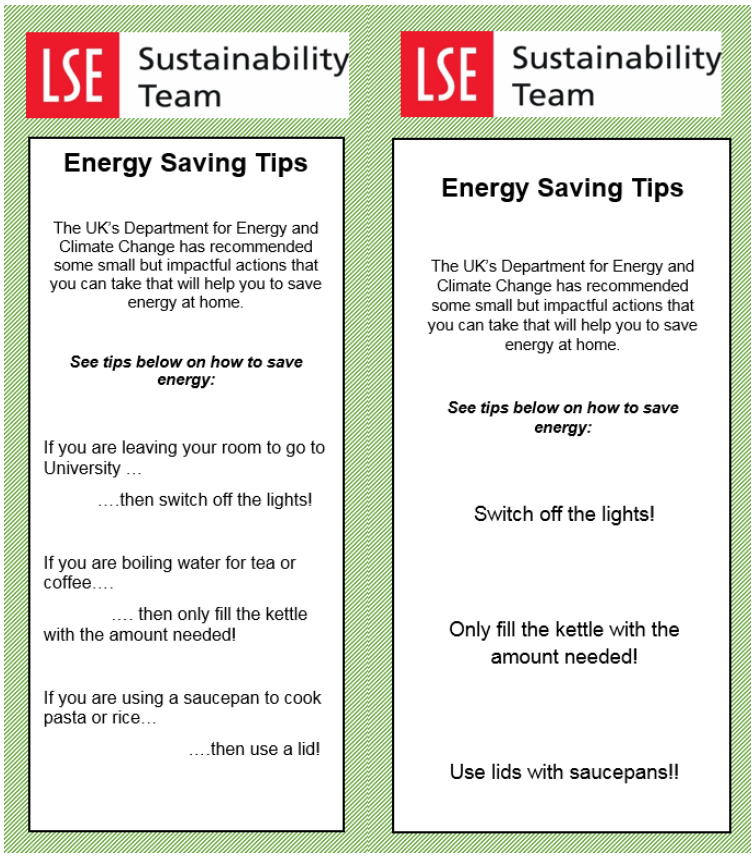
Within this context, the current work investigates two behaviour change interventions that use and build on a behaviour change strategy from social psychology. Both interventions have low information requirements and do not rely on price mechanisms. The results of the first study suggest that encouraging people to form implementation intentions around electricity saving behaviour can bring about real and substantial energy savings. Moreover, that the effect lasted for the four-week monitoring post-intervention suggests that this intervention might be able to produce even longer term-environmental benefits. The results of the second study suggest that providing electricity saving tips with situational cues does not make them any more effective. Future work should explore other ways to present energy saving tips with a view to increasing their impact. More generally, the work demonstrates the benefits of evaluating behaviour change interventions based on their ability to reduce actual environmental impact, but also provides a cautionary tale against a sole focus on whether something PEB interventions work at the expense of knowing why.

Appendices 7

Appendix 7A: Study 1 door hanger designs



Appendix 7B: Study 2 door hanger designs



Appendix 7C: Pre-intervention sample tests Study 1

Study 1	Baseline Meter reading (kW h)	N
Did not answer door	8756.649	37
	(582.0055)	
Answered door	9771.097	93
	(414.8577)	

- Results of a two-sided t-test indicate that there is no significant difference at the 10% significance level between baseline consumption across residents of rooms that did answer the door compared to those who did not.

Appendix 7D: Pre-intervention balance test Study 1

Study 1	Meter reading (kW h)	Not concerned	Somewhat concerned	Very concerned	N
Control	9629.28 (614.9)	4	19	23	46
Treatment	8470.3 (479.1)	4	12	31	47

- Results of a chi-squared test found no evidence of a significant difference between the level of concern for the environment across treatment and control at the 10% significance level.
- Results of a two-sided t-test found no evidence of a significant difference between baseline consumption across treatment and control at the 10% significance level.

Appendix 7E: Pre-intervention balance test Study 2

Study 1	Meter reading (kW h)	N
Control	165.7	70
	(8.833)	
Treatment	163.97	70
	(9.076)	

- Results of a two-sided t-test found no evidence of a significant difference between baseline consumption across treatment and control at the 10% significance level.

Appendix 7F: Regression analysis including interactions for Study 1

Variables	1 month electricity consumption (kW h)	1 month electricity consumption (kW h)	1 month electricity consumption (kW h)
Treated	-171.1***	-174.2***	-79.50
	(60.97)	(65.05)	(110.8)
Environmental concern	Reference group: Not concerned		
Somewhat concerned		-20.22	-8.026
		(73.39)	(110.1)
Concerned		-0.923	83.67
		(74.32)	(125.7)
Interactions			
Treated X Somewhat concerned			-3.890
			(139.9)
Treated X Concerned			-159.6
			(148.8)
Constant	814.0***	822.8***	775.5***
	(52.86)	(66.91)	(87.20)
N	93	93	93
R-squared	0.080	0.081	0.097

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

- Results the effect of the treatment was not found to vary significantly depending on the level of concern for the environment the participants reported.

8. Conclusions

Economics, psychology and epidemiology have all contributed greatly to our understanding of the relationship between human beings and the natural world. Environmental and ecological economics have provided important insights into the interdependence of the economic and ecological systems (Costanza et al. 2014; Beder 2011), while environmental psychology and epidemiology have shed light on interrelationships between individuals and their physical surroundings (Staats 2012; Steg, van den Berg, and De Groot 2012). Both economics and psychology have also enhanced our understanding of humans' use and abuse of natural resources (Steg, Perlaviciute, and van der Werff 2015; Pawlik and Steg 2013). However, our knowledge of the significance of the natural environment for human wellbeing and of effective strategies to encourage environmental protection remains limited (Sandifer, Sutton-Grier, and Ward 2015; Clayton et al. 2015).

The premise of the current work is that much stands to be gained from interdisciplinary research which draws from all three fields in its examination of these issues. The four research papers contained in the thesis employ approaches and methods from across these disciplines to: explore the relationship between a negative element of environmental quality (EQ) – air pollution – and human wellbeing and behaviour (Part 1); and investigate behaviours which can promote environmental quality (Part 2). Together the papers provide new and important insights into the reciprocal nature of the relationship between individuals and the natural world. The research also highlights questions for future research and insights for policymakers focused on promoting both human and environmental wellbeing.

8.1 The findings and contributions of this thesis

8.11 Part 1: Exploring the relationship between air quality, subjective wellbeing and behaviour

Air pollution is considered the world's single biggest environmental health risk (WHO, 2012) and is estimated to cost the global economy 5 trillion US dollars annually (The World Bank 2016). This relationship between wellbeing and air pollution has traditionally been examined by investigating and costing the health effects of air pollution exposure (Atkinson et al. 2015; Carey et al. 2013; DEFRA 2011), or by using traditional non-market valuation techniques such as revealed and stated preference methods (Chay and Greenstone 2005; Carlsson and Johansson-Stenman 2000). In contrast, the current work explores the costs of air quality using individuals' reports of their own wellbeing. The use of these psychological measures of wellbeing have greatly increased in environmental economics in recent years (Binder and Blankenberg 2017). Of particular relevance to the current work is prior literature which has explored associations between air pollution and life satisfaction at both a macro and micro level (Welsch 2006; Levinson 2012; MacKerron and Mourato 2009). Despite the evidence that these studies provide of negative links between air pollution people's subjective wellbeing (SWB), however, many important gaps in our understanding of this relationship remain.

To date, the literature on air pollution and SWB has almost exclusively focused on life satisfaction. This is despite an emerging consensus that measures which capture hedonic feelings and eudemonic sentiments separately, as well as those which assess wellbeing at an experiential level, provide additional insights into how individuals' lives are going, over and above what life satisfaction reports can tell us (Dolan, Kudrna, and Stone 2016; Stone and Mackie 2013). We also lack evidence of the pathways through which air quality affects SWB of all kinds. To date, very little SWB work has considered the production process that converts environmental quality into SWB and even less has tested potential pathways empirically (MacKerron and Mourato 2013; Smyth, Mishra, and Qian 2008). As a result, we have an incomplete picture of how air pollution relates to SWB, and for those relationships, for which we have evidence, we have only a limited understanding of why.

Part 1 of this thesis addresses these issues by adopting a multidimensional approach to modelling the relationship between air pollution and SWB (Paper 1& 2) and investigating whether visiting the outdoors and engaging in physical activity mediate the link between air quality and how people report feeling (Paper 2). The papers use GIS mapping techniques, which are common in hedonic pricing methods in environmental economics(Bateman, Lovett, and Brainard 2003), to link local levels of air pollution to a range of subjective wellbeing and behavioural measures from UK-based surveys. The findings of the research are presented in Table 8.1 below.

The papers contained in Part 1 of the thesis represent a number of important contributions. First, the papers present some of the first evidence of relationships between air pollution and measures of SWB other than life satisfaction. No existing work has compared and contrasted how SWB relates to air quality across such a wide range of SWB measures which capture both hedonic and eudemonic wellbeing. Relatedly, the exploration of the relationship between the two behaviours of interest in Paper 2 – visiting the outdoor and physical activity – and such a wide range of SWB measures is also novel. Second, in relation to Paper 1, the estimates presented of the relationship between air pollution and SWB are nationally representative and provide the first- ever picture of how the SWB of people across the UK is related to local levels of air pollution. Third, Paper 2 also includes the first use of mediation analysis to explore the behavioural pathways between air pollution and SWB. Although this approach is commonly used in epidemiological literature which explores the relationship between environmental quality and health, it has, until now, been altogether missing from the EQ-SWB research. Finally, Paper 2 presents the first evidence linking local background concentrations of air pollution to the frequency with which people visit the outdoors and echoes the findings of one other study based on a US sample which finds evidence of a negative link between air pollution and physical activity. Together Papers 1 and 2 present significant contributions to our understanding of how living in a polluted environment relates to what we do, and to how we think about our lives and feel as we go about them.

Table 8.1: Summary of the main findings from the papers in Part 1

Paper 1- Bad Air Days: The relationship between air pollution and different measures of subjective wellbeing
• Local background concentrations of fine particulate matter are negatively associated with life satisfaction, how worthwhile individuals consider their activities to be and reports of happiness in the UK. • Local background concentrations of fine particulate matter are unrelated to reports of anxiety in the UK. • The relationship between SWB and fine particulate matter holds when the sample is restricted to people who have lived at their home for at least 6 months. • All three of the relationships between SWB and fine particulate matter decrease when self-reported health controls are included in the model specifications but remain significant.
Paper 2- Every breath you take, every move you make: Visits to the outdoors and physical activity help to explain the relationship between subjective wellbeing and air pollution
• Local background concentrations of fine particulate matter are negatively associated with life satisfaction and how worthwhile individuals consider their activities to be. • Local background concentrations of fine particulate matter are unrelated to reports of happiness and anxiety. • More frequent visits to the outdoors are positively associated with life satisfaction, how worthwhile an individual considers their activities to reports of happiness and anxiety. • Engaging in physical activity is significantly positively associated with how worthwhile individuals consider their activities to be when visits to the outdoors are not controlled for, but unrelated when they are. • Physical activity is unrelated to life satisfaction, happiness and anxiety yesterday. • Visits to the outdoors and physical activity are both negatively associated with local background concentrations of fine particulate matter. • Physical activity and visits to the outdoors totally mediate the relationship between local background concentrations of fine particulate matter and how worthwhile individuals' consider their activities to be. • Visits to the outdoors partially mediate the relationship between local background concentrations of fine particulate matter and life satisfaction.

8.12 Part 2: Investigating individual behaviours which can promote EQ

Human behaviour is central to the issues of environmental degradation that the Earth is currently facing (Oreskes 2004; Ceballos et al. 2015). With a view to contributing to the mitigation of these problems, researchers in the behavioural sciences are focused on enhancing our understanding of the psychological drivers of environmentally significant behaviour and developing effective interventions to encourage pro-environmental behaviour (PEB) (Clayton et al. 2015; Steg and Vlek 2009; Abrahamse et al. 2005; Bolderdijk et al. 2013). The current work seeks to contribute to these goals by exploring the wellbeing consequences of engaging in SWB (Paper 3) and testing behaviour change interventions targeting energy consumption (Paper 4).

While PEB clearly matters to the wellbeing of the planet, the consequences of PEB for the individual engaged in it are far less understood. The pursuit of human wellbeing in a material sense has led to the current levels environmental degradation (McGregor 2014). Pro-environmental behaviour often involves forgoing consumption for the good of others, and therefore, at least on the surface, appears to be at odds with individual wellbeing. It is widely acknowledged, however, that our welfare is not solely determined by our material consumption (Juster 1990). Convincing evidence in support of this idea has come from studies in both economics and psychology which uses SWB measures and demonstrates that pro-social actions including volunteering and charitable giving can yield psychological benefits (Meier and Stutzer 2008; Dunn, Aknin, and Norton 2008).

Importantly, if PEB can also enhance the psychological wellbeing of the individual engaged in it, then this could lessen or even eliminate the trade-off between environmental protection and individual wellbeing. Existing work based on life satisfaction data has found some evidence to suggest this is the case, but much like the air pollution research, it has not explored the relationship between PEB and wellbeing across all of the various dimensions of wellbeing (Verdugo 2012; Corral-Verdugo et al. 2011; Kaida and Kaida 2016; Binder and Blankenberg 2016). From a theoretical perspective, the distinction between hedonic and eudemonic wellbeing may be particularly important in this context. While it is not clear that all PEBs are experienced as pleasurable, based on their positive impact on others and the environment they may all seem worthwhile (Venhoeven, Steg, and Bolderdijk 2017).

Like our understanding of the psychological consequences of engaging in PEB, we have limited knowledge of whether and how behaviour change interventions can deliver real environmental benefits. This is in part because many studies in environmental psychology which evaluate interventions focus on psychological measures of PEB, including individuals' self-reported PEB and their pro-environmental intentions (Gardner and Stern 2008). The assumption underlying this approach is that these psychological measures of PEB reflect individuals' engagement in real impactful pro-environmental actions. This is not necessarily the case. Firstly, self-reported PEB may not reflect real engagement, for example, people may overreport PEB due to social desirability bias (Gatersleben, Steg, and Vlek 2002; Kormos and Gifford 2014). Secondly, the PEBs that individuals report engaging in may not have a substantial environmental impact (Gardner and Stern 2008; Huddart Kennedy, Krahn, and Krogman 2015). Finally, in reference to measures of PEB intention, there is often a gap between what people say they will do and what they actually end up doing (Gollwitzer and Sheeran 2006).

Part 2 of this thesis addresses these gaps by exploring the relationship between engagement in PEB and a range of SWB measures which reflect both eudemonic and hedonic wellbeing (Paper 3), and testing the effect of two behaviour change interventions based on a technique from social psychology on electricity consumption (Paper 4). Paper 3 presents analysis of secondary data and Paper 4 reports two natural field experiments from a hall of residence in London. The main findings of the research are presented in Table 8.2 below.

The findings of the research are presented in Table 8.2 below. Paper 3 adopts a novel multidimensional approach to modelling the relationship between SWB and PEB, providing the first empirical evidence in support of the theorised differences across hedonic and eudemonic wellbeing (Venhoeven, Bolderdijk, and Steg 2013). Second, Paper 3 presents the first SWB-PEB investigation which explores general tendencies to engage in PEB using multivariate analysis on a range of PEB measures which are specifically linked environmental benefits. Thirdly, this approach also allows for the first exploration of whether the relationship between SWB and PEB varies across distinct clusters of PEB and a discussion of the potential explanations for the differences based on similar characteristics within those clusters. Fourthly, Paper 4 provides the first causal estimates of electricity, monetary and CO_2 savings from an

implementation-intention intervention in a residential setting. Fifth, it demonstrates that adding situational cues to energy savings tips does not achieve greater electricity savings. Overall Part 2 of the thesis contributes to our understanding of PEB, and informs strategies to encourage it.

Table 8.2: Summary of the main findings from the papers in Part 2

Paper 3- Green without anxiety: The relationship between pro-environmental behaviour and different measures of subjective wellbeing
• More than half of the variation in self-reported engagement across five different PEBs can be explained by two components – the first of which represents a general measure of PEB and the second which reflects engagement in more compared to less common behaviours. • General engagement in PEB is found to be significantly positively related to life satisfaction and how worthwhile an individual considers their activities to be. • General engagement in PEB is found to be unrelated to reports of happiness and anxiety yesterday. • Engaging in relatively more common compared PEBs is significantly positively related to life satisfaction, how worthwhile individuals consider their activities to be and their reports of their happiness, as well as being negatively related to how anxious they reported feeling on the previous day. • Concern for the environment is not associated with life satisfaction, or individuals' reports of their happiness or anxiety. • Concern for the environment is significantly positively associated with how worthwhile individuals consider their activities to be when PEB is not controlled for, but unrelated when it is. • The relationship between life satisfaction, happiness, anxiety and PEB is independent of whether the individual expressed concern over damage to the natural environment. • The relationship between PEB and how worthwhile individuals consider their activities to be is stronger for those who do not express concern for over damage to the natural environment.
Paper 4- Converting good intentions into positive environmental impact
• Encouraging individuals to form implementation intentions across three impactful electricity savings behaviours yielded electricity savings of approximately 21% over a four-week period, compared to providing tips alone. • These savings represent substantial reductions in CO_2 emissions and cost savings. • Encouraging the formation of implementation intentions was not significantly more effective at influencing the behaviour of those who expressed concern for the natural environment relative to those that did not. • Providing electricity saving tips with situational cues was no more effective at achieving electricity savings compared to providing standard tips.

8.13 Collective contributions

While each of Papers 1-3 papers make specific contributions to the environmental SWB literature, they also make a collective contribution. The findings of all three papers stress the importance of exploring the determinants of wellbeing using a multidimensional approach to modelling SWB. As previously discussed (see Section 2), this approach is reflected to some extent in existing research which has explored how individual characteristics are related to SWB. However, the multidimensional approach is far from universal and the work that does use a range of measures rarely contains SWB measures which assess SWB both at different levels and of different types (Dolan and Kudrna 2016; Dolan, Kudrna, and Stone 2016). Across all three papers, the relationships explored between SWB, air pollution, visiting the outdoors and physical activity depend on the measure in question. The results highlight the incomplete picture provided by research that focuses on life satisfaction as the sole indicator of SWB, and the importance of including measures of both positive and negative measures of hedonic wellbeing.

Carrying out similar analysis across the two papers in Part 1 of the thesis demonstrates the advantages of including the same SWB measures across different surveys. Paper 2 repeats the analysis of the relationship between local air pollution and the ONS four that was presented in Paper 1, finding that three of the four relationships documented hold. The relationships between life satisfaction, how worthwhile individuals consider their activities to be, and anxiety yesterday are all equivalent across Papers 1 and 2. Interestingly, the results differ in relation to happiness yesterday. Paper 1 finds evidence of a relationship between local air pollution levels and happiness yesterday, whereas Paper 2 does not. The difference in this result may be due to sampling issues or the different compositions of the respective populations. The APS result was based on a much larger sample of individuals and was weighted so that it represented the whole population of the UK in a single year. In contrast, the MENE result is based on a subsample of respondents in a national survey in England, over the course of four consecutive years. Future research should explore the relationship between happiness and air pollution in other populations to build up a body of evidence around this potential link. Exploring the determinants of wellbeing in different samples will ultimately provide a much better

evidence base for the relationships of interest in this and other work. The availability of responses to the ONS four from many different sample populations will greatly facilitates this exploration.

The results of Papers 1-3 also point out that there is much to be gained in terms of our understanding of the good life by going beyond thinking about how individuals' characteristics relate to how they feel and exploring a wider range of determinants. The current work demonstrates that where people live and how they spend their time matter to their wellbeing. Paper 2 also highlights that the former may influence the latter in a production process that leads to wellbeing. While it has been proposed that time use is more closely associated with experiential wellbeing than evaluative wellbeing (Kahneman 2004), overall life satisfaction is found to be related to the behaviours explored in Papers 2 and 3, suggesting that the activities people engage in are important predictors of how they fare in life and can influence their wellbeing beyond the momentary experience. While this may seem intuitive, there is surprisingly limited empirical evidence on the relationship between SWB and time-use. The results of the current work serve as a reminder to SWB researchers and policymakers to go beyond thinking about socio-demographics when looking to understand individual wellbeing.

Finally, across all three papers, it is interesting to note that air pollution, visits to the outdoors, and physical activity are more closely related to the three positive measures of SWB than they are to individuals' anxiety on the previous day. This same pattern also appears when considering the variance explained by the models as a whole and in other work that has explored the determinants of the ONS four (Deeming, 2013). The r-squared statistics for the models including the socio-demographic and local area controls were by far the smallest across the four different SWB models in all three papers. This marked difference suggests that the standard determinants and the environment related variables included in the current work do a better job of predicting who is doing well, in terms of life satisfaction, worthwhile activities and happiness, than they do of predicting who is doing badly in society, as defined by feeling anxious. This finding also highlights the need to go beyond the standard determinants and the ones explored in the current work when trying to identify the causes of misery.

Beyond the links between Papers 1-3, there are also some significant insights to be drawn from the papers that consider PEB (Papers 3-4). The results of both papers suggest alternative strategies to price and consumption feedback which may be effective at encouraging PEB. Although such strategies represent the most commonly explored intervention types in the literature on energy consumption (Wang et al. 2009), alternatives are necessary as PEB involves a range of behaviour many of which do not involve money, and feedback on individuals PEB engagement is not always possible. Paper 3 presents evidence linking PEB to eudemonic wellbeing, highlighting feelings of meaning as a potential basis for PEB intervention strategies. Study 1 in Paper 4 presents an example of an intervention strategy which successfully delivered medium-term changes in environmentally significant behaviour without using price or consumption feedback.

Additionally, Paper 4 discusses the need for techniques which can enhance the effectiveness of PEB tips. While the results of Study 2 in Paper 4 find that adding situational cues to tips about electricity saving behaviours does not achieve this goal, the results of Paper 3 highlight other types of information that could be added to tips with a view to making them more effective. This information might include prompts about the eudemonic wellbeing the individual themselves or other individuals derive from engaging in PEB (Aknin et al. 2013). Other related strategies could provide information which directly targets individuals perceptions of the worthwhileness of PEB, for example, by providing feedback in relation to the environmental impact of the recommended actions (Aknin, Dunn, and Norton 2012). Importantly, Paper 4 demonstrates the advantages to testing any equivalent strategies in relation to PEB using experimental methods in a field setting.

By drawing on approaches from economics, psychology and epidemiology, and combining a range of methods and data sources, the four empirical papers presented in this work considerably enhance our understanding of the reciprocal relationship between human wellbeing, behaviour and the natural environment. More general lessons are also drawn from the collective work which contribute to both subjective wellbeing and behaviour change research.

8.2 Main limitations and future research

A number of limitations apply to the research presented in this thesis, providing avenues for future research. First, issues around causality and adaptation are relevant to Papers 1-3. Second, all four papers would benefit from the inclusion of more and better measures. Finally, the psychological mechanism behind the successful intervention Study 1 of Paper 4 and the generalisability of the findings are unclear.

8.21 Issues of causality (Papers 1-3)

The data used in the first three studies were chosen on the basis that they provided a detailed picture of the left-hand side variable of interest – SWB. To the author's knowledge, no other UK data sources exists which assesses SWB across such as wide range of dimensions, both in terms of different levels and different types (see Section 2 for further discussion). However, notwithstanding the appeal of the data from the perspective of exploring different dimensions of wellbeing, they are limited in other ways. The cross-sectional nature of both the APS and the MENE surveys means the results from the first three papers represent partial associations between the determinants of interest (air pollution and nature-based activities) and the outcomes (nature-based activities and SWB). Whether these relationships represent the theorised causal relationships is unknown and unknowable from the data. Reverse causality and omitted variable bias may affect the estimates presented (Dolan, Peasgood, and White 2008). Reverse causality is a potential issue in Paper 2, for example, because being more satisfied may cause people to engage in more nature-based activities and PEB. Omitted variable bias could affect the results in Paper 3, for example, if a third factor such as optimism causes people to engage in PEB, but also report higher levels of SWB. Both of these issues are relevant to all three papers and, due to the cross-sectional nature of the data, cannot be ruled out.

Although care is taken to control for the observed individual (Papers 1-3) and local area characteristics (Papers 1 & 2), the analysis cannot control for unobserved individual characteristics such as personality or identify the direction of causality. The use of panel data would lessen concerns about omitted variable bias and could address problems of reverse causality by looking at changes in the determinants over time.

Better yet, random or quasi-random allocation, which could be achieved using experimental or quasi-experimental methods, would address both of these issues. As discussed in the data and methods section these data are not available. Future research should move beyond cross-sectional work, if and when appropriate panel data becomes available. It should also look to identify natural experiments or appropriate instruments, such as the installation of scrubbers and prevailing wind patterns as used by Luechinger (2009), and carry out field experiments in order to better get at the causal relationships between both elements of environmental quality, individual behaviour and SWB.

8.21 Issues of adaptation (Papers 1-3)

Another key issue related to the cross-sectional nature of the data, and one that is also a challenge to SWB research more generally, is the issue of adaptation. Although the extent to which individuals adapt to both positive and negative life circumstances is a major focus of SWB research (see Luhmann et al. (2012) for a meta-analysis), the existing literature has provided almost no insight into whether individuals adapt to the circumstances and behaviours explored in the current work.Whether or not we adapt to or become sensitised to elements of environmental quality, for example, over time is unclear. While existing work has speculated about habituation effects in relation to air quality (MacKerron and Mourato 2009; Levinson 2012), only one paper to date has explored whether people habituate to air pollution using SWB data. This study was carried out by Menz (2011) who explored the relationship between PM_{10} and life satisfaction at a macro level and over time. He finds that past levels of particulate matter significantly reduce current levels of life satisfaction, suggesting that people do not habituate to air pollution. Future research could speak to this question at a micro level by tracking people's SWB in response to shocks in air pollution over time. If individuals do adapt completely to background concentrations of air pollution and other elements of environmental quality, the usefulness of SWB as an indicator could be challenged. Just because an individual can become accustomed to living in very poor environmental conditions does not mean the issue should not receive policy attention (Stone and Mackie 2013). As a first order question, however, we need to know if they do.

Another substantive gap in the SWB literature is our understanding of the extent to which individuals adapt to the activities they engage in. Existing research has almost exclusively focused on life circumstances. This gap may be the result of the challenges in identifying how the wellbeing that individuals derive from engaging in behaviours changes over time. While longitudinal work can provide good evidence of individuals' adaptation to life circumstances, its ability to speak to their adaptation to activities is more limited. Individuals for whom the wellbeing benefits of spending time in nature, for example, decrease over time may be likely to simply opt out of engaging in such activities. If this is the case, then surveys which follow people over time will only capture individuals who continue their engagement and who are likely to have systematically different adaptation patterns. In a rare example of a study which explores the relationship between volunteering and life satisfaction over time Binder and Freytag (2013) find that the life satisfaction benefits of volunteering for those that continue to do so increase over time, but as highlighted above this work cannot speak to the adaptation profiles of those that stop. Another possible approach would be to carry out experimental work and mandate participants in a treatment group to engage in these activities and track their SWB post-treatment over time. This approach would also be problematic, however, because it would lack external validity; it would not reflect the wellbeing effects over time of individuals voluntarily choosing to engage in these activities in their day to day life.

Investigating adaptation in the context of the EQ-SWB relationship, and adaptation to behaviours is not straightforward based on the data requirements and the above-mentioned limitations. The problem is further complicated by the possibility that adaptation to environmental quality, nature-based activities and PEB may all vary across different dimensions of wellbeing. Venhoeven, Steg, and Bolderdijk (2017), for example, have suggested that the level of pleasure an individual gets from a pro-social activity may be subject to greater adaptation than is the purpose they derive from it. While the authors do not provide empirical support for this claim, they raise an important question about whether the SWB adaption individuals experience in relation to these conditions and activities of interest depends on the measure of SWB used. These questions are of great importance and should be a central focus in future work which looks to understand the relationships between individuals and the environment.

8.3 More and better measures (Papers 1-4)

Questions can also be asked about the quality and range of measures used in all four papers. Papers 1-3 make use of proxy experiential measures, for example. These measures are based on questions that refer to yesterday, rather than assessing SWB in the moment, rendering them measures of remembered utility and opening them up to related biases including the peak-end effect and duration neglect (Kahneman et al. 2004). Future research should explore the possibility of using experience sampling or daily reconstruction methods to get at more direct measures of experiential wellbeing. Such measures would be particularly useful in linking how people feel to the behaviour they are engaging in, while also providing insight into the duration of those activities. These approaches would also facilitate the measurement of a wider range of emotions than the two explored in the current work, and therefore could be particularly valuable when considering negative experiential wellbeing (Stone and Mackie 2013). With technological advances, the use of these measures to understand the behaviour and wellbeing of large samples are becoming ever more feasible (MacKerron and Mourato 2013), so this is a promising avenue for future work.

In addition, the second and third paper make use of self-reported behavioural measures of both nature-based activities (Paper 2) and PEBs (Paper 3). The measures included capture a subset of these types of behaviours and the research would benefit from including a more comprehensive range of both types, including, for example, a measure of the time people spend in their garden and engaging in environmental citizenship behaviours such as signing petitions and protesting. Additionally, the validity of self-reported behavioural measures is a topic of debate within the literature. Over-reporting is thought to be a concern when the behaviours are considered socially desirable, such as in the case of PEBs (Kormos and Gifford 2014). Future research should look to incorporate more objective measures of both kinds of behaviours where possible. Technologies such as smartphone-based pedometers and GPS trackers have the potential to provide detailed objective information on individuals' nature-based activities. The collection of objective measures of a wide range of individuals' pro-environmental behaviours presents a greater challenge, but as was the case with experiential SWB, methods which specifically focus on capturing individuals' activity profiles could improve the validity of these measures.

Lastly, Paper 4 would benefit from the inclusion of both behaviour and SWB measures. In the absence of behavioural measures, it is not clear which of the targeted behaviours or other electricity saving behaviours are driving the results in Study 1. Future research should look to include behavioural measures alongside consumption outcomes if possible in order to understand what actions the intervention is successful at influencing (Steg and Vlek 2009). Beyond that it would be remiss, in the context of the current PhD, not to highlight the fact that Paper 4 does not consider the wellbeing consequences of the interventions for the participants. This is commonly the case in the behavioural science literature relating to PEBs, with a recent study by Gosnell, List, and Metcalfe (2016) representing an exception. Without considering this outcome, the paper cannot account for some of the important potential benefits or costs of the interventions. The correlational results from Paper 3 suggest that the students may have gained eudemonic wellbeing benefits from engaging in the behaviours in Study 1, but because it was not possible to follow up with the students and track their SWB, it is not possible to discern if this was the case. Future experimental work looking to encourage pro-social behaviours should weigh up the benefits of augmenting evaluations with surveys which include SWB measures against the downsides of the participants being aware of the research taking place. Alternative sources such as resident satisfaction data, if available, could also be considered as proxies for SWB measures. Collecting SWB data would bring together the mixed methods used in the current thesis, both survey data and field experiments, and provide robust causal evidence in relation to the encouragement of PEB and the wellbeing consequences of doing so.

8.3 Under what circumstances and why? (Paper 4)

The natural field experiments presented in Paper 4 provide causal evidence for the relationships of interest, in this case, the impact of two interventions in delivering electricity savings. The generalisability of the results to populations other than students living in halls of residence is unclear, however. The intervention may be more effective in this context than it would be elsewhere. As other research carried out in halls of residence has found equivalent effect-sizes and that the magnitude of the impact of these interventions are higher than those generally documented in household

energy intervention, this is likely to be the case (Alberts et al. 2016; Abrahamse et al. 2005). One explanation for why student's energy consumption behaviour appears to be particularly subject to influence from interventions is that University represents a moment of change in the people's lives and their behaviour is, therefore, likely to be more malleable (Bamberg 2006). Additionally, the study does not shed light on the psychological mechanisms giving rise to the effect of implementation intentions on electricity consumption. This understanding is necessary if the intervention is to be effectively stripped back. Future research should look to carry out multi-armed field experiments across different populations in order to not only answer questions about whether the interventions work but also to understand in what populations they do and why (Schultz 2014).

8.3 Policy implications

The work is all based on the UK and ranges in its application from national to local level. The policy implications of this work, however, extend beyond the borders of the UK. Some come directly from the findings while some others come from placing those findings in the context of policy discussions around the related issues more broadly.

8.31 Part 1

Air pollution, which is the focus of Part 1 of this thesis, is a major policy issue in both the UK in many countries around the world (DEFRA 2016; World Health Organisation 2016). Papers 1 and 2 present a range of policy insights with regards to this issue, with a focus on fine particulate matter. Valuation approaches in the UK and elsewhere often focus on the health costs associated with air pollution, with some also including the impact on building and materials (WHO 2015; DEFRA 2011; US Environmental Protection Agency 2017, 2011). Both papers in the current work, provide evidence of a negative relationship between air pollution and SWB, over and above its effect through health. This suggests that calculating the wellbeing costs to society of air pollution based on health effects alone underestimates its deleterious effect. That the papers present evidence linking local levels of air pollution to how individuals feel challenges policymakers to adopt a more comprehensive approach to considering the negative impacts of air pollution. This would likely increases the policy priority afforded to issues around air quality.

Paper 2 makes further contributions to this policy area. It finds that both visits to the outdoors and physical activity help to explain the relationship between air pollution and SWB. This expands the policy options available to a policymaker when they when looking to combat the negative effects of this environmental bad; it may be more efficient to target these behaviours directly, for example, with a view to enhancing wellbeing rather than focusing on improving air quality alone. Importantly, however, the long-term benefits must be taken into account when weighing up these two approaches and the potential for them to act as complementary policies, rather than as substitutes should be considered. The findings also provide insights into the conditions under which improved air quality will deliver enhanced wellbeing;

policymakers should be aware that the eudemonic benefits of improvements in air quality may be restricted to those who can visits the outdoors and engage in physical activity and may wish to compensate those who cannot. Finally, the evidence that air pollution not only appears to influence people's wellbeing but also the activities they engage in may instigate more support for policies to tackle air problems. When compared to SWB, both lower levels of physical activity and less frequent visits to the outdoors may represent more tangible effects of air pollution which could motivate citizens to advocate for policies to improve air quality.

8.32 Part 2

The encouragement of pro-environmental behaviour, which is the main focus of Part 2 of the thesis, is also a major policy concern in the UK and many other developed nations (Lucas et al. 2008; European Commision 2012; Nielsen et al. 2017; OECD 2011, 2017; Behavioural Insights Team 2011). Both Papers 3 and 4 contribute important policy insights towards this goal. Paper 3 documents evidence which suggests that engaging in PEB can promote eudemonic wellbeing and life satisfaction, but that it is unrelated to individual experiences of positive and negative hedonic wellbeing. This contributes to policymakers understanding of the benefits of PEB. While PEB is often represented as a sacrifice, the results of this research suggest that policies which encourage PEB may simultaneously improve both the wellbeing of the targeted populations and reduce environmental impact. These findings also highlight the potential of PEB promotion strategies focused on enhancing and making salient the feelings of worthwhileness associated with PEB (Aknin et al. 2013; Aknin, Dunn, and Norton 2012), as well as those relating to other motivations related to eudemonic wellbeing including individuals desire for competence and to be needed (Kaplan 2000; Schultz and Zelezny 2003).

Paper 4, identifies a behavioural intervention which can achieve real energy savings in a residential context and, importantly, does not rely on price mechanism or consumption feedback. The findings of the current work, alongside existing literature, suggest that eliciting implementation intentions around impactful electricity saving behaviours is a very promising behaviour change strategy which could be employed at relatively low cost and yield significant environmental benefits (Bell et al. 2016;

Loy et al. 2016; Holland, Aarts, and Langendam 2006). The intervention was tested in the context of student halls of residents and is, therefore, most directly of relevance to that context. With this in mind, the results of Study 1 were shared with the LSE Sustainability Team and the private halls company which hosted the trials. The results of the intervention are also potentially relevant to many other public institutions in which individuals do not have financial incentives to save on electricity, such as offices and army bases (McMakin, Malone, and Lundgren 2002; OECD 2011).

8.33 More general policy insights

This work also provides more general insights for policymakers in two key areas: the first relates to the use of SWB in policy and the second to partnerships between government, non-governmental organisations, private companies and researchers in order to carry out large-scale field experiments.

SWB wellbeing is gaining traction in policy circles around the world (OECD Better Life Initiative 2013; Stiglitz, Sen, and Fitoussi 2009; O'Donnell and Oswald 2015; O'Donnell et al. 2014) In the UK, for example, the government is currently using SWB measures to track SWB levels over time and explore the determinants of wellbeing (Evans, Macrory, and Randall 2015). Policymakers are paying attention, both out of interest in enhancing individual subjective wellbeing, but also due to a growing body of evidence linking SWB to other important policy outcomes including health productivity and longevity. People with higher SWB have higher levels of immunity and recover more quickly when exposed to a cold virus (Cohen et al. 2003). They also perform better at work (Cropanzano and Wright 2001) and have longer life expectancy (Diener and Chan 2011). Despite the increasing interest in SWB, however, a number of substantive barriers exist to widespread adoption of SWB into policy.

One of the key challenges to incorporating SWB into policy is the lack of agreement on a single measure which can be used to monitor national SWB, inform the design of public policy and appraise policy interventions (O'Donnell et al. 2014). This thesis contributes to this discussion and emphasises the importance of considering a range of measures. In particular, the differences across the measures raise the question: what type of wellbeing should policymakers normatively care

about? If policymakers wish to focus on reducing misery rather than increasing happiness, for example, then the findings of the current work suggest that reducing air pollution and encouraging physical activity, for example, may not be a policy priority. Moreover, these results highlight that needs for policymakers to be aware policies may involve trade-offs across different dimensions of wellbeing.

A related question is whether policymakers should aim to help people to achieve a balance between hedonic and eudemonic wellbeing. According to the Pleasure-Purpose Principle put forward by Dolan (2014), good lives are those which strike an optimal balance between the hedonic and eudemonic feelings over time. The findings in the current work suggest that PEB enhances eudemonic, but not hedonic wellbeing, Within the PPP framework the encouragement of PEB might have different wellbeing impacts on individuals depending on the extent to which they currently have the optimal balance of pleasure and purpose or if they lack in one or the other. This idea emphasises the benefits to policymakers of knowing something about target individuals' current SWB profiles, in order to know the extent to which encouraging them to engage in PEB will enhance their overall wellbeing. PEB interventions could be directly targeted at individuals who have recently retired, for example, with a view to replacing the eudemonic wellbeing they previously derived from paid work (Son and Wilson 2012). These issues come back to a challenge to the SWB account raised in Section 2 about whether some forms of wellbeing are better than others. If policymakers take the view that both are important, at least to some extent, then issues of balance will be important to consider.

Lastly, in relation to Paper 4, these studies, and other work based on natural experiments (Allcott and Mullainathan 2010), demonstrate the benefits of carrying out proper evaluations to obtain causal evidence of what works when it comes to encouraging PEB. Finding a partner to test the interventions presented in Paper 4, however, was a challenge. Despite exploring the possibility of working with a number of local authorities and government bodies, in the end it was necessary to collaborate with a private company in order to carry out the trials. In 2012 Haynes, Goldacre, and Torgerson (2012) published a report entitled 'Test, Learn, Adapt' on behalf of the UK Cabinet Office in which they explore the use of randomised controlled trials to test the effectiveness of public policy interventions in the UK. While they acknowledge that UK's Behavioural Insights Team has been successful in incorporating such trials in

their work across UK government, including in relation to energy use (Behavioural Insights Team 2011), they suggest that their use outside the work of the Behavioural Insights Team is not routine, and advocate for their extensive use in domestic public policy to test the effectiveness of new and existing interventions.

Over the course of the design and arrangement of the studies in Paper 4, it became clear was that there are still many government bodies, especially those relating to local government, for whom these methodologies are new or which do not have the capacity to oversee or the necessary date collection systems in place. Private institutions appeared to be better equipped to partner with on this type of project and more motivated to do so with a view to achieving money savings. One policy lesson which can be drawn from this is the need for information to be provided at the local authority level about the benefits of such trials. Furthermore, training should be made available for those who are interested in partnering with researchers or carrying them out themselves. This would likely make carrying out research studies, such as those presented in Paper 4, easier. Doing so would produce good quality evidence of what works and why when it comes to addressing many important policy issues, including those relating to the environment.

8.4 Concluding remarks

This thesis presents new evidence of connections between human behaviour, wellbeing and the natural world. While the first two papers emphasise the importance of environmental quality for what individuals do and how they feel, the second part of the thesis focuses on what to do about the worsening state of the environment and explores the wellbeing consequences of taking such action. The overall picture from the combined work is of an interdependent relationship between human beings and their natural environment.

Given the environmental crisis that we find ourselves in, this interdependency is clearly a significant source of environmental degradation and individual wellbeing loss; our behaviour is currently damaging the environment at an alarming rate, and the poor condition of the environment is linked to worse wellbeing outcomes for us. At the same time, however, the evidence presented in this thesis suggests that engaging with nature and living in a better-quality environment could enhance individual wellbeing and that behaviour change interventions to promote PEB may lead to significant psychological and environmental benefits. These findings reflect the very same interdependency and provide motivation for taking action to protect the environment, as well as guidance on how to encourage individuals to do so.

In his exploration of human nature and PEB, Kaplan (2000) posits that human beings are neither entirely self-interested nor pure altruists. Instead, he suggests we are reasonable people, made up of a mix of motivations. Existing research from both economics and psychology supports this view of human nature, finding that messages which present environmental issues as being personally relevant and having positive solutions are more effective at encouraging action than those that highlight abstract negative consequences and emphasise sacrifice (Jacquet et al. 2013; Whitmarsh and O'Neill 2010; De Dominicis et al. 2014). In order to motivate reasonable people, Kaplan suggests, multiply desirable choices are necessary. The psychological and environmental co-benefits from living in and helping to create a better natural environment presented in the current work represent such choices. These positive links can be leveraged to benefit society, the planet and generations to come. While the epigraph to this thesis paints us as both conquerors and victims of the environment, this approach recasts us as stewards and beneficiaries instead.

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