Aggregate Risk or Aggregate Uncertainty? Evidence from UK Households

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Abstract

Under Knightian uncertainty, households base their decisions on beliefs which are negatively distorted by their preferences. We use this insight to measure the amount of uncertainty faced by UK households relying on the Bank of England Inflation Attitudes Survey that asks households for their expected inflation as well for their preferences about future inflation and nominal interest rates. We find evidence that (i) Knightian uncertainty increases after major economic events such as the failure of Lehman Brothers or the referendum in favor of Brexit, (ii) it is driven partly by future monetary policy and partly by the economic environment, and (iii) it is only mildly correlated with other existing measures of uncertainty based on stock market volatility and counting of words in official reports or the social media. If households had treated uncertainty as measurable risk, consumption and output would have been around 1 percent higher both during the Great Recession and in recent years.

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1 Introduction

Knight (1921) has emphasized the distinction between risk, which can be represented by well-specified predetermined probability distributions, and uncertainty which cannot. Risk can be evaluated using expected utility, uncertainty requires agents also to choose their subjective probability distribution. Knightian uncertainty could matter for understanding crisis (Caballero and Krishnamurthy 2008), business cycles (Ilut and Schneider 2014), asset prices (Backus, Ferriere, and Zin 2015 and Bianchi, Ilut, and Schneider 2018), firm dynamics (Ilut and Saijo 2016), and unconventional monetary policy (Michelacci and Paciello 2018). Yet, there is little direct evidence about whether households take decisions based on risk or uncertainty and whether uncertainty varies cyclically. Here we measure the amount of uncertainty faced by households and characterize its time series evolution by relying on a common feature of ambiguity aversion models characterizing agents' optimizing behavior under Knightian uncertainty (Gilboa and Schmeidler 1989, Epstein and Schneider 2003, Hansen and Sargent 2001, Strzalecki 2011, and Maccheroni, Marinacci, and Rustichini 2006): under Knightian uncertainty, agents take decisions based on beliefs which are negatively distorted by their preferences, the more so the greater the amount of uncertainty they face.

To identify Knightian uncertainty, we use data from the Bank of England Inflation Attitudes Survey (BIAS) that ask UK households for their expected inflation as well for their preferences about future inflation and nominal interest rates over the period 2003-2019. To interpret the data and identify the amount of uncertainty faced by households, we consider the problem of households who supply labor services in a competitive labor market and differ in their financial asset position. Households think that nominal interest rates are determined by a central bank as a function of inflation (with elasticity greater than 1) and a monetary shock according to a simple Taylor rule and agree that inflation is an increasing function of the output gap (wages scaled by aggregate productivity) according to a traditional Phillips curve. In the economy there are monetary and technology shocks, which can both stimulate (or contract) the economy, have (qualitatively) similar effects on nominal interest rates but have opposite effects on inflation—monetary shocks increase inflation, while technology shocks reduce it. Shocks could be either a source of risk, which households would evaluate using expected utility under rational expectations, or a source of Knightian uncertainty, which households would process using the multiple priors utility model of Gilboa and Schmeidler (1989) and Epstein and Schneider (2003) leading to maximin preferences—an analytically convenient characterization for households' ambiguity aversion resulting from Knightian uncertainty.

Under rational expectations, households base their decisions on the same beliefs, which are determined only by their information set. Under uncertainty, households choose their subjective probability distribution about the future realization of shocks and base their decisions on beliefs that are tilted towards the worst case scenario for the household. Generally, households with greater wealth and less debt, in brief creditor households, are more likely to dislike monetary shocks, that increase inflation and reduce the real return on financial investment, and are more likely to dislike technology shocks, that might cause deflation and through the Taylor rule reduce the nominal and real return on investment. Generally, households who dislike monetary shocks and like technology shocks tend to act on beliefs associated with higher future expected inflation, the more so the greater the amount of Knightian uncertainty they face.

To sum up, the model has three implications that we can use in the BIAS data to identify the amount and the source of the Knightian uncertainty faced by UK households. The first is that wealthier households are more likely to dislike both future inflation and a future reduction in nominal interest rates (in the model driven by either monetary or technology shocks). The second is that households' beliefs about future inflation are negatively distorted by households preferences for higher inflation and nominal rates. The third is that this bias varies over time, reflecting the amount of Knightian uncertainty about future changes in monetary policy and technology. In the BIAS data, preferences on inflation are elicited by asking the following question to UK households: "If a choice had to be made either to raise interest rates to try to keep inflation down, or keep interest rates down and allow prices in the shops to rise faster, which would you prefer—interest rates to rise or prices to rise faster?" We say that the household *dislikes inflation* if, in answering the question, the household prefers an increase in interest rates to an increases in inflation. Preferences about interest rates are elicited asking the following question: "Which would be best for you personally, for interest rates to go up over the next few months, or to go down, or to stay where they are now, or would it make no difference either way?". The household *dislikes interest rates*, if personally she would prefer interest rates to go down.

We find support for the key implications of the model. Roughly, a household with negative wealth equal to two times average UK annual labor income (debtor household) dislikes inflation with a probability of 50 percent compared with a probability of 70 per cent for a household with wealth greater than four times average yearly labor income. The former (debtor) households dislike interest rates with a probability of 90 percent while the latter (creditor) households dislike it with a probability of just 40 per cent. On average in the sample, households who dislike inflation, have an expected inflation at 1 year ahead time horizon which is 15 basis points higher than the expected inflation of households who like inflation. This difference falls by around 5 basis points when looking at expected inflation at 2 or 5 years ahead time horizon. Differences in expected inflation due to preferences are virtually zero in the early 2000's and peak to around 40 basis points in 2012. The results hold true, after controlling for several variables that might affect the information set available to households as proxied for example by their geographical location, educational level, age, and understanding about the functioning of monetary policy and the economy in general.

A concern with our empirical strategy is that households might report their rational expectations beliefs rather then the beliefs on the basis of which they act.[1] Another concern is that households preferences could affect households' self-reported beliefs, but the component of beliefs due to preferences could have no or little effects on households' choices—i.e. be just a form of "cheap talking." In practice we find that changes in inflation expectations due to preferences change the saving, consumption, and financial portfolio behavior of households in a way that is quantitatively similar to (and certainly at least as large as) the component of expected inflation which is not due to preferences. This provides support to our identification strategy.

A second concern with our identification strategy is that differences in preferences might be correlated with differences in the information set available to households, so that our reduced form coefficients might un-accurately reflect distortions in subjective beliefs due to Knightian uncertainty. To address this concern we rely on a key property of the model that implies that preferences about inflation and interest rates are (at least partly) caused by differences in the financial position of the household, which can be used to instrument household preferences. To help guaranteeing that the instrument satisfies the exclusion restriction, we control for differences in education, several demographic variables, and even for household's self-reported beliefs about whether the UK economy (rather than the household) would benefit from experiencing higher inflation.[2] After instrumenting households' preferences with their financial position, we find that the distortion in beliefs due to preferences increases, which suggest that differences in information sets do not fully drive the bias in expectations due to preferences. Finally, in the paper we address the concern that households self-select into reporting their preferences or beliefs about expected inflation. To control for possible selection biases, we consider a selection model and exploit information on household's understanding of the questions in the survey which makes them more likely to answer them.

For robustness, we also checked that a similar negative bias of expectations due to preferences arises when households are asked to predict the future evolution of nominal interest rates, rather than inflation.

Given our characterization of households in the economy, we estimate the amount of

[1]See Hurd (2009), Kézdi and Willis (2011), Armantier, de Bruin Wändi, Topa, van der Klaauw, and Zafar (2015), and Gennaioli, Ma, and Shleifer (2016) for empirical evidence suggesting that agents act on the basis of their self-reported beliefs and expectations.

[2]The exclusion restriction would still hold in rational inattention models: under rational inattention, wealth matters for beliefs because wealth affects preferences and households with stronger preferences have greater incentives to acquire information to predict future states of the economy.

Knightian uncertainty about monetary policy and technology using indirect inference, taking our regression coefficients for the effects of preferences on expected inflation as estimation targets. We find substantial time series variation in the amount of Knightian uncertainty faced by UK households. Knightian uncertainty increases after major economic events such as the failure of Lehman Brothers or the referendum in favor of Brexit, and it is driven partly by future monetary policy and partly by the technology. Uncertainty about monetary policy dominates the period 2010-2013, while uncertainty about technology is predominant at the beginning of the Great Recession and in more recent years of the sample. Our measure of Knightian uncertainty is only mildly correlated with other existing measures of uncertainty based on stock market volatility, using the 360-day standard deviation of the return on the FTSE-UK stock market index. It is also mildly correlated with indexes constructed counting words in official reports by the IMF, such as the World Uncertainty Index by Ahir, Bloom, and Furceri (2018), or indexes constructed counting words in the social media, such as the Economic Policy Uncertainty index by Baker, Bloom, and Davis (2016).

After recovering the amount of Knightian uncertainty about monetary policy and technology in the data, we aggregate the consumption choices of all households in the economy and calculate by how much aggregate consumption and output would have changed (both in partial and general equilibrium) if households had processed uncertainty in the form of measurable risk. We find that consumption and output would have been higher by approximately 1 percentage point at the beginning of the Great Recession and over the period 2018-2019. We also find that monetary policy uncertainty has little effects on output while uncertainty due to technology is highly contractionary on output. This happens because UK households tend in a large proportion to dislike inflation so when faced with uncertainty about monetary policy households tend to act on the basis of subjective beliefs that tend to overpredict future inflation, which is expansionary on aggregate demand and stimulates the economy.

Related literature Ellsberg (1961) first provided experimental evidence consistent with the idea that, under uncertainty, agents choose their subjective probability distribution over-weighting their worst case scenario. Yet so far, there is little direct household-level evidence that Knightian uncertainty shapes households decisions and that the amount of uncertainty varies over time. Ilut and Schneider (2014), Bianchi, Ilut, and Schneider (2018), and Bhandari, Borovička, and Ho (2016) have first estimated the amount of Knightian uncertainty faced by households in the economy using (aggregate) time series evidence. These papers rely on the existence of a representative household which prevents them from explicitly modelling heterogeneity in household preferences and the associated disagreement in household beliefs. Here we exploit panel data and a unique feature of the BIAS, that contains self-reported household preferences about future inflation and interest rates. We show that household preferences are aligned with the theoretical predictions of the model and use the size of the correlation between households preferences and their beliefs as a novel margin to measure different sources of uncertainty. Our measures are available in real time and policy makers can use them to convert households' uncertainty into households' risk—conveying more accurate information about the probability distribution of future states of the economy. This would be highly expansionary when uncertainty is about the economy (technology), rather than czxabout monetary policy.

Several papers have shown the relevance of ambiguity aversion and Knightian uncertainty for business cycle analysis. Ilut and Schneider (2014) show that shocks to the degree of ambiguity can drive the business cycle, Backus, Ferriere, and Zin (2015), Ilut (2012), and Bianchi, Ilut, and Schneider (2018) examine asset pricing, Ilut and Saijo (2016) focus on firm dynamics, Ilut, Valchev, and Vincent (2016) study firm pricing decisions, Monti and Masolo (2017) show that Knightian uncertainty bout the behavior of the policy- maker helps explain the evolution of trend inflation in the US, while Ilut, Krivenko, and Schneider (2018) devise methods suitable for stochastic economies where ambiguity-averse agents differ in their perception of exogenous shocks, and study the implications for precautionary savings and asset premiums. Here we emphasize that households' heterogeneity in preferences about future inflation and interest rates provide a novel approach to measure the amount of uncertainty they face in the economy.

Section 2 characterizes a simple model of ambiguity version. Section 3 discusses the data. Section 4 presents the empirical evidence on the effects of preferences on beliefs. Section 5 presents time series evidence. Section 6 calibrates the model, estimates Knightian uncertainty by indirect inference and quantifies its implications for consumption and output. Section 7 concludes. The Appendix contains details on theoretical derivations, data and model computation.

2 The model

We consider an analytically tractable New Keynesian economy in discrete time. The economy is populated by a unit mass of households, $i \in [0, 1]$, who differ only in net financial wealth, a_{it}, invested in one-period bonds. There is also a unit mass of firms that demand labor to produce intermediate goods sold under monopolistic competition; prices are sticky subject to adjustment costs. The nominal interest rate is set according to a simple Taylor rule. We focus on household i and compare her problem under measurable risk with the one under Knightian uncertainty. The economy is at time $t_0 = 0$ and we assume for simplicity that all risk or uncertainty is resolved in the following period, at time $t_0 + 1$. We first describe the economy and then discuss the equilibrium. The purpose of the model is to provide a simple theoretical framework useful for interpreting the BIAS data.

2.1 Assumptions

Household Household i is infinitely-lived, with subjective discount factor β and per period preferences over consumption c_{it} are given by

$$U(c_{it}) = \frac{c_{it}^{1-\sigma}}{1-\sigma}, \tag{1}$$

with $\sigma > 1$. At each point in time t, the household supplies inelastically one unit of labor in the market and chooses the pair $\{c_{it}, a_{it+1}\}$ subject to the budget constraint

$$c_{it} + a_{it+1} \leq \iota_{it} + r_t\, a_{it}, \tag{2}$$

where a_{it+1} measures the units invested in bonds at time t, $(r_t - 1)\, a_{it}$ is capital income, while $\iota_{it} = w_t + \tau_{it}$ denotes household's income other than capital income, equal to the sum of wages w_t and government transfers τ_{it} possibly targeted to household i (see below). Household i has Maximin preferences as in the multiple priors utility model of Gilboa and Schmeidler (1989), whose axiomatic foundations are provided by Epstein and Schneider (2003). This means that the utility of household i is given by the sum of the felicity from time-t consumption plus the expected continuation utility, which is evaluated at the household's worst-case scenario on the possible realization of the economy $\omega \in R^q$ in the following period with q representing the different possible sources of uncertainty or risk. Maximin preferences are convenient to guarantee an analytically tractable characterization of household behavior under Knightian uncertainty, having rational expectations under measurable risk as a particular case.[3] Formally, we assume that preferences at time t order future streams of consumption, $\mathbf{C_t} = \{c_s(h^s)\}_{s=t}^{\infty}$, so that utility is defined recursively as

$$V_t(\mathbf{C_t}) = U(c_t(h^t)) + \beta \min_{\Omega \subseteq \mathcal{S}_t, G \in \mathscr{P}_t(\Omega)} \int_{\Omega} V_{t+1}(\mathbf{C_{t+1}})\, G(d\omega), \tag{3}$$

where h^t denotes history up to time t, and Ω is the support of the probability distributions G that household i ascribes to the realizations of the possible state of the economy ω in the next period. Household i chooses consumption plans, $c_t(h^t)$ and savings $a_{t+1}(h^t)$ to maximize (3). Under Knightian uncertainty, the household chooses supports Ω from the set $\mathcal{S}_t$ and the associated probability distribution G from the set $\mathscr{P}_t(\Omega)$, so as to minimize

[3] Similar results would arise under alternative modelling assumptions for ambiguity aversion, for example using multiplier preferences, as in Hansen and Sargent (2001). Multiplier preferences include maximin preferences as a special limit case and, as shown by Strzalecki (2011), are a special case of the variational preferences proposed by Maccheroni, Marinacci, and Rustichini (2006).

the continuation utility V_{t+1}. Under measurable risk, the household maximizes expected utility taking Ω and the associated probability distribution G as given (at all t: the sets $\mathscr{S}_t$ and $\mathscr{P}_t$ are singletons. The assumption that uncertainty or risk can arise just at $t = t_0$ means that for $t \neq t_0$, $\mathscr{S}_t$ is a unit set which contains just one value, say $\{\tilde{\omega}_t\}$, and the set of distribution functions $\mathscr{P}_t(\{\tilde{\omega}_t\})$ is again a singleton: a single degenerate distribution that assigns a value of one to $\tilde{\omega}_t$.

Monetary policy rule The (gross) interest rate paid in period t is given by $r_t = R_{t-1}/\Pi_t$, where $\Pi_t = p_t/p_{t-1}$ is gross inflation realized in period t and R_t is the (gross) nominal interest rate set by the monetary authority at period t according to the Taylor rule

$$\ln R_t = \phi \ln \Pi_t - \ln \beta - m_t \tag{4}$$

where $\phi > 1$, $1/\beta$ represents the natural rate of interest, and m_t is a monetary shock assumed to evolve as follows:

$$m_t = \varrho_m m_{t-1} + v_t \tag{5}$$

where $v_1 \in \{-\overline{v}_0, \overline{v}_0\}$ with $\overline{v}_0$ known at time $t_0 = 0$ measuring the amount of risk or uncertainty about monetary policy faced by households at t_0. For $t' \neq 1$ we assume for simplicity that $v_{t'} = 0$ for sure. The assumption that v_1 has a discrete (bivariate) support is just for analytically convenience.

Firms There is a mass 1 of monopolistically competitive firms each producing a differentiated variety, with elasticity of substitution $\theta > 1$. A perfectly competitive final good producer assembles the output of all varieties $j \in [0, 1]$ to obtain final output equal to

$$Y_t = \left(\int_0^1 y_{jt}^{\frac{\theta-1}{\theta}} dj \right)^{\frac{\theta}{\theta-1}}, \tag{6}$$

where y_{jt} is the amount of variety $j \in [0, 1]$ used in production. The variety j is produced according to the following production function

$$y_{jt} = x_{jt}^{1-\alpha} (e^{z_t} \ell_{jt})^{\alpha} \tag{7}$$

where x_{jt} is the amount of final output used in production, z_t is exogenous productivity assumed to evolve as follows

$$z_t = \varrho_z z_{t-1} + \epsilon_t \tag{8}$$

where $\epsilon_1 \in \{-\overline{\epsilon}_0, \overline{\epsilon}_0\}$ with $\overline{\epsilon}_0$ known at t_0 measuring the amount of risk or uncertainty about technology faced by the household at t_0. For $t' \neq t_0 + 1$ we assume for simplicity that $\epsilon_{t'} = 0$ for sure.[4] Finally, ℓ_{jt} denotes firm j's demand for labor whose unit cost is w_t. Firm j sets the nominal price for its variety p_{jt}, choose labour ℓ_{jt} and the demand of intermediate inputs x_{jt} to maximize the present value of profits equal to

$$d_{jt} \equiv \frac{p_{jt}}{p_t} y_{jt} - w_t \ell_{jt} - x_{jt} - \kappa\left(\pi_{jt}, Y_t\right).$$

In solving the problem, firm j takes as given the demand schedule by the competitive firm,

$$y_{jt} = Y_t \left(\frac{p_{jt}}{p_t}\right)^{-\theta}$$

the aggregate nominal price, $p_t = \left(\int p_{jt}^{1-\theta} dj\right)^{\frac{1}{1-\theta}}$, and the wage rate, w_t. As in Rotemberg (1982), firm j set her time-t nominal price p_{jt} subject to the following convex adjustment costs:

$$\kappa\left(\pi_{jt}, Y_t\right) = \frac{\kappa_0}{2}\left(\pi_{jt}\right)^2 Y_t, \tag{9}$$

where $\pi_{jt} = (p_{jt} - p_{jt-1})/p_{jt-1}$, and $\kappa_0 > 0$. For simplicity we assume that prices at t_0 are predetermined (before the uncertainty shock), $\Pi_{j0} = 1$, and normalized to one $p_{j0} = 1$, $\forall j \in [0, 1]$.

Market clearing In equilibrium, aggregate output Y_t is equal to aggregate consumption $C_t \equiv \int_0^1 c_{it}\, di$, plus government expenditures G (constant over time), plus demand for intermediate inputs $X_t \equiv \int_0^1 x_{it}\, di$, so that $\forall t$

$$Y_t = C_t + G + X_t.$$

Clearing of the labor market implies that labor demand is equal to labor supply, $\int_0^1 \ell_{it} di = 1$. Since bonds are in net supply A, clearing the financial market requires that $\int_0^1 a_{jt} dj = A$. For simplicity we assume that the government owns all firms in the economy and rebates profits partly back to households and partly use them to finance government expenditures and interest rate payments on government debts, so that the government budget constraints reads as follows:

$$\int_0^1 d_{it}\, di = G + \int_0^1 \tau_{it} di + r_t A.$$

For simplicity we assume that government transfers take the following simple log-linear form:

$$\ln \tau_{it} = \ln \overline{\tau} + \overline{\tau}_{imt} m_t + \overline{\tau}_{izt} z_t \tag{10}$$

[4]For simplicity, we assume that innovations about technology and monetary policy are independent.

with $\overline{\tau}_{imt}$ and $\overline{\tau}_{izt}$ possibly independent of i. The coefficients $\overline{\tau}_{imt}$ and $\overline{\tau}_{izt}$ characterize all reasons aside from differences in financial portfolios that affect the preferences of household i for monetary and technology shocks (say differences across households in the indexation of transfers and wages to inflation and/or aggregate productivity). In the quantitative analysis we will calibrate them to match the distribution of households' preferences (for inflation and nominal interest rate changes) in the UK population.

2.2 Equilibrium

We now characterize the equilibrium of the model at $t \geq t_0+1$, after uncertainty is resolved, for given realizations of m_t and z_t, and derive households expectations at $t = t_0$ for inflation at $t \geq t_0 + 1$ taken both under measurable risk and under Knightian uncertainty.[5]

Equilibrium We prove in the appendix that, after all risk or uncertainty is resolved at $t \geq t_0 + 1$, the following standard Phillips curve holds (up to a first order approximation)

$$\Pi_t = (1-\beta) + \beta\Pi_{t+1} + \kappa\left(\ln w_t - \ln \bar{w} - z_t\right), \quad \forall t \geq t_0 + 1 \tag{11}$$

with $\kappa > 0$. In equilibrium we also have that, $\forall t \geq t_0 + 1$, gross inflation, Π_t satisfies

$$\Pi_t = \Pi_t\left(m_t, z_t\right) \equiv 1 + \overline{\pi}_{mt} m_t + \overline{\pi}_{zt} z_t. \tag{12}$$

Finally, and again $\forall t \geq t_0 + 1$, logged wages, $\ln w_t$, nominal interest rates, R_t and real returns r_t are given by:

$$\begin{aligned} \ln w_t &= \ln \overline{w} + \overline{w}_{mt} m_t + \overline{w}_{zt} z_t, & (13)\\ \ln R_t &= -\ln\beta + \overline{R}_{mt} m_t + \overline{R}_{zt} z_t, & (14)\\ r_t &= -\ln\beta + \overline{r}_{mt} m_t + \overline{r}_{zt} z_t, & (15) \end{aligned}$$

These equilibrium quantities correspond to the equilibrium under a representative household, which is a canonical benchmark in the new Keynesian literature. The coefficients $\overline{u}_{jt}$ $\forall u = \pi, w, R, r$, $\forall j = m, z$ and $\forall t \geq t_0 + 1$ are derived in the appendix. The household i takes them as given in maximizing her utility in (3). Both the monetary and the technology shocks stimulate the economy, $\overline{w}_{mt} > 0$ and $\overline{w}_{zt} > 0$. The monetary shock is inflationary $\overline{\pi}_{mt} > 0$, while the technology shock is deflationary $\overline{\pi}_{zt} < 0$. Both shocks tend to reduce the nominal interest rate $\overline{R}_{mt} < 0$ and $\overline{R}_{zt} < 0$ as well as the real return on financial assets $\overline{r}_{mt} < 0$ and $\overline{r}_{zt} < 0$.

[5]The appendix discusses the equations defining the equilibrium output of the model at $t = t_0$.

Given the equilibrium functions (12)-(15), we can calculate the continuation utility of household i starting from time t_0+1 onwards. This continuation utility is function of the units invested in bonds at time t_0, denoted by a, and the realization of the shocks at time t_0+1, v_{t_0+1} and ϵ_{t_0+1}. This continuation utility is denoted by $\overline{V_i}\left(a, v_{t_0+1}, \epsilon_{t_0+1}\right)$ and measures the present discounted value of utility of household i starting from period t_0+1, given household's wealth a at the end of period t_0. Let ϕ_j, $j=m,z$ denote the probability that the household ascribes to a negative realization of the monetary shock, when $j=m$, or to the technology shock, when $j=z$. Then the expected continuation utility of the household at t_0 after investing a units of wealth in bonds is equal to

$$\widehat{V}_i\left(a, \phi_m, \phi_z\right)=\sum_{\substack{v\in\{-\bar{v}_0,\bar{v}_0\}\\ \epsilon\in\{-\bar{\epsilon}_0,\bar{\epsilon}_0\}}}\left[\phi_m+(1\text{-}2\phi_m)\,\mathbb{I}(v>0)\right]\left[\phi_z+(1\text{-}2\phi_z)\,\mathbb{I}(\epsilon>0)\right]\overline{V}_i\left(a, v, \epsilon\right), \quad (16)$$

where innovations are assumed to be mutually independent.

Measurable risk Under measurable risk, household i maximizes utility taking the probability distribution for monetary policy and technology shocks as given. We conveniently assume that innovations have an expected value normalized to zero, which yields the following value for the problem of household i:

$$V_i^{\sigma}\left(a_{i0}\right)=\max_{a'}\left[\frac{\left(\iota_{i0}+\bar{R}\,a_{i0}-a'\right)^{1-\sigma}}{1-\sigma}+\beta\widehat{V}_i\left(a', 1/2, 1/2\right)\right]. \quad (17)$$

Given (12), the inflation expected at t_0 by household i for time t_0+n, $n\geq 1$, is equal to

$$E_{t_0}^{\sigma}(\Pi_{t_0+n})=1, \quad (18)$$

which is equal for all households in the economy (it is independent of i). The 1 in the right hand side of (18) follows just the normalizing assumption that shocks have zero mean and there is no predictable component in the future evolution of the economy. In brief we concluded that:

Result 1. Under measurable risk, households' beliefs about future inflation are independent of households' preferences.

Knightian uncertainty When the household has multiple priors about the possible realizations of monetary and technology shocks, she solves the following problem:

$$V_i^{\kappa}\left(a_{i0}\right)=\max_{a'}\left\{\frac{\left(\iota_{i0}+\bar{R}\,a_{i0}-a'\right)^{1-\sigma}}{1-\sigma}+\beta\min_{\phi_m,\phi_z\in\{0,1\},}\widehat{V}_i\left(a', \phi_m, \phi_z\right)\right\}. \quad (19)$$

To map the model into the data we assume that the household cannot choose an interior probability. The minimization problem in (19) under the household's optimal savings a' determines the worst case beliefs of household i, in brief her *beliefs*. Let's denote this worse case beliefs by the following pair:

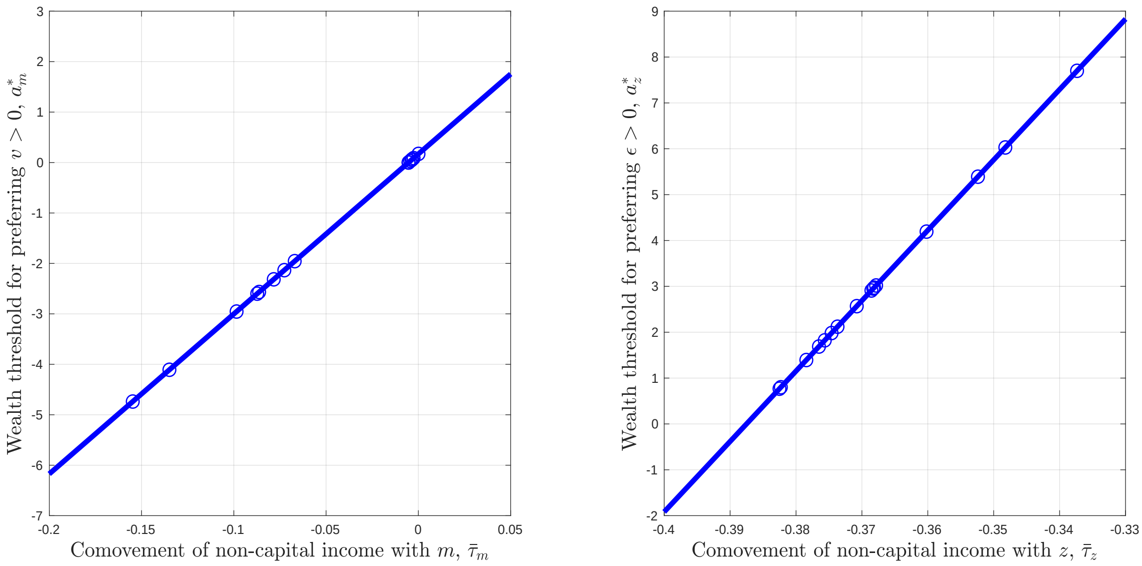
$$s_i^* = (v_i^*, \epsilon_i^*) \tag{20}$$

where $v^* = [1 - 2\phi_{mi}(a)]\,\overline{v}_0$ and $\epsilon^* = [1 - 2\phi_{zi}(a)]\,\overline{\epsilon}_0$ where $\phi_{mi}(a)$ and $\phi_{zi}(a)$ are the probabilities that solve the minimization problem in (19) at the optimal saving decision of the households a' (which in equilibrium is function just of a.) Generally, for given transfer function in (10), wealthier households (higher a) are more likely to dislike expansionary monetary shocks and technology shocks because they reduce the real return on saving: monetary shocks reduce the nominal rate, which stimulates demand and thereby inflation; technology shocks are deflationary because of the Phillips curve in (11) and thereby reduce real rates through the Taylor rule in (4), which satisfies $\phi > 1$. As a result higher a (for given transfer function τ in (10)) is more likely to make $\phi_{mi}(a)$ and $\phi_{zi}(a)$ both equal to 1. To illustrate this point, the left panel of Figure 1 shows the level of wealth a_m^* at the beginning of time t_0 below which the household prefers $v_{t_0+1} > 0$ to $v_{t_0+1} < 0$ for different values of the elasticity of the transfer function to the monetary shock $\bar{\tau}_m$ in (10). The right panel shows the level of wealth a_z^* at the beginning of time t_0 below which the household prefers $\epsilon_{t_0+1} > 0$ to $\epsilon_{t_0+1} < 0$, for different values of the elasticity of the transfer function to the technology shock $\bar{\tau}_z$ in (10). The wealth thresholds are expressed in units of yearly steady state labor income, w. The circles correspond to values of $\bar{\tau}_m$ and $\bar{\tau}_z$ observed in the data given our calibration below. As the real rate is decreasing both in ϵ and v, households will prefer an expansionary monetary policy and technology shock if their wealth at t_0 is $a_{i0} < a_m^*$ and $a_{i0} < a_z^*$, respectively. The values of a_m^* and a_z^* are increasing in the elasticities of the tranfer functions to the shocks: higher $\bar{\tau}_{im}$ and $\bar{\tau}_{iz}$ leads to higher non-capital income in response to monetary policy and technology shocks and the household should be wealthier to dislike the shocks. By comparing the left with the right panel in the figure, we also observe that, for given transfer function, $a_m^* < a_z^*$. This is because technology shocks increases labor income more than monetary policy shocks, thus the household has to be substantially richer to dislike a technology shock. This discussion leads to the following conclusion:

Result 2. For given transfer function τ in (10), wealthier households are more likely to dislike expansionary monetary and technology shocks.

We next derive the relationship between beliefs about monetary and technology shocks and beliefs about inflation. Let $E_{t_0}^k(\Pi_{t_0+n})$ denote the beliefs at t_0 of inflation at $t_0 + n$ on the basis of which households act, once faced with Knightian uncertainty. From (12), it

Figure 1: Beliefs wealth thresholds as a function of $\bar{\tau}_m$ and $\bar{\tau}_z$ in (10)



(a) Monetary policy shock **(b) Technology shock**

The left panel shows the level of wealth at the beginning of time t_0, a, below which the household prefers $v_{t_0+1} > 0$ to $v_{t_0+1} < 0$, for different values of the elasticity of the transfer function to the monetary shock $\bar{\tau}_m$ in (10). The right panel shows the level of wealth at the beginning of time t_0 below which the household prefers $\epsilon_{t_0+1} > 0$ to $\epsilon_{t_0+1} < 0$ for different values of the elasticity of the transfer function to the technology shock $\bar{\tau}_z$ in (10). The wealth threshold is expressed in units of yearly steady state labor income, w. The circles correspond to values of $\bar{\tau}_m$ and $\bar{\tau}_z$ observed in the data given our calibration.

follows that $\forall n \geq 1$

$$E_{t_0}^{\kappa}(\Pi_{t_0+n}) = E_{t_0}^{\sigma}(\Pi_{t_0+n}) + \overline{\pi}_{mt_0+n}\varrho_z^{n-1}v_i^* + \overline{\pi}_{zt_0+n}\varrho_z^{n-1}\epsilon_i^* \tag{21}$$

which, given (20), is function of households' preferences and households' financial position, and varies across households in the economy. $E_{t_0}^{\sigma}(\Pi_{t_0+n})$ corresponds to the beliefs under rational expectations. Since generally $\overline{\pi}_{mt}$ and $\overline{\pi}_{zt}$ are negative, we have that for given transfer function in (10), wealthier households tend to act on beliefs that put more weight on high future expected inflation. We can conclude that:

Result 3. Under Knightian uncertainty, households' beliefs about future inflation are negatively distorted by households' preferences for monetary and technology shocks.

Given the worst case beliefs in (20) we can also define the best case beliefs of the household as equal to

$$s_i^{**} = -s_i^*. \tag{22}$$

This would amount to asking the household who takes as a reference status quo her worse case beliefs (the beliefs on the basis of which she acts) for whether she would prefer a different realization of the monetary shock or the technology shock. We can construct a dummy for whether the household prefers a monetary expansion to a monetary tightening, i.e.

$$d_{mi} = 1 - \phi_{mi}(a), \tag{23}$$

and another dummy for whether the household prefers a technology improvement to a technology regress:

$$d_{zi} = 1 - \phi_{zi}(a). \tag{24}$$

With this notation we have that, $\forall n \geq 1$, $E^{\kappa}_{t_0}(\Pi_{t_0+n})$ in (21) can be expressed as equal to

$$E^{\kappa}_{t_0}(\Pi_{t_0+n}) = E^{\sigma}_{t_0}(\Pi_{t_0+n}) - \overline{\pi}_{mt_0+n}\varrho_m^{n-1}\overline{v}_0 d_{mi} - \overline{\pi}_{zt_0+n}\varrho_z^{n-1}\overline{\epsilon}_0 d_{zi}, \tag{25}$$

which says that under, Knightian uncertainty, rational expectation beliefs, equal to $E^{\sigma}_{t_0}(\Pi_{t_0+n})$, are (negatively) distorted by household's preferences. Equation (25) can be estimated in the data after eliciting household's preferences for a monetary loosening versus a monetary tightening, and a technology improvement versus a technology regress. Preferences about monetary policy shocks are directly elicited in the BIAS. Preferences about technology shocks can be indirectly inferred from preferences about nominal interest rates elicited by BIAS, after controlling for preferences for monetary shocks: given (14) this indirectly back up household preferences for technology shocks. Finally notice that the dummies d_{mi} and d_{zi} in (23) and (24) are function just of the financial portfolio position of the households that can be used as an instrument to obtain exogenous variation in household's preferences. Using the regression coefficients in (25) as estimation targets in the model, we can backup the amount of Knightian uncertainty faced by UK households. Summing up, (25) implies that

Result 4. The effects of household' preference dummies on household' beliefs about future inflation reflect the amount of Knightian uncertainty about future monetary and technology changes.

3 Data and preferences

We start describing the data. Then we analyze the determinants of households' preferences for inflation and interest rates.

3.1 Data

Our main source of data is the Bank of England Inflation Attitudes Survey (BIAS). The BIAS is a quarterly survey, conducted on behalf of the Bank of England to assess public attitudes towards inflation and monetary policy. People aged 16 and over are interviewed throughout the United Kingdom. Once weighted, the raw data are fully representative of the UK population. The survey is ran quarterly since 2001, but some questions are asked just in the first quarter of the year and other questions are started to be asked only since 2003. Overall, our sample period is 2003:I-2019:I. Table 1 provides descriptive statistics for some key variables. Descriptive statistics for other variables used in the analysis are

Table 1: Descriptive statistics

VARIABLES	(1) mean	(2) sd	(3) N	(4) min	(5) max
Year	2,011.12	4.94	68,425.00	2,003.00	2,019.00
Expect. Π over next 12 months	2.82	1.86	47,273.00	-1.00	5.50
2-years ahead Π^e (extended)	3.09	2.65	31,774.00	-5.50	10.50
5-years ahead Π^e (extended)	3.64	2.93	28,172.00	-5.50	10.50
Reported Π over last 12 months	3.08	1.93	58,862.00	-1.00	5.50
1-year ahead realized Π, % (CPI)	2.23	1.06	64,093.00	0.10	4.10
1-year ahead realized Π, % (CPIH)	2.13	0.81	64,093.00	0.40	3.50
1-year ahead realized Π, % (RPI)	2.95	1.32	64,093.00	-0.10	5.30
HH does not know Π^e	0.15	0.36	68,425.00	0.00	1.00
HH does not know past Π	0.14	0.35	68,425.00	0.00	1.00
i affects Π in 1-2 months	0.34	0.47	68,425.00	0.00	1.00
i affects Π in 1-2 yrs	0.38	0.49	68,425.00	0.00	1.00
HH dislikes Π	0.61	0.49	68,425.00	0.00	1.00
HH prefers high Π	0.17	0.37	68,425.00	0.00	1.00
HH doesn't know preference for Π	0.23	0.42	68,425.00	0.00	1.00
HH expects 1yr i up	0.47	0.50	68,425.00	0.00	1.00
HH expects 1yr i down	0.07	0.25	68,425.00	0.00	1.00
HH expects 1yr i unchanged	0.27	0.44	68,425.00	0.00	1.00
HH doesn't know expected 1yr i	0.19	0.39	68,425.00	0.00	1.00
HH prefers i up	0.23	0.42	68,425.00	0.00	1.00
HH prefers i down	0.27	0.45	68,425.00	0.00	1.00
HH prefers i unchanged	0.21	0.41	68,425.00	0.00	1.00
HH is indifferent on i	0.18	0.39	68,425.00	0.00	1.00
HH doesn't know preference for i	0.10	0.30	68,425.00	0.00	1.00
Income above 25000 pounds	0.51	0.50	68,425.00	0.00	1.00
Household with mortgage	0.29	0.46	68,425.00	0.00	1.00
Top Wealthy HH	0.19	0.39	68,425.00	0.00	1.00
Upper Middle Wealthy HH	0.27	0.44	68,425.00	0.00	1.00
Lower Middle Wealthy HH	0.20	0.40	68,425.00	0.00	1.00
Poor HH	0.34	0.47	68,425.00	0.00	1.00

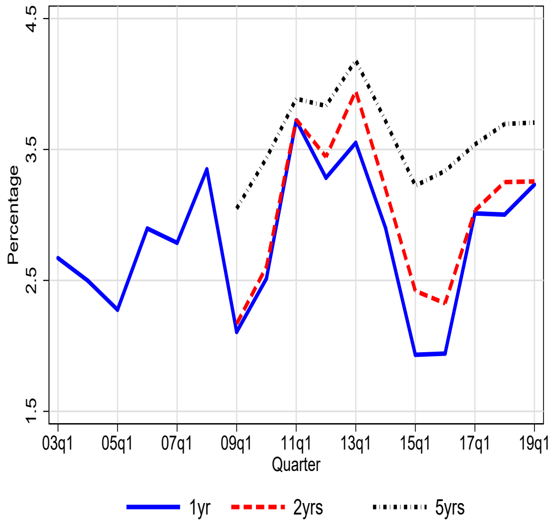
in Table A1 in the Appendix. The BIAS asks households about their expected inflation as well their preferences about future inflation and interest rates. Expected inflation at a

1 year time horizon is obtained by asking the following question: "How much would you expect prices in the shops generally to change over the next twelve months?". Starting from the first quarter of 2009, an analogous question is asked at a time horizon of 2 and 5 years. The profile of expected inflation is plotted in panel (a) of Figure 2. Panel (a) of Figure 3 shows the evolution of three measures of realized inflation: the blue solid line corresponds to CPI inflation; the red dashed line includes into the CPI also owner occupiers' housing costs (CPIH); the black dotted line measures inflation using the Retail Price Index (RPI), which used to be the principal official measure of inflation in the UK until very recent years. Panel (b) in Figure 3 also shows logged GDP per capita, normalized to zero at the beginning of the sample period, (left scale of the y-axis) and employment rate as a dashed red line (right scale of the y-axis). The Great Recession materializes in 2008 and GDP and employment comoves closely. Between 2008:I and 2009:I, GDP falls by more than 7 percentage points, while the fall for the employment rate is by more than 2 percentage points. On average, expected inflation in the BIAS tends to slightly overpredict future realized inflation, but the wedge is small and reverts sign when looking at RPI inflation, see Table 1.

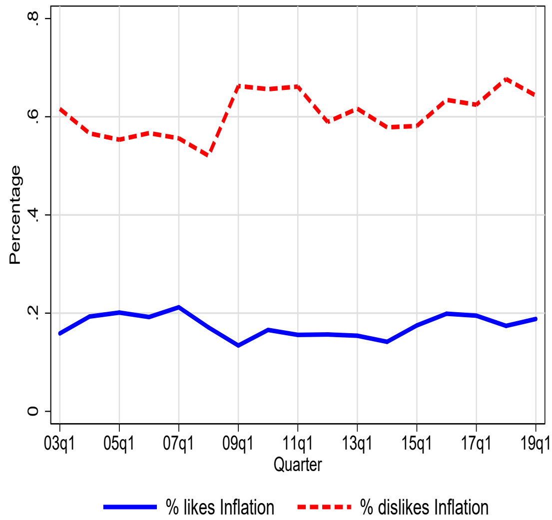
Households' preferences about inflation are elicited by asking the following question: "If a choice had to be made either to raise interest rates to try to keep inflation down, or keep interest rates down and allow prices in the shops to rise faster, which would you prefer—interest rates to rise or prices to rise faster?" Possible answers are: (i) Interest rates to rise; (ii) Prices to rise faster; or (iii) No idea. We interpret this question as eliciting household's preferences about a monetary shock (m_t): whether the household prefers a monetary loosening (m_t positive) versus a monetary tightening (m_t negative). In terms of the model, the answer to the question identifies the value of the dummy d_{mi} in (23). We say that the household *likes inflation* (in response to a monetary shock), and set $d_{mi} = 1$, if the household chooses option (ii) in answering the above question. The household *dislikes inflation* if the household chooses option (i) in answering the above question. The fraction of households who dislike inflation oscillates around 60 percent, whereas the fraction of households reporting to like inflation oscillates around 20 percent. These fractions have remained relatively constant over the sample period, see panel (b) in Figure 2. Panel (c) of Figure 3 characterizes monetary policy by the Bank of England in terms of prices and quantities over the sample period: the blue solid line on the left y-axis is the official rate set by the Bank of England, the red dashed line on the right y-axis is the level of assets held by the Bank. Quantitative easing started in March 2009.[6]

[6]The official bank rate (also called the Bank of England base rate or BOEBR) is the interest rate that the Bank of England charges banks for secured overnight lending. It is the UK key interest rate for enacting monetary policy. The security for the lending can be any of a list of eligible securities (commonly Gilts) and are transacted as overnight repurchase agreements. Changes to BOEBR are recommended by the Monetary Policy Committee and enacted by the Governor of the Bank of England.

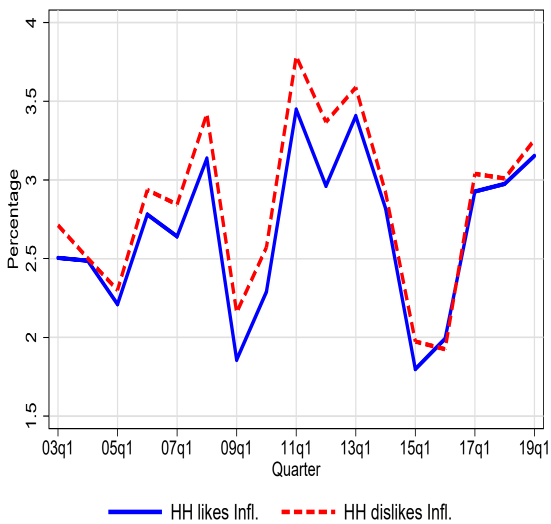
Figure 2: Expected inflation



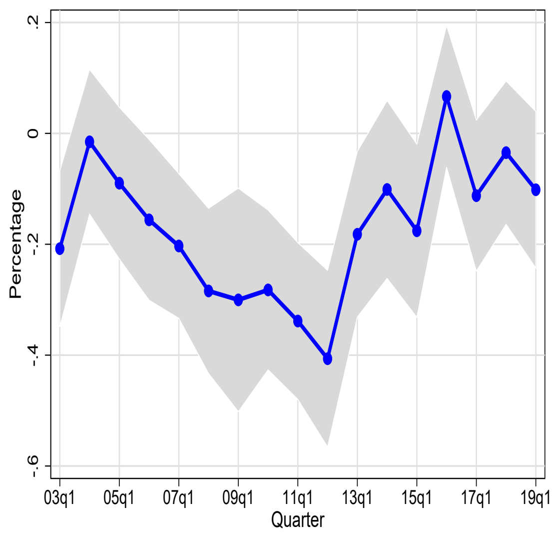
(a) Expected inflation



(b) Preferences



(c) Expected inflation & preferences

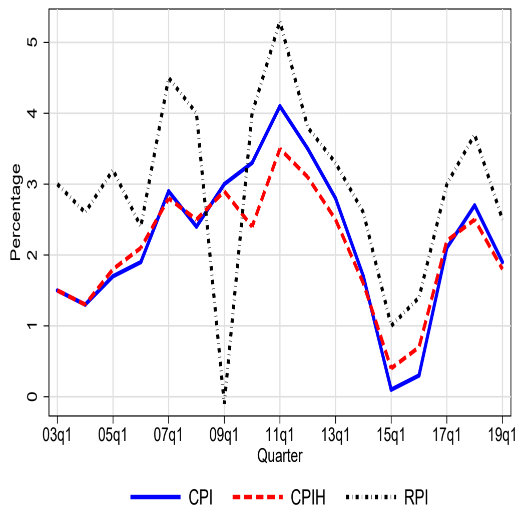


(d) Difference between HH likes & dislikes inflation

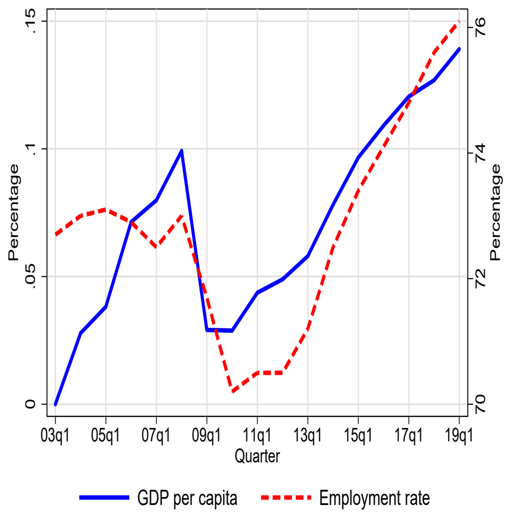
Panel (a) plots average expected inflation in the BIAS data at 1, 2 and 5 years horizon. Panel (b) plots the fraction of households who report to like and dislike inflation. Panel (c) reports the 1 year ahead inflation expected by households in the BIAS conditional on households reporting to like inflation ($d_{mi} = 1$) and dislike inflation $d_{mi} = 0$, respectively. Panel (d) reports the difference in the average expected inflation of households who like inflation and the average expected inflation of households who dislike inflation. Preferences are elicited through the following survey question: "If a choice had to be made either to raise interest rates to try to keep inflation down, or keep interest rates down and allow prices in the shops to rise faster, which would you prefer—interest rates to rise or prices to rise faster?".

Under Knightian uncertainty, households beliefs about future inflation are negatively distorted by households preferences and this distortion varies over time, reflecting the amount of Knightian uncertainty faced by households. Panel (c) shows expected inflation separately for households who like inflation (households with $d_{mi} = 1$) and for household who dislike inflation (households with $d_{mi} = 0$). There is a statistically significant difference in expected inflation: this difference is measured in panel (d) with the grey area representing 95 percent confidence intervals. Households who report to prefer higher inflation have lower expected inflation than households reporting to dislike inflation. The difference peaks to around 40 basis in 2012:I, while it is not statistically different from zero in 2004:I and 2016:I.

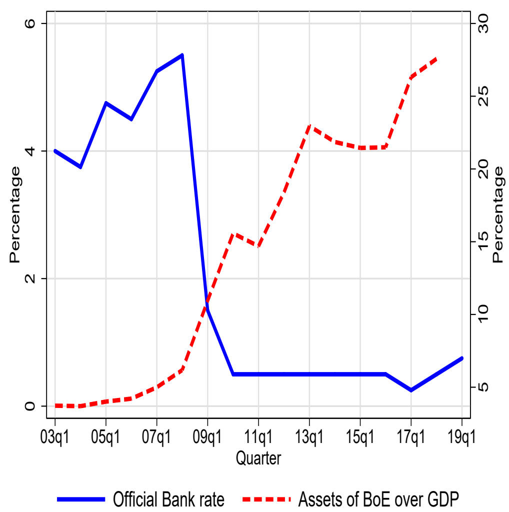
Figure 3: The UK economy



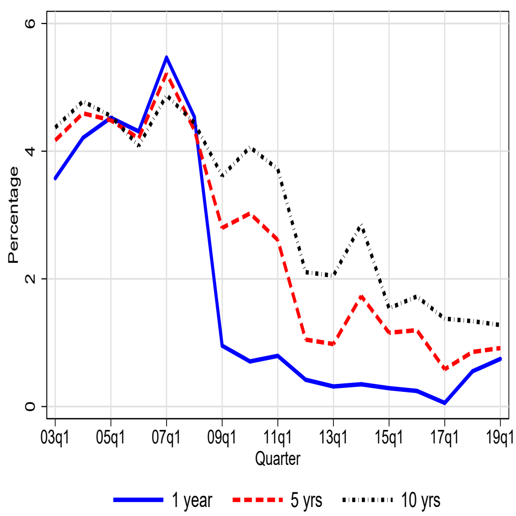
(a) Inflation



(b) GDP and employment



(c) Monetary policy



(d) Interest rates on GILTS

Preferences about interest rates are elicited by asking the following question: "Which would be best for you personally, for interest rates to go up over the next few months, or to go down, or to stay where they are now, or would it make no difference either way?" Possible answers are: (i) Go up; (ii) Go down; (iii) Stay where they are; (iv) Make no difference; (v) No idea. To interpret this question structurally in terms of the model, we rely on the Taylor's rule in (4). After controlling for preferences about the monetary shock, say for the value of d_{mi}, preferences about interest rates elicit preferences about technology shocks: a household likes low interest rates if she likes technology shocks, since, after controlling for m_t, low interest rates rates can only be due to low inflation triggered by an expansionary technology shock. In other words, after controlling for d_{mi}, we interpret the answers to the above question as (indirectly) eliciting the value of d_{zi} in (24): intuitively a household who *dislikes interest rates*, and chooses option (ii) in the above question, is a household who prefers a technology expansion to a technology regression. The fraction of households who would prefer interest rate to go up (option i) is around 26 percent on average (Table 1). Over the period nominal interest rates exhibit a clear negative trend. Panel (d) of Figure 3 shows the evolution of interest rates on fixed-interest loan securities issued by the UK government (GILTS) at different maturities over our sample period: the blue solid line corresponds to the 1-year maturity, the red dashed line to the 5-years maturity, the black dotted line to the 10-years maturity. They were relatively stable before the start of the Great recession and immediately started to fall after the start of the recession.

3.2 Determinants of preferences

The model predicts that wealthier creditor households are more likely to dislike both a monetary loosening and a technology expansion. The BIAS contains information on whether the household has a mortgage and it also assigns the household to one of 4 economic class variables constructed using the NRS social grade classification, roughly associated with the quartile of the UK wealth distribution to which the household in the BIAS belongs to. We refer to households in the 4 groups as a "Top Wealthy" household, a "Upper Middle Wealthy" household, a "Lower Middle Wealthy" household, and a "Poor" household, respectively. We take these 4 dummy variables together with the dummy for whether the household has a mortgage as characterizing household's wealth and her portfolio position in the BIAS. To show visually the relation between households' wealth and their preferences for inflation and interest rates we construct 16 groups of households, depending of whether the household belongs to one of the 4 economic class variables by the NRS, whether the household has a mortgage and whether her annual income is above or below 25000 pounds per year, which roughly corresponds to the median income in the UK population and is information available in the BIAS. For each group, we calculate the average wealth level of households in the group by using the Wealth and Assets Survey (WAS) for wave 3 (2010-

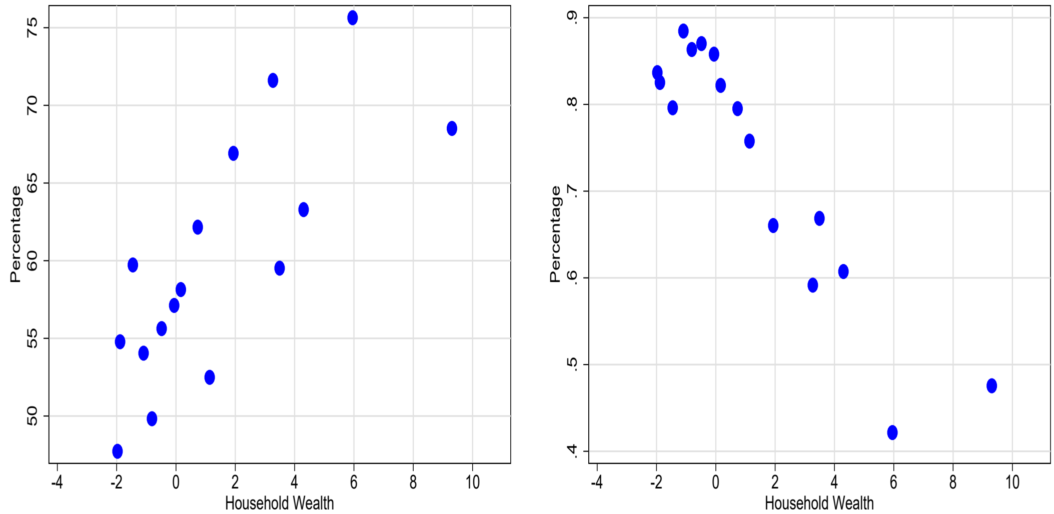
1012), which is the first wave of WAS with detailed household's information needed to reconstruct the 4 economic class variables by NRS in the WAS.[7] We measure household's wealth by adding the value of all real and financial assets of the household after subtracting all household's debt (the sum of the amount owed by the household on all mortgages and other loans). Values are calculated as a ratio of average net annual income in the UK economy. Panel (a) of Figure 4 shows the fraction of households who dislike inflation as a function of the level of average wealth of households in the group.[8] Wealthier households are more likely to dislike inflation. Roughly, a household with negative wealth equal to two times average UK annual labor income dislikes inflation with a probability of 50 percent compared with a probability of 70 per cent for a household with wealth greater than four times average yearly labor income. Panel (b) of Figure 4 analyzes the relation between household's wealth and the fraction of households who dislike both inflation and higher interest rates as a proportion of the number of households who dislike inflation, which is a way of reporting preferences for nominal interest rates after controlling for household's preferences for inflation. Intuitively, this fraction measures the fraction of households who dislike a technology expansion. Consistent with the model, panel (b) indicates that wealthier households are less likely to dislike higher real rates (i.e. lower technology shocks). A household with negative wealth equal to two times average UK annual labor income dislike higher interest rates with a probability of 90 percent while households with wealth greater than four times average yearly labor income dislike higher interest rates with a probability of just 40 per cent.

To study more formally how household's wealth affects household's preferences for inflation (in response to a monetary shock) we run a multinomial Logit for whether the household likes inflation, dislikes inflation, or has no idea about her preferences for inflation, which are mutually exclusive category. We control for a full set of time dummies, 5 geographical dummies (for leaving in Scotland, Wales, Northern Ireland, Midlands or South of England), 6 age dummies, a dummy for gender, a dummy for being employed, 5 income group dummies, and 3 educational dummies (for less than high school, high school degree and for having a college degree or more). Descriptive statistics for these variables are in Table A1 in the Appendix. These variables control for possible differences in the information set of households. The omitted category is "Poor" households. Table 2 reports the resulting average marginal effects on the probability of the 3 categorical variables for preferences for inflation. Households with a mortgage have a probability which is 10 percent higher to like inflation, than a household without a mortgage. A top wealthy household

[7] WAS is a survey conducted by the Office for National Statistics (ONS), which is unique in measuring UK households' assets, savings and debt. WAS over-samples wealthier households and is fully representative of the UK wealth distribution.

[8] The values underlying the scatter plots in Figure 4 are in Table A2 in the appendix.

Figure 4: Preferences and Net wealth



(a) % **dislikes** Π **and wealth**

(b) % **dislikes** Π & i **over HHs who dislike** Π

Wealth excludes value of main residence. Values are calculated as a ratio of average net income in the economy. They refer to 2010-2012. Data on wealth come from the Wealth and Assets Survey.

Table 2: Determinants of preferences for inflation

VARIABLES	(1) HH_dislikes_infl_	(2) HH_likes_infl_	(3) HH_does_not_know
Household with mortgage	-0.08***	0.10***	-0.03***
	(0.00)	(0.00)	(0.00)
Top Wealthy HH	0.10***	0.01*	-0.11***
	(0.01)	(0.01)	(0.00)
Upper Middle Wealthy HH	0.07***	0.00	-0.08***
	(0.01)	(0.00)	(0.00)
Lower Middle Wealthy HH	0.04***	0.01	-0.04***
	(0.01)	(0.00)	(0.00)
Observations	68,425	68,425	68,425

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.10

The table reports the average marginal effects on the probability of the three categorical variables for preferences for inflation after estimating a Multinomial logit. All regressions contain a full set of time dummies. 5 geographical dummies for leaving in Scotland, Wales, Northern Ireland, Midlands or South of England, six age dummies, a dummy for gender, dummy for being employed, five income group dummies, and educational dummies for Less than high school, High school degree and for having a College degree or more. The omitted category is the "Poor" household category.

has a 10 percent higher probability to dislike inflation than a poor household. Interestingly, this last marginal effect comes from a reduction in the probability that the household does not report her preferences for inflation, which is an issue we will address later.

Given household's preferences for inflation, in Table 3 we study the determinants for whether the household prefers lower or higher interest rates. We run a multinomial Logit for whether the household would like interest rate to go up, go down, or stay where they are, for whether interest rates make no difference to the household or for whether the household has no idea about her preferences for interest rates. The controls are as in Table 2. We also control for household's preferences for inflation, since our interpretation for preferences for interest rates hold only after controlling for household's preferences for monetary policy. The omitted category is a "Poor" household who do not know her preferences for inflation. A household who dislikes inflation has a 15 percent higher probability to prefer interest rates to go up than a household who has no preference for inflation. A household with mortgages have a 21 percent higher probability to prefer interest rate ro remain the same or to go down, than a household without a mortgage. A top wealthy household has a 16 percent higher probability to prefer interest rates to go up than a poor household. This increase in probability comes roughly equally from all the other 4 categories for preferences on interest rates.

4 Effects of preferences on expectations

We now study in more details how preferences affect household beliefs. In this Section we study average effects over the entire sample period. The next Section deals with time-series effects. We first analyze expected inflation at a 1 year ahead time horizon and deal with possible biases due to selection or the endogeneity of preferences. Secondly, we analyze the effects (i) on expected inflation at 2 and 5 years time horizon, (ii) at different quartiles of the distribution of expected inflation, and (iii) on expected future interest rate changes (rather than expected inflation). We conclude by studying whether the component of expected inflation due to households' preferences affects households' choices for consumption, savings, portfolio allocations and wages.

4.1 Baseline evidence

We run the regression (25) on the BIAS data. The dependent variable is the 1 year ahead expected inflation of the household, $n = 1$. In column 1 of Table 4 we just add as a regressor whether the household likes inflation, which corresponds to the dummy d_{mi} in (25). This specification corresponds to (25) with the regression constant measuring $E^{\sigma}_{t_0}(\Pi_{t_0+n})$. The regression is ran on the sample of households who report both their expected inflation and their preferences—for inflation in columns 1-2 as well as for interest rate changes in columns

Table 3: Determinants of preferences for interest rate changes

VARIABLES	(1) Go_up	(2) Go_down	(3) Same	(4) Indifferent	(5) Not_know
HH dislikes Π	0.15***	-0.01*	-0.01**	0.03***	-0.16***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
HH prefers high Π	0.00	0.09***	0.05***	-0.06***	-0.07***
	(0.01)	(0.01)	(0.01)	(0.00)	(0.00)
Household with mortgage	-0.12***	0.11***	0.10***	-0.07***	-0.03***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Top Wealthy HH	0.16***	-0.05***	-0.03***	-0.05***	-0.03***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.00)
Upper Middle Wealthy HH	0.12***	-0.04***	-0.01**	-0.04***	-0.02***
	(0.01)	(0.01)	(0.01)	(0.00)	(0.00)
Lower Middle Wealthy HH	0.08***	-0.03***	-0.00	-0.04***	-0.01***
	(0.01)	(0.01)	(0.01)	(0.00)	(0.00)
Observations	68,425	68,425	68,425	68,425	68,425

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.10

The table reports the average marginal effects from estimating a Multinomial logit on the probability of the five categorical variables for preferences for interest changes: whether the household would like interest rate to go up, go down, or stay where they are, whether interest rates make no difference to the household or whether the household has no idea about her preferences for interest rates. All regressions contain a full set of time dummies. 5 geographical dummies (for leaving in Scotland, Wales, Northern Ireland, Midlands or South of England), 6 age dummies, a dummy for gender, a dummy for being employed, 5 income group dummies, and 3 educational dummies (for Less than high school, High school degree and for having a College degree or more). The omitted category is a "Poor" household who do not know their preference for inflation.

3-4. On average a household who likes inflation has a 1 year ahead expected inflation which is lower by 18 basis points. The regressions in columns 2-4 of Table 4 also control for a full set of time dummies, 5 geographical dummies (for leaving in Scotland, Wales, Northern Ireland, Midlands or South of England), 6 age dummies, a dummy for gender, a dummy for being employed, 5 income group dummies, and 3 educational dummies (for less than high school, high school degree or a college degree or more). Their estimated coefficients are in Table A3 in the Appendix. The controls are intended to account for differences in the information set available to households or in their ability to process information, that might lead to differences in households rational expectation beliefs, say in the value of $E^{\sigma}_{t_0}(\Pi_{t_0+1})$ in (25). In addition to these controls, the regression in columns 3 includes household's preferences for changes in interest rates. The regression in column 4 further adds information on household's knowledge about monetary policy—as proxied by whether the household knows about the Monetary Committee and is aware that the Bank

Table 4: Effects of Preferences on expected inflation

VARIABLES	(1) Π^e	(2) Π^e	(3) Π^e	(4) Π^e
HH prefers high Π	-0.18***	-0.14***	-0.15***	-0.13***
	(0.02)	(0.02)	(0.02)	(0.02)
HH prefers i up			-0.13***	-0.08***
			(0.02)	(0.02)
HH prefers i unchanged			-0.16***	-0.13***
			(0.02)	(0.02)
HH is indifferent on i			-0.06**	-0.03
			(0.03)	(0.03)
BoE sets i				-0.13***
				(0.02)
HH knows Monetary Cmte.				-0.05**
				(0.02)
BoE is independent				-0.11***
				(0.02)
UK econ. needs high Π				-0.42***
				(0.03)
UK econ. is indifferent on Π				-0.33***
				(0.02)
Dk whether UK needs Π				-0.30***
				(0.03)
Observations	47,273	47,273	45,715	45,715
Method	OLS	OLS	OLS	OLS
R^2	0.08	0.09	0.09	0.10
Wald test	0.00	0.00	0.00	0.00

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.10

The table reports the coefficients of a regression where the dependent variable is expected inflation at a 1 year ahead time horizon. In addition to the regressors reported in the Table, the regressions in columns 2-4 also control for a full set of time dummies, 5 geographical dummies (for leaving in Scotland, Wales, Northern Ireland, Midlands or South of England), 6 age dummies, a dummy for gender, a dummy for being employed, 5 income group dummies, and 3 educational dummies (for less than high school, high school degree or a college degree or more). In columns 1-2, the excluded category is a household who dislikes inflation. In columns 3-4, it is a household who dislikes both inflation and interest rates to go down. The last row in each column reports the p-value for the null hypothesis that all preference coefficients are equal to zero.

of England is independent and sets the interest rates—as well as household's self-reported beliefs about whether the UK economy (rather than the household) would be better off by having higher inflation. The reference group in columns 3 and 4 is a household who dislikes inflation and would prefer interest rate to go down. We take the controls in column

4 to be quite conservative since, under Knightian uncertainty, the same reasons that might lead the household to believe that the UK would be better off by having higher inflation would also lead the household to distort her beliefs about future inflation. The last row in each column reports the p-value of a Wald-test for the null hypothesis that all preference coefficients (for inflation and interest rates) are equal to zero, which is strongly rejected in all specifications. On average, after including the full set of controls, a household who likes inflation has lower expected inflation by around 13 basis points. A household who would like interest rate to go up (following our model, a household who dislikes technology expansions) tends to have a lower expected inflation by around 10 basis points, which falls slightly to 8 basis point when considering the more restrictive specification of column 4. There is no statistically significant difference on expected inflation between a household who prefers interest rates to go up and a household who prefers interest rates to remain unchanged, which is consistent with the fact that, over our sample period, interest rates have a negative trend, see panel (d) in Figure 3: loosely speaking, interest rates either fall or remain the same. Thereafter we are going to impose that the two regression coefficients are exactly equal, which will help in gaining statistical power, and we are going to focus on the specification with the same full set of controls as in column 4 of Table 4.

Since households self-select into reporting their preferences as well as their expected inflation, the regressions in Table 4 might be plagued by a selection bias. To deal with this issue, we consider a selection model and exploit the fact that households are more likely to report their beliefs about future inflation and their preferences for inflation and interst rates if they provide an estimate for today inflation and understand the idea that higher interest rates set by the Bank of England are likely to reduce inflation at a time horizon of 1 month and 1 year, which is key to understand the logic underlying the question that we use to classify whether the household likes or dislikes inflation. Specifically, we construct the following three dummies: one for whether the household does not provide any estimate for "how prices have changed over the last twelve months"; one for whether the household agrees or strongly agrees with the statement that "a rise in interest rates makes prices in the high street rise more slowly in the short term (say a month or two)"; and finally one for whether the household agrees or strongly agrees with the statement that "a rise in interest rates makes prices rise more slowly in the medium term (say a year or two)". Column 1 of Table 5 reports the average marginal effects of a Probit regression for observing future inflation and preferences for inflation and interest rates, which corresponds to the fist stage regression used by Heckman (1979) to control for selection biases. Column 2 reports the average marginal effects on the probability for the household reporting her expected inflation and he preferences for inflation and interest rate changes using a logit model rather than a probit model, which is the fist stage regression used by Lee (1979, 1983) to control for the existence of a selection bias. Table 6 reports the coefficients of the second stage

Table 5: Probit or Logit of observing future inflation: First stage Heckman (1979) or Lee (1982)

VARIABLES	(1) Observing Π^e and U	(2) Observing Π^e and U
HH does not know past Π	-0.42***	-0.44***
	(0.01)	(0.01)
i affects Π in 1-2 months	0.06***	0.07***
	(0.01)	(0.01)
i affects Π in 1-2 yrs	0.09***	0.10***
	(0.01)	(0.01)
HH prefers high Π	0.29***	0.30***
	(0.01)	(0.01)
HH prefers i up or equal	0.44***	0.46***
	(0.00)	(0.00)
Observations	68,425	68,425
Method	Heckman-Probit	Lee-Logit
Wald test	0.00	0.00

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.10

Column (1) reports the average marginal effects for observing future inflation and households' preferences for inflation and interest rate changes using a Probit model. Column (2) reports the average marginal effects on the probability of observing future inflation and preferences using a logit model. The controls are the same as in column 4 of Table 4. The instruments for selections are obtained constructing the following three dummies: one for whether the household does not provide an estimates for how prices have changed over the last 12 months and one for whether she agrees or strongly agrees with the statement that "a rise in interest rates would make prices in the high street rise more slowly in the short term (say a month or two)" and a third one for whether she agrees on the statement that"a rise in interest rates would make prices in the high street rise more slowly in the medium term (say a year or two).

regression where the dependent variable is expected inflation and we deal with the selection bias by following Heckman (1979) and Lee (1979, 1983) in adding the inverse Mills ratio as obtained by estimating a Probit model (as in column 1 of Table 5) or a logit model (as in column 2 of Table 5) to the set of regressors present in the specification of column 4 in Table 4. Standard errors are calculated by bootstrapping the two-step procedure. A negative coefficients on the inverse Mills ratio indicates a negative correlation between the error in the structural equation (for the effects of preferences on expected inflation) and the error in the selection equation (for reporting expected inflation and preferences). The last row reports the p-value for the null hypothesis that all preference coefficients are equal to zero. Overall, controlling for selection into reporting expectations and prefrences increases the magnitude of the estimated coefficients on household's preferences: by around 4 basis point when considering household's preferences for higher inflation and by more than 10

Table 6: **Effects of Preferences on expectations: Selection and IV**

VARIABLES	(1) Π^e	(2) Π^e	(3) Π^e	(4) Π^e
HH prefers high Π	-0.20***	-0.19***	-3.06***	-3.05***
	(0.03)	(0.03)	(0.62)	(0.62)
HH prefers i up or equal	-0.22***	-0.21***	-2.40***	-2.40***
	(0.04)	(0.04)	(0.65)	(0.65)
Inverse Mill's ratio, probit	-0.19***		-0.26***	
	(0.05)		(0.08)	
Inverse Mill's ratio, logit		-0.18***		-0.26***
		(0.05)		(0.08)
Observations	37,031	37,031	37,031	37,031
Selection	Heckman-Probit	Lee-Logit	Heckman-Probit	Lee-Logit
2nd stage	OLS	OLS	IV	IV
Wald test	0.00	0.00	0.00	0.00

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.10

The table reports the coefficients of a regression where dependent variable is 1 year expected inflation and regressors are listed by rows. The last row reports the p-value for the null hypothesis that all preference coefficients are equal to zero. Columns 1 and 3 deal with selection into reporting expectations and prefrences by using a Probit model as in Heckman (1979), columns 2 and 4 using a logit model as in Lee (1979, 1983). The controls are the same as in column 4 of Table 4. The instruments for selection are the same as in 5. Columns 2 and 4 instrument household's preferences for inflation and interest rates using information on household's portfolios as measured by 4 dummy variables for household's wealth together with the dummy for whether the household has a mortgage.

basis points when considering her preferences for higher (or equal) interest rates. Differences in preferences might be correlated with differences in the information set available to households, so that our reduced form coefficients might un-accurately reflect distortions in subjective beliefs due to Knightian uncertainty. To address this concern we rely on a key property of the model that implies that preferences about inflation and interest rates are (at least partly) caused by differences in the wealth position of the household, which can be used as a relevant instrument for household's preferences. Household's wealth portfolios are characterized by the previously discussed 4 dummy variables for wealth together with the dummy for whether the household has a mortgage. To help guaranteeing that the instrument satisfies the exclusion restriction, we again control for the same extensive set of controls as in column 4 of Table 4. We simultaneously deal with the selection bias and for the endogeneity of preferences follwoing the procedure discussed in Section 19.6.2 in Wooldridge (2010). Essentially we first estimate a probit (or a logit) model for the selection indicator including all exogenous variables: those determining preferences and those determining selection into expectations and preferences and use the probit (or logit) model to obtain the inverse Mills ratios. Then we estimate the (structural) equation for expected inflation by two Stage Least Square (2SLS) adding the inverse Mills ratios as a regressor and using information on household's wealth portfolios as relevant instruments for household's preferences. Standard errors are calculated by bootstrapping the entire procedure. After simultaneously controlling for selection into reporting beliefs and preferences as well for the possible endogeneity of preferences, we still find that a household who prefers high inflation and higher or equal interest rates tends to have lower expected inflation. The effects remain statistically significant. Yet the size of the estimated coefficients substantially increase, with their standard errors also increasing by a similar order of magnitude.

4.2 Further evidence

Starting from 2009, the BIAS also asks households for their expected inflation at a 2 and a 5 year time horizon. We ran the same regression as in column 4 of Table 4 using expected inflation at these longer time horizons as a dependent variable. Given the change in the sample period, as a term of comparison, we also report the estimates using the 1 year expected inflation. Table 7 reports the results. The last row of each column reports the

Table 7: Effects of Preferences on expectations: Additional evidence from 2009

VARIABLES	(1) 1yrΠ^e	(2) 2yrΠ^e	(3) 5yrΠ^e
HH prefers high Π	-0.23***	-0.14***	-0.19***
	(0.04)	(0.04)	(0.05)
HH prefers i up	-0.11**	-0.18***	-0.27***
	(0.05)	(0.05)	(0.06)
HH prefers i unchanged	-0.13***	-0.16***	-0.23***
	(0.04)	(0.04)	(0.05)
HH is indifferent on i	-0.02	-0.02	-0.09
	(0.05)	(0.05)	(0.06)
Observations	29,983	25,636	22,936
Method	OLS	OLS	OLS
R^2	0.10	0.07	0.02
Wald test	0.00	0.00	0.00

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.10

The table reports the coefficients of a regression where the dependent variable is expected inflation at 1 year, 2 years and 5 years time horizon in column 1 , 2 and 3, respectively. The specification is the same as in column 4 of Table 4. The last row reports the p-value for the null hypothesis that all preference coefficients are exactly equal to zero. The reference group is a household who dislikes inflation and would prefer interest rate to go down.

p-value for the null hypothesis that all preference coefficients are exactly equal to zero. The reference group is the same as in column 4 of Table 4: a household who dislikes inflation and would prefer interest rate to go down. Relative to this reference household, on average a household who prefers high inflation has a lower expected inflation by 23 basis point at a 1 year time horizon. This difference falls by around 5-7 basis points when looking at expected inflation at a 2 or 5 years ahead time horizon. This indicates that households face Knightian uncertainty also at longer time horizons.

Table 8 reports the coefficients of quantile regressions where the dependent variable is expected inflation at a 1 year time horizon. The controls are the same as in column 4 in Table 4. The coefficients on preferences are listed by rows. The last row reports the p-value for the null hypothesis that all preference coefficients are equal to zero. The effects of preferences on beliefs appears to be present at all quartiles of the distribution of expected inflation. The effects at the median are similar to the effects at the mean that suggests that the previous estimates are not driven by the presence of outliers. The effects of preferences on beliefs is somewhat stronger for households with higher expected inflation—they are stronger at the top quartile than at the bottom quartile). In Table A6, we also studied whether the effect of preferences on expected inflation varies across households with different educational levels, or different level of income. We find that the effects are not statistically different across groups. We interpret this evidence as suggesting that the coefficients of preferences on beliefs measure the underlying level of uncertainty generally faced by households in the economy when taking their decisions.

For robustness, in Table 9 we also checked that a similar negative bias of expectations due to preferences arises when households are asked to predict the future evolution of nominal interest rates, rather than future inflation. We estimate an ordered logit model using as dependent variable categorical variables constructed from the following question: "how do you expect interest rates to change over the next twelve months?". The qualitative answers to the question allows us to construct the three following categorical variables: (i) interest rates will rise, (ii) interest rates will stay about the same, and (iii) interest rates will fall. On average, 47 percent of UK households believe that interest rates will rise, see Table 1. We then estimate an ordered logit model including households' preferences for future changes in interest rates as controls.[9] In the model we also include the full set of controls as in column 4 in Table 4.[10] The reference group is a household who prefer interest rates to remain unchanged. The model is estimated on the sample of households who report their expectations on the future evolution of interest rates as well their personal preferences

[9]Table A5 reports analogous results using an Ordered Probit model rather than an ordered probit model.

[10]Table A4 in the Appendix reports the analogous results when the regressions do not contain any additional controls.

Table 8: **Effects of Preferences on expectations: Quantile Regressions**

VARIABLES	(1) 1st quart. Π^e	(2) 1st quart. Π^e	(3) Median Π^e	(4) Median Π^e	(5) Top quart. Π^e	(6) Top quart. Π^e
HH prefers high Π	-0.07***	-0.09***	-0.11***	-0.11***	-0.16***	-0.19***
	(0.02)	(0.02)	(0.02)	(0.02)	(0.04)	(0.04)
HH prefers i up		-0.06***		-0.06**		-0.13***
		(0.02)		(0.03)		(0.04)
HH prefers i unchanged		-0.10***		-0.12***		-0.16***
		(0.02)		(0.03)		(0.04)
HH is indifferent on i		-0.01		-0.02		-0.06
		(0.02)		(0.03)		(0.04)
Observations	47,273	45,715	47,273	45,715	47,273	45,715
Method	OLS	OLS	OLS	OLS	OLS	OLS
Controls	YES	YES	YES	YES	YES	YES
Wald test	0.00	0.00	0.00	0.00	0.00	0.00

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.10

The table reports the coefficients of quantile regressions where dependent variable is expected inflation at a 1 year time horizon. The controls are the same as in column 4 in Table 4. The coefficients on preferences are listed by rows. The last row reports the p-value for the null hypothesis that all preference coefficients are equal to zero.

for nominal interest rate changes. The results in Table 9 indicate that a household who personally prefers interest rate to go down has a probability to believe that interest rates will go up which is 7 percentage point higher than the analogous probability by a household who prefers interest rates to remain unchanged. This evidence is again consistent with the idea that households face some Knightian uncertainty.

4.3 Effects of preferences on choices

Even if households' preferences do affect households' self-reported beliefs, it might be that the component of beliefs due to preferences could have no or little effects on households' choices—i.e. they could be just a form of "cheap talking" with no material consequences on households' decisions. We investigate this issue in Tables 10 and 11 using a set of questions available in the BIAS since 2011. In particular, we estimate a linear probability model for whether in the light of household's expectations of price changes over the next twelve months the household "brings forward major purchases" (columns 1 and 2 of Table 10), "spends less" (columns 3 and 4 of Table 10), "shops around more" (columns 5 and 6 of Table 10), "pushes for a pay increase" (columns 7 and 8 of Table 10), "searches for more income" (columns 1 and 2 of Table 11), "saves more in financial assets" (column 3 and 4 of Table 11), "does something else" (column 5 and 6 of Table 11), and "takes no action" (columns 7 and 8

Table 9: Effects of Preferences on expected interest rates, Ordered Logit

VARIABLES	(1) ie_down	(2) ie_equal	(3) ie_up
HH prefers i up	0.01***	0.02***	-0.02***
	(0.00)	(0.00)	(0.01)
HH prefers i down	-0.02***	-0.05***	0.07***
	(0.00)	(0.00)	(0.01)
Observations	44,284	44,284	44,284
Method	Ordered Logit	Ordered Logit	Ordered Logit
Variables	Yes Controls	Yes Controls	Yes Controls
Wald test	0.00	0.00	0.00

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.10

The table reports the average marginal effects on the probability of the future dynamics of (nominal) interest rates, using an ordered logit model. The last row reports the p-value for the null hypothesis that all preference coefficients are all equal to zero. The controls are the same as in column 4 of Table 4.

of Table 11). We reports the estimated coefficients for expected inflation. The odd columns of each Table correspond to the OLS estimates, the even columns to the IV estimates obtained by instrumenting household's expected inflation with their preferences for higher or lower inflation and higher or lower interest rate changes, as measured by the previously discussed dummies for households' preferences as, for example, in column 4 of Table 4. The IV estimates measure the effects on choices of the components of expected inflation due to household's preferences (say the effects of the distortion of beliefs due to Knightian uncertainty). The two rows at the bottom of each even column in the tables report the test by Durbin (1954) and the one by Hausman (1978) for the null hypothesis that the effects of expected inflation on choices are the same in the OLS and in the IV specification. In calculating the Durbin and the Hausman tests we use a robust Variance Covariance Matrix. Generally expected inflation increase the probability that the household cuts spending, shops around more, searches for more income, and does something else, which suggests that changes in household's expected inflation changes her actions. The estimates in Tables 10-11 also indicate that changes in inflation expectations due to preferences change the saving, consumption, and financial portfolio behavior of households in a way that is quantitatively similar to (and generally larger than) the component of expected inflation unrelated to preferences. This provides support to the idea, that households preferences not only distort their beliefs but also their choices.

Table 10: Effects of Expected Inflation on choices I

VARIABLES	(1) Major	(2) Major	(3) Cut Spend.	(4) Cut Spend.	(5) Search	(6) Search	(7) Pay	(8) Pay
Expected infl.	0.00	0.01	0.02***	0.40***	0.01***	0.49***	0.00***	0.04
	(0.00)	(0.02)	(0.00)	(0.10)	(0.00)	(0.12)	(0.00)	(0.04)
Observations	17,400	17,400	18,086	18,086	18,298	18,298	17,395	17,395
Method	OLS	IV	OLS	IV	OLS	IV	OLS	IV
R^2	0.12	0.12	0.15		0.12		0.13	
Durbin		0.73		0.00		0.00		0.36
Wu-Hausman		0.73		0.00		0.00		0.36

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.10

The Table reports the OLS and the IV coefficient of expected inflation on a dummy for whether, in the light of household's expectations of price changes over the next twelve months, the household "brings forward a major purchase" (columns 1 and 2), "spends less" (columns 3 and 4), "shops around more" (columns 5 and 6), or "pushes for pay increase" (columns 7 and 8). The two rows at the bottom of each even column report the Durbin and the Wu-Hausman tests for the null hypothesis that the effects of inflation expectations on choices is the same in the OLS and the IV specification. In the IV specification, expected inflation is instrumented using households' preferences for inflation and interest rate changes as measured by the dummies in column 4 of Table 4. The other controls are the same as in column 4 of Table 4.

Table 11: Effects of Expected Inflation on choices II

VARIABLES	(1) Income	(2) Income	(3) Save	(4) Save	(5) Other	(6) Other	(7) No act.	(8) No act.
Expected infl.	0.01***	0.18***	-0.00	-0.05	-0.02***	-0.33***	-0.00	-0.09***
	(0.00)	(0.06)	(0.00)	(0.04)	(0.00)	(0.09)	(0.00)	(0.03)
Observations	17,620	17,620	17,496	17,496	17,294	17,294	14,804	14,804
Method	OLS	IV	OLS	IV	OLS	IV	OLS	IV
R^2	0.18		0.13		0.12		0.17	
Durbin		0.00		0.14		0.00		0.00
Wu-Hausman		0.00		0.14		0.00		0.00

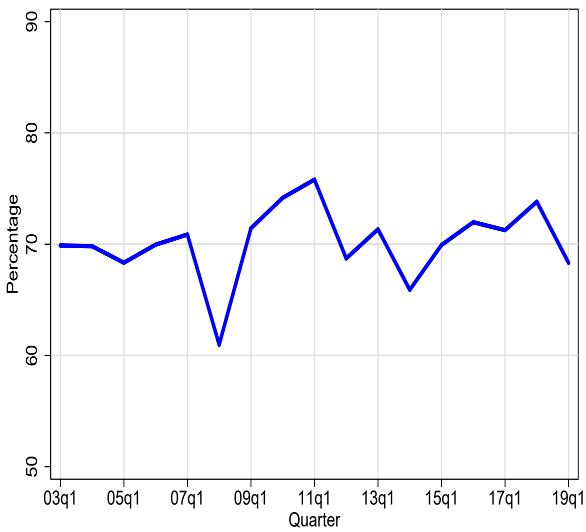
Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.10

The Table reports the OLS and the IV coefficient of expected inflation on a dummy for whether, in the light of household's expectations of price changes over the next twelve months, the household "searches for more income" (columns 1 and 2), "saves more in financial assets" (column 3 and 4), "does something else" (column 5 and 6), "takes no action" (columns 7 and 8). The two rows at the bottom of each even column report the Durbin and the Wu-Hausman tests for the null hypothesis that the effects of inflation expectations on choices is the same in the OLS and the IV specification. In the IV specification, expected inflation is instrumented using households' preferences for inflation and interest rate changes as measured by the dummies in column 4 of Table 4. The other controls are the same as in column 4 of Table 4.

5 Time series evolution

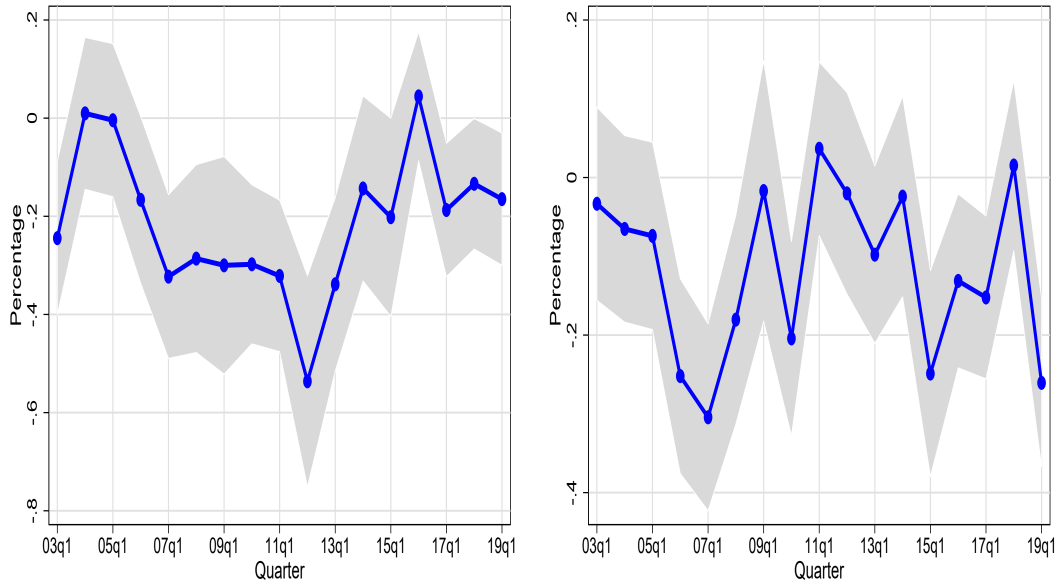
We now study how the coefficients of the regression in (25) change over our sample period. Figure 5 shows that the fraction of households who report their preference for inflation and interest rates as well as their beliefs about future inflation. The series has an average close to 70 percent but exhibits some fluctuations, which might cause changes in the importance of the selection bias over time. To address this, we estimate the same selection model as in column 1 of Table 6 after allowing all regression coefficients to vary over time—this means the coefficients on all controls in the selection equation as well as all controls entering the structural equation for the effects of preferences on expected inflation, including the inverse Mill's ratio. Panel (a) of Figure 6 shows the resulting time series profile of the dummy variable coefficients for whether the household likes inflation. Panel (b) shows the time series profile of the dummy variable coefficients for whether the household would personally prefer interest rate to go up (or remain the same). The grey areas represent 90 percent confidence intervals for the estimated coefficients. We focus the analysis on the results based on the probit specification but quantitatively similar results are obtained when accounting for selection through a logit model. Intuitively, Panel (a) measures Knightian uncertainty

Figure 5: Fraction of households reporting preferences and beliefs



about monetary policy, Panel (b) about technology shocks (say the underlying economic environment). The two profiles indicate that Knightian uncertainty generally increases after major economic events such as the failure of Lehman Brothers or the referendum in favor of Brexit, and it is driven partly by uncertainty about future monetary policy and partly by uncertainty about future technology shocks. Uncertainty about monetary policy dominates the period 2010-2013, while uncertainty about technology is predominant in the late years of the sample. It is also sizable at the start of the Great Recession.

Figure 6: Monetary Policy and Economic Uncertainty

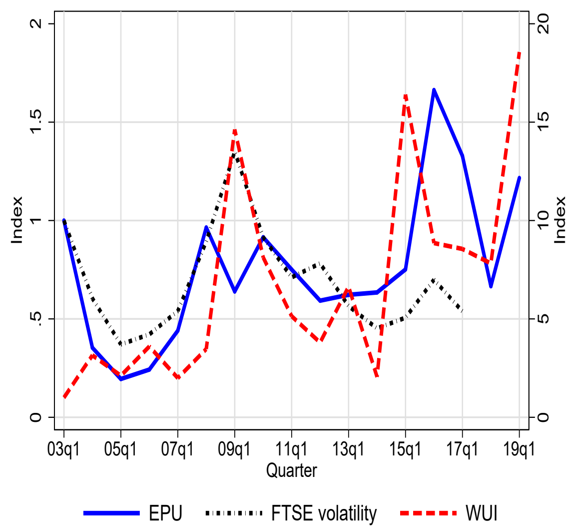


(a) Monetary Policy uncertainty with controls & selection **(b) Economic uncertainty with controls & selection**

The controls are the same as in column 4 of Table 4. The specification is the same as in column 1 of Table 6 after allowing all coefficients to vary over time including those in the selection equation and the inverse Mill's ratio in the equation for the effects of preferences on expected inflation.

We compare our measure of Knightian uncertainty for monetary policy (Panel (a) of Figure 6) and technology shocks (Panel (b) of Figure 6) with other measures of uncertainty already proposed in the literature and plotted in panel (a) of Figure 7. The blue solid line corresponds to the Economic Policy Uncertainty (EPU) index by Baker, Bloom, and Davis (2016), the red dashed line to the World Uncertainty Index (WUI) by Ahir, Bloom, and Furceri (2018), constructed counting words related to uncertainty in official reports by the IMF, the black dotted line to the 360-day standard deviation of the return on the UK national stock market index (FTSE). The Table in panel (b) of Figure 7 reports the correlation between our two measures of uncertainty in Figure 6 with the three measures in panel (a) of Figure 7. Since according to our measures, uncertainty increases when the regression coefficients become more negative, a more negative correlation indicates a stronger correlation between our measure and the other existing measures, which are all defined as strictly positive variables increasing with the amount of uncertainty in the economy. Our measure of Knightian uncertainty is correlated with the three previously discussed indexes. Monetary policy uncertainty is more strongly correlated with stock market volatility, suggesting that Knightian uncertainty about monetary policy is an important driver of the volatility of stock market returns, while its correlation with the EPU or WUI is quantitatively small, suggesting that monetary policy matters little for the overall amount of Economic Policy uncertainty present in the UK economy. Our measure of uncertainty about technology is mostly correlated with the WUI, while its correlation with both the volatility of stock market returns and EPU is mild. This might suggest that the UK economy has faced some Knightian uncertainty over the period, but this uncertainty might not be fully reflected in stock market returns, whose volatility might reflect mostly the beliefs of the subset of creditor wealthy households who invest their financial wealth in stocks.

Figure 7: Other measures of uncertainty



(a) Other measures of uncertainty

	Like Π	Like i up
Contemporaneous volatility		
EPU index	0.14	-0.06
WUI index	0.01	-0.35
Stock market volatil.	-0.43	0.08
Lagged volatility		
EPU index lag. 1	0.10	0.34
WUI index lag. 1	0.15	0.01
Stock market volat. lag.	-0.19	0.24

(b) Correlations

EPU stands for the Economic Policy Uncertainty index by Baker, Bloom, and Davis (2016) available at www.PolicyUncertainty.com. WUI is the World Uncertainty Index obtained from The World Uncertainty Index by Ahir, Bloom, and Furceri (2018). FTSE-Volatility is the 360-day standard deviation of the return on the national stock market index (FTSE) as calculated from the Worldbank

6 Measuring uncertainty

We use the model of Section 2 to estimate the amount of Knightian uncertainty about monetary policy and technology implied by the previous estimates. Uncertainty about monetary policy and technology is measured by $\overline{v}_t$ and $\overline{\epsilon}_t$, respectively. We first calibrate some model key parameters and then estimate the amount of Knightian uncertainty through indirect inference, taking the regression coefficients in Figure 6 as estimation targets. As in Section 2, we assume the economy is initially in a steady state and consider a sequence of unexpected shocks to uncertainty that households assume will be resolved in the following year. This procedure is simple, transparent, and allows us to characterize non linear effects in the household decision problem, which permits to compare the effects of risk (that matters only up to a second order) with those of uncertainty.[11] After recovering the amount of Knightian uncertainty, we aggregate the consumption choices of all households in the economy and calculate by how much aggregate output would have changed if households had processed uncertainty in the form of measurable risk.

6.1 Calibration

We calibrate the model at the yearly frequency. The time discount factor is set to $\beta = 0.95$, which yields a yearly return on savings of 5% roughly equal to the average yearly return on the UK stock market. Following Guvenen (2006) we set the elasticity of intertemporal substitution (EIS) to 0.5, implying $\sigma = 2$. The elasticity of substitution across goods is set to $\theta = 5$, consistent with micro level evidence on the elasticity of substitution across varieties (Nevo 2001; Chevalier, Kashyap, and Rossi 2003; and Broda and Weinstein 2006) and in the range of values typically used in macro models, see for example Midrigan (2011). The elasticity of the production function to labor, α, is set equal to 0.85 to target a labor share of output of 2/3 in steady state, a common value in the literature. The parameter governing the convex cost of price adjustment is $k_0 = 9.5$ which, together with θ and α, implies a slope of the new Keynesian Phillips curve of $\kappa = 0.44$. Under Calvo pricing, this slope would imply a yearly frequency of price changes of 1/2, in line with the literature. The coefficient of the Taylor rule is set to the common value $\phi = 1.5$. We set the persistence of the monetary shock to $\rho_m = 0.4$, and the persistence of the productivity shock to $\rho_z = 0.99$. We allow the transfer function τ to vary across 16 different group of households, set depending on whether the income of the household is above or below the median in the UK population, the household has a mortgage or not and household's wealth belongs to one of the four wealth dummies in the BIAS. Since no shocks materializes at time t_0, there are no transfers at t_0 and without loss of generality we can set $\bar{\tau} = \bar{\tau}_{im0} = \bar{\tau}_{iz0} = 0$. For simplicity we assume, that the household thinks that the transfer coefficients will remain constant in every period thereafter: $\bar{\tau}_{imt} = \bar{\tau}_{im}$ and $\bar{\tau}_{izt} = \bar{\tau}_{iz}$, $\forall t \geq t_0$. This formulation implies that, to fully characterize the transfer function in a group of households, we only have to calibrate two values, that we set by targeting the fraction of households in the group that like a monetary policy loosening and productivity expansion, as implied by Figure 4. More formally, in each group, we calculate the wealth thresholds a^*_m and a^*_z below which households in the group prefer a monetary loosening to a monetary contraction

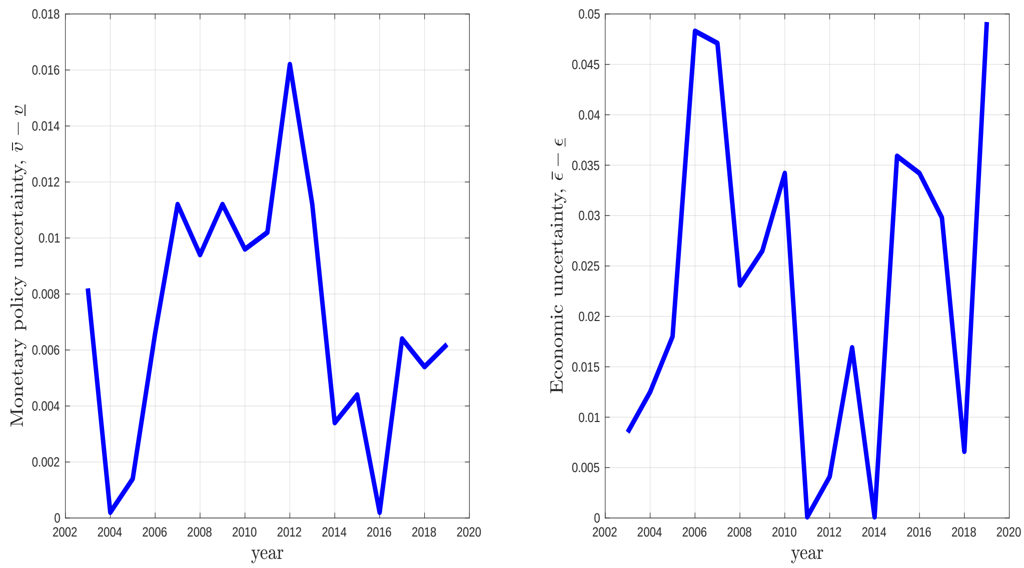
[11] Ilut, Krivenko, and Schneider (2018) propose a method to solve models with heterogeneous agents and Knightian uncertainty through linear approximation. Their method is hard to apply in our context with 160 types of different types of households. Since our estimation targets are obtained by estimating regressions which contain a full set of time dummies, that control for aggregate changes in the state of the economy, we generally believe that the assumptions that the economy is initially in a steady state and that the shocks are unexpected matter little for the estimated time series profile of Knightian uncertainty that we back up from the data.

and a technology expansion to a technology regression, respectively. