

# Relationship of Weather and Maize Yields in Kenya

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## **Abstract**

This paper contributes to better understanding of effects of drought on food security in Kenya which should lead to improving of early warning systems and food security.

**Keywords:** Climate change, climate knowledge, climate policy, lasso, risk perception, willingness to pay

# 1 Introduction and literature research

Findings:

- OND last year dry spell, max rain very important for Maize, but cumulative precipitation for the same period not so important
- Mar-Sept last year temperature very important for maize yields
- SD temperature last year positive and significant
- dry spell 20 MAM last year important (but not dry spell MAM10)
- interesting. Precipitation 2 months MAM last year very significant and positive
- mean temp last year negative and significant, hill shaped

New findings:

- The yields seem to be more responsive to weather on west than on east

Consequences of drought and extreme heat waves on agriculture have been well documented (Deschenes and Greenstone, 2007; Bello and Maman, 2015; Lesk et al., 2016; Mehrabi and Ramankutty, 2017; Schwalm et al., 2017). [I can go into details about these studies if not long enough.](#) Agricultural drought and soil moisture are important factors for plant health but also for land-atmospheric feedback and temperature variability (Nicolai-Shaw et al., 2017).

Frequent occurrence of severe drought has been a major problem in Kenya as well as in other Sub-Saharan countries (Gitu and Nzuma, 2003; D'Alessandro et al., 2015; Nicholson, 2017). Besides compromising food security, drought usually leads to severe damage in water supply, electricity and the environment. In 2010-2011, the most devastating drought in decades resulted in food crisis in many East African countries including Kenya (Chen and Georgakakos, 2015). Widespread catastrophic droughts occurred also in 1984-1985, 2005 and 2008 (Hastenrath et al., 2007, 2010, 2011; Chen and Georgakakos, 2015). As a consequence of climate change, the situation is likely to get worse since dry areas have strong tendency to get drier while wet areas are getting wetter (Trenberth et al., 2014; Chen and Georgakakos, 2015; Kabubo-Mariara and Kabara, 2015). Strong downwards trend in precipitation has been observed in the tropics from 10°N to 10°S, especially after 1977 (Trenberth et al., 2007). During the period 1900 – 2005, the climate has become wetter in many parts of the world (eastern parts of America, northern Europe, northern and central Asia) but it has become much drier in Mediterranean, Sahel, southern Africa and parts of Southern Asia. Furthermore, increased frequency of heavy rain events has been observed also in the areas with decline in total rainfall (Trenberth et al., 2007).

Large literature has focused on relationship of agricultural production and climate in Sub-Saharan Africa. A frequent finding is that increase in temperature affects crop revenue negatively while increase in precipitation has positive effects. Bello and Maman (2015) and

Ochieng et al. (2016) found these results by the means of Ricardian analysis. Ochieng et al. (2016) focused on Kenya while Bello and Maman (2015) address the situation on Niger. D'Alessandro et al. (2015) [identify and assess risks to agriculture in Kenya](#).

Other studies investigate the relationship of climate and yields in the context of climate change. Kabubo-Mariara and Karanja (2007) argue that in Kenya, higher summer temperatures are harmful while higher winter temperatures are beneficial. Furthermore, fall and summer precipitation is positively correlated with net revenue. Kurukulasuriya et al. (2008) and Seo et al. (2008) investigate the distribution of climate change impacts on agriculture in Africa. They argue that mild scenario would result in income gains for African farmers while more severe scenario is likely to be harmful. Mendelsohn (2008) reviewed several papers on effects of climate change on agriculture in developing countries and confirms that tropical and sub-tropical counties are much more sensitive to climate change than temperate agriculture. Another meta-study of climate change impacts of crop productivity in Africa in South Asia was conducted by Knox et al. (2012) who conclude that the projected mean change in yield is -8% by the 2050s in both regions.

[Then maybe something about agriculture in Kenya. for example:](#)

Kabubo-Mariara and Kabara (2015) [have a look at this study](#). [Looks like very much similar to what I want to estimate. Kenya, panel, fixed and random effects...](#)

D'Alessandro et al. (2015)

Lesk et al. (2016): Global, but estimate of national cereal production losses from extreme weather disasters

Previous studies focused on responses to drought related disasters or emergency situations include Sandstrom and Juhola (2017), who questioned whether drought is actually a major cause of food insecurity in Ethiopia, Kenya and Somalia. They analysed causes of the

food crisis identified in the humanitarian appeal documents. Majority of these documents consider food availability and food production as a major cause of food crisis. Sandstrom and Juhola (2017) argue that there is a tendency to explain failure of more complex food systems as 'droughts' and insufficient attention is paid to non-climatic drivers such as food prices or conflicts. Sandstrom and Juhola (2017) also find that a large share of humanitarian response budget is focused on emergency food aid in comparison to the share focused on interventions to build resilience. They suggest to increase the budget share focused on agricultural and livestock production to build resilience.

Shifting from reactive to proactive approach in disaster risk reduction has been promoted in recent literature (Mechler, 2005; Lavell et al., 2012; Nicholson, 2017). Forecast based financing has been recommended as it can avoid significant disaster losses (Nicholson, 2017). It has been shown that investment into disaster risk reduction had usually been outweighed by avoided losses (Mechler, 2005). Risk assessment is essential for disaster risk reduction (Lavell et al., 2012). Therefore, the main purpose of this paper is to develop a model for assessing the risk of drought based on weather data.

As a measure of food security we use agricultural maize yields and as measures of drought we use variables created by aggregating daily temperature and precipitation data.

A number of previous studies have focused on analysis of relationship of agricultural yield and measures of precipitation and temperature in Kenya or in other countries in Sub-Saharan Africa. Commonly used measures of precipitation and temperature include monthly averages (or monthly totals in case of precipitation) and their variances or standard deviations (Abraha and Savage 2006; Lobell et al. 2008; Thornton et al. 2009). Adejuwon (2004) analysed relationship of crop yields and three measures of precipitation. The measures of precipitation include: *(i)* Total rainfall during the first month of the period from sowing to harvesting (June) *(ii)* Total rainfall during the first two months

of the period from sowing to harvesting (June and July) and *(iii)* Total rainfall during the first three months of the period from sowing to harvesting (June, July and August). Based on his results, weather during June and July is the most important for crop yield in Sub-Saharan West Africa. Other studies utilised seasonal totals or means (Sagoe 2006; Lobell and Burke 2010 and others, find!!) or annual totals or means (Blignaut et al., 2009). Some authors have utilized simulated daily extremes, averages or daily measures of variance (Schulze et al. 1993; Chipanshi et al. 2003; Abraha and Savage 2006) or yearly extremes (Sagoe, 2006). Another measures which have been proposed for modelling the variability of maize yield are numbers of wet and dry days per a defined period, usually a month or a season (Ben Mohamed et al. 2002; Abraha and Savage 2006; Sagoe 2006; Giannakopoulos et al. 2009) or length of rainy season (Leemans and Solomon 1993; Ben Mohamed et al. 2002). The definition of wet and dry days and rainy season vary across the literature. For example, Ben Mohamed et al. (2002) has assumed that rainy season begins when the amount of rainfall in three consecutive days reach at least 25mm and no dry spell of more than seven days occurs in the following thirty days. According to this study, the end of the rainy season is defined as that rainy day after which rain recorded during 20 days is less than 5mm. Ben Mohamed et al. (2002) has also found sea surface temperature anomalies at various locations and amount of rainfall in July, August and September to be significant for millet crops in Niger. The author has also considered the maximum air temperature in the hottest month (April) and the minimum air temperature in the coldest month (January) as possible predictors of crops in Niger, but he did not find them significant.

An important group of studies that analyse relationship of yield and climate in Sub-Saharan Africa has utilised degree days (Schulze et al. 1993; Tingem et al. 2008; Walker and Schulze 2008; Tingem et al. 2009) or number of days with temperature above certain level or within defined range (Giannakopoulos et al. 2009; Laux et al. 2010).

(Thornton et al. 2009) also uses diurnal daily

Erin Lentz, can we cite her paper???

Blignaut: annual averages Chipanschi: daily maximum and minimum temperatures  
Giannoukopoulos: number of hw days and so... Laux et al.: daily Tmax  $\geq 30^{\circ}\text{C}$  Lobell  
et al. 2008: Monthly temp and prec. Lobell and Burke 2010: Temp. growing season  
average, precip;growing season total

(Abraha and Savage 2006; Adejuwon 2004; Ben Mohamed et al. 2002; Blignaut et al. 2009;  
Chipanshi et al. 2003; Giannakopoulos et al. 2009; Laux et al. 2010; Leemans and Solomon  
1993; Lobell et al. 2008; Lobell and Burke 2010; Sagoe 2006; Schulze et al. 1993; Thornton  
et al. 2009; Tingem et al. 2008, 2009; Walker and Schulze 2008)

Add more studies. Then separate somehow into groups of different topics.. It  
is worth mentioning at this place that large literature has investigated impacts of climate  
change on agriculture..worldwide or in Kenya??Mendelsohn, Dinar, Dalfelt 2000 and 2009  
and Seo, Mendelsohn, Dinar, Hassan, Kurukulasuriya 2008

## 2 Methodology

### 2.1 Measures of yield and climate

Prior we started our research, we had to answer the following questions: How do we  
measure food security? And how do we measure drought? To answer the first questions,  
the measure which has been used as a proxy for food security in the literature are as follows:

We were also considering to use food prices or export and import prices/retail prices,  
however, there were some problems...maybe some references to those who also considered

food prices??

The other important questions which need to be answered before starting our research are: How is drought defined? What are the ways of measuring drought? and How shall we measure drought for the purpose of our study? According to the international meteorological community, drought can be defined in several ways. In particular, drought is a '*prolonged absence or marked deficiency of precipitation*', a '*deficiency of precipitation that results in water shortage for some activity or for some group*' or a '*period of abnormally dry weather sufficiently prolonged for the lack of precipitation to cause a serious hydrological imbalance*' (Heim, 2002; Trenberth et al., 2007). American Meteorological Society (1997) has defined three types of droughts: (i) 'Agricultural drought' which is defined in terms of moisture deficits in upper layer of soil up to about one meter depth (ii) 'meteorological drought' which refers to prolonged deficit of precipitation and (iii) 'hydrological drought' which relates to low streamflow, lake and levels of groundwater. The American Meteorological Society (1997) policy statement was later replaced by another statement (American Meteorological Society, 2013) which besides the three types of drought above, covers also the 'socioeconomic drought' which associates the supply and demand of some economic good with elements of meteorological, agricultural and hydrological drought (Heim 2002; Trenberth et al. 2007).

Numerous definitions of drought and their role have been reviewed and discussed by Wilhite and Glantz (1985) and Wilhite (2000). They have distinguished two main categories of definitions of drought: (i) conceptual and (ii) operational. Conceptual definitions are dictionary types, usually defining boundaries of the concept of drought<sup>1</sup>. Operational

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<sup>1</sup>An example of conceptual definition of drought is an 'extended period - a season, a year, or several years of deficient rainfall relative to the statistical multi-year mean for a region' Schneider and Hare (1996).



definitions are essential for an effective early warning system. An example of operational definition of agricultural drought can be obtaining the rate of soil water depletion based on precipitation and evapotranspiration rates and expressing these relationships in terms of drought effects on plant behaviour (Wilhite, 2000).

In order to compare severity of drought across different time periods or geographical locations a numerical measure turns out to be necessary. However, as a result of a large disagreement about a definition of drought, there is no single universal drought index. Instead of that a number of measures of drought has been developed (Wilhite and Glantz, 1985; Wilhite, 2000; Heim, 2002).

For an extensive overview of various drought indices see Heim (2002), Monacelli et al. (2005), Zargar et al. (2011) or Svoboda et al. (2016). Keyantash and Dracup (2002) quantify, evaluate and compare number of drought indices for meteorological, hydrological and agricultural forms of drought. Based on several criteria they conclude that rainfall deciles and SPI perform the best for meteorological drought.

In the recent period, remote sensing data have been collected and used increasingly to monitor levels of greenness and closely related vegetation conditions (Nicolai-Shaw et al., 2017). Based on these data, various measures such as the vegetation condition index (VCI) have been developed and used for quantifying drought strength and severity (Klisch and Atzberger, 2016).

A description of other drought indices and measures can be found in Appendix 1.

We initially analysed SPEI and VCI indices and we tried to use them as input variables for our analysis. However, there were some serious problems with these measures.....

Therefore we opted for a different approach to gauging drought severity. In particular, we decided to utilize daily precipitation data from...CHIRPS?? with resolution... and daily

temperature data from..at resolution..... The frequency of the maize yield data is yearly while we have daily weather data available. Hence, the weather data need to be aggregated in order to obtain a dataset conformable with the yield data. There are many possibilities how to aggregate daily weather data. Based on the literature research in Section 1 and complexity of deriving the measures, we short-listed the following aggregates of the weather data:

maybe also describe the two rainy seasons and why we created the monthly variables? or maybe this in intro?

- **Precipitation:**

- Seasonal cumulative rainfall
- Seasonal standard deviation actually it is monthly at the moment. I am not sure how I would aggregate this over season??
- Seasonal coefficient of variation actually it is monthly at the moment. I am not sure how I would aggregate this over season??
- Maximum length of dry spell in number of days
- 

## 2.2 Data

## 2.3 Linear mixed models

Kenya consists of 47 counties with semi-autonomous county governments (Barasa et al., 2017). As a result of the high degree of county-level autonomy, the policies and regulations are likely to differ across the counties, hence the effects of weather on crop yield are likely

to be different across the counties. Therefore, following the standard methodology, we estimated a battery of linear mixed effects models (or linear mixed models) commonly used to analyse longitudinal data (Bates et al., 2000). These types of models include both fixed effects and random effects. Fixed effects are analogous to parameters in a classical linear regression model and value of each effect is assumed to be fixed over all counties (Bates, 2010). On the other hand, random effect are unobserved random variables. There are at least three benefits of treating a set of parameters as a random sample from some distribution. *(i)* Extrapolation of inference to a wider population *(ii)* improved accounting for system uncertainty and *(iii)* efficiency of estimation (Kery, 2010b,a).

Formally, a linear mixed model can be described by the distribution of two vectors of random variables: the response  $\mathcal{Y}$  and the vector of random effects  $\mathcal{B}$ . The distribution of  $\mathcal{B}$  is multivariate normal and the conditional distribution of  $\mathcal{Y}$  given  $\mathcal{B} = \mathbf{b}$  is multivariate normal of a form (Bates, 2010; Kery, 2010b):

$$(\mathcal{Y}|\mathcal{B} = \mathbf{b}) \sim N(\mathbf{X}\beta + \mathbf{Z}\mathbf{b}, \sigma^2\mathbf{I}), \quad (1)$$

where  $\mathbf{X}$  is an  $n \times p$  model matrix of fixed effects,  $\beta$  is a  $p$ -dimensional fixed-effects parameter,  $\mathbf{Z}$  is an  $n \times q$  model matrix for the  $q$ -dimensional vector of random-effects variable  $\mathcal{B}$  evaluated at  $\mathbf{b}$  and  $\sigma$  a scale factor. The distribution of  $\mathcal{B}$  can be written as:

$$\mathcal{B} \sim N(0, \mathbf{\Sigma}), \quad (2)$$

where  $\mathbf{\Sigma}$  is a  $q \times q$  positive semi-definite variance-covariance matrix

### 3 Results and discussion

Table 1: *Linear mixed effects models: Maize yield and weather*

Fixed effects:	Scaled		Unscaled <sup>a</sup>	
	<i>Estimate</i>	<i>p-value</i>	<i>Estimate</i>	<i>p-value</i>
Intercept	−0.059	0.646	1.379	$1 \times 10^{-7***}$
Prec. cum. MAM+OND lag 1, east	0.054	0.041*	$3 \times 10^{-4}$	0.177
Prec. cum. MAM lag 1, west	0.025	0.477	$3 \times 10^{-4}$	0.197
Temp. avg. Mar.-Sep. lag 1, east	−0.045	0.244	−0.029	0.001**
Temp. avg. Mar.-Sep. lag 1, west	−0.130	0.0001***	−0.027	0.001**
Prec. max OND, east	0.133	0.013*	0.004	0.085 <sup>•</sup>
Prec. max OND, west	0.144	0.004**	0.011	$9 \times 10^{-6***}$
Temp. sd. Oc.-Mar. lag 1, east	0.049	0.199	0.075	0.369
Temp. sd. Oc.-Mar. lag 1, west	0.225	$4 \times 10^{-12} ***$	0.494	$7 \times 10^{-12} ***$
<b>Random effects:</b>				
Intercept				
Prec. cum. MAM+OND lag 1				
Prec. max OND				
Temp. avg. Mar.-Sep. lag 1				

Notes: 584 observations; <sup>•</sup>  $p < 0.1$ ; \*  $p < 0.05$ ; \*\*  $p < 0.01$ ; \*\*\*  $p < 0.001$

<sup>a</sup> The variety with unscaled variables fails to converge.

**Table 2: *Mixed effects model: Log of maize yield and weather***

<b>Fixed effects:</b>	<i>Estimate</i>	<i>p-value</i>
Intercept	0.158	0.086 <sup>•</sup>
Prec. cum. MAM+OND lag 1, east	0.066	0.008**
Prec. cum. MAM lag 1, west	−0.006	0.861
Temp. avg. Mar.-Sep. lag 1, east	−0.036	0.292
Temp. avg. Mar.-Sep. lag 1, west	−0.081	0.008**
Prec. max OND, east	0.081	0.056 <sup>•</sup>
Prec. max OND, west	0.108	0.009**
Temp. sd. Oc.-Mar. lag 1, east	0.101	0.003**
Temp. sd. Oc.-Mar. lag 1, west	0.142	$6 \times 10^{-7}$ ***
<b>Random effects:</b>		
Intercept		
Prec. cum. MAM+OND lag 1		
Prec. max OND		
Temp. avg. Mar.-Sep. lag 1		

*Notes:* 584 observations

<sup>•</sup>  $p < 0.1$ ; \*  $p < 0.05$ ; \*\*  $p < 0.01$ ; \*\*\*  $p < 0.001$

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## Appendix 1 Drought indices and measures

Examples of early measures of drought are Wilhite and Glantz (1985), Munger (1916), Blumenstock (1942) or McQuigg (1954). Munger (1916) suggested to use length of period without 24-h precipitation of 1.27 mm. Wilhite and Glantz (1985) is based on a measure of precipitation over a given time period. Blumenstock (1942) proposed to measure severity of drought as a length of drought in days where the end of a drought is defined by occurrence of 2.54 mm of precipitation in 48 hours. McQuigg (1954) developed the Antecedent Precipitation Index (API) which is based on amount and timing of precipitation and it was used for forecasting of floods. Hence, the API is a reverse drought index.

The study of Palmer (1965) was a significant milestone in the history of quantification of drought severity. Palmer (1965) developed the Palmer Drought Severity Index (PDSI) using a complex water balance model. The PDSI is based on a hydrological accounting system, which incorporate antecedent precipitation, moisture supply and moisture demand (Heim, 2002; Palmer, 1965). As the PDSI suffers from several weaknesses (for details see e.g. Heim 2002), other indices were developed in the following decades. These include the standardized precipitation index (SPI) developed by McKee et al. (1993) and the standardized precipitation evapotranspiration index (SPEI) developed by Vicente-Serrano et al. (2010). The SPI specifies observed precipitation as a standardised departure from a chosen probability distribution which models the precipitation data. Values of SPI can be viewed as a multiple of standard deviations by which the observed amount of rainfall deviates from the long-term mean (John Keyantash and National Center for Atmospheric Research Staff (Eds.), 2016).<sup>2</sup> The SPEI is similar to SPI, but unlike SPI, the SPEI includes the role of evapotranspiration (which captures increased temperature). It is based on water balance, therefore it can be compared to the self-calibrated PDSI (Vicente-Serrano et al.,

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<sup>2</sup>Can be created for various periods of 1-36 months, usually using monthly data.

2010).

## Appendix 3 Tables

**Table A1:** *List of considered (but not selected) predictors in multisplit lasso*

Variable	Description
Religion	11 categories including atheist, no religion and prefer not to say
Race	8 categories including prefer not to answer
Length in UK	Question: <i>How long have you been living in the UK?</i> Response = 5 categories: All life ,more than 10 years, 5 – 10 years, 1 – 5 years, less than 1 year
Occupation	14 categories
Sector	18 categories
Operating system	7 categories
Social value orientation	Response = 4 categories: altruist, prosocial, individualist, competitive
Discount rate 0 vs. 5	Annual, %, invest now for five years from now
Discount rate 1 vs. 2	Annual, %, invest a year from now for two years from now
Discount rate 1 vs. 6	Annual, %, invest a year from now for six years from now
Degree of present bias	Continuous, preferences on time
Degree of hyperbolicity	Continuous, preferences on time
Annual discount rate	Continuous, preferences on time
Subsistence income (reserve)	Continuous, ???
Altruist	Dummy (0/1)
Prosocial	Dummy (0/1)
Individualist	Dummy (0/1)
Competitive	Dummy (0/1)
Egalitarian	Dummy (0/1)
Ineqaverse	Dummy (0/1)
Longitude	Longitude of survey response. Degrees
Latitude	Latitude of survey response. Degrees
Letter	First letter of surname, A=1,B=2,...
Siblings	Number of siblings
Older	Number of older siblings
Children	Number of children
Grandchildren	Number of grandchildren

*Note:* Variables in this table were not selected by multisplit lasso into any model.



**Table A2:** *List of considered (but not selected) predictors in multisplit lasso*

Variable	Description
Handedness	0=right, 1=left
Time	Time taken to complete survey, in minutes
Hour	Hour of survey, 24 categories
Day of week	7 categories
Day of the month	Day of survey, 1 – 31
Fair share	<i>Ordinary working people do not get their fair share of the nation's wealth.</i> Degree of agreement with the statement above, 5 categories
Hard work	Question: <i>How important is hard work for getting ahead in life?</i> Response = 5 categories, degree of agreement
Better off parents	Question: <i>Compared with your parents when they were about your age, are you better or worse in your income and standard of living generally?</i> Response = 5 categories (degree of agreement) and <i>Don't know</i>
Better off children	Q: <i>Compared with you, do you think that your children, when they reach your age, will be better or worse in their income and standard of living generally?</i> Answer = 5 categories (degree of agreement) and <i>Don't know</i>
Always up	Dummy (0/1), Children better off me and me better off parents
Always down	Dummy (0/1), Parents better off me and me better off children
Up then down	Dummy (0/1), Me better off parents and me better off children
Down then up	Dummy (0/1), Parents better off me and children better off me
Financial literacy	3 financial problems, no. of correct answers, ?
Understands portfolio	Dummy (0/1), 1 = understands
Incoherent dr.	Dummy (0/1), Incoherent answers between investments (0 = coherent)
Primed attitudes	1 = priming questions about time, risk, social were asked, 0 = not
Prime climate	0 = shown picture of polar bear on melting ice (negative), 1 = shown picture of people enjoying beach (positive)
Prime pension	0 = picture of troubled old man, 1 = picture of happy old man
Prime school	0 = picture of unruly kids, 1 = picture of well-behaved kids
Prime NHS	0 = picture NHS in crisis, 1 = picture love NHS
Female $\times$ handed	Interaction female and handedness
Female $\times$ children	Interaction female and number of children
Age $\times$ children	Interaction age and number of children

*Note:* Variables in this table were not selected by multisplit lasso into any model.

(continued)

**Table A3: *Descriptive statistics: Continuous variables***

<b>Variable:</b>	<b>Mean</b>	<b>St. dev.</b>	<b>Min</b>	<b>Max</b>
Income - predicted (£ per year)	27729	11719.89	3611	58326
Net assets - total assets minus total debts (£)	152542	223612.90	−400000	2500000
Population (per Km <sup>2</sup> , LSOA <sup>a</sup> level)	3336	2975.38	7	25280
Population (per Km <sup>2</sup> , LAD <sup>b</sup> level)	3193	3164.75	10	13870
How much is tax gas and electricity (£/yr.)	144.90	111.94	−50	500
How much is duty transport fuel (pence/yr.)	25.18	13.68	0	60
Behavioural variables				
Social value orientation (ring measure)	26.28	15.52	−16.26	83.93
Annual discount rate,%, invest now for a year from now <sup>c</sup>	148.7	181.81	1	500
Risk aversion - estimated median of quadratic utility function	0.33	0.01	0.29	0.38
Risk aversion - estimated median of log utility function	1.81	1.08	0.67	4.33
Risk aversion - estimated median of power utility function	0.42	0.07	0.33	0.57
Risk aversion - estimated mean of power utility function	0.74	0.26	0.33	1.07

*Notes:* Total number of observations: 8541

a Lower Layer Super Output Area

b Local Authority District

c This variable is called *Discount rate year from now* in the tables with regression estimates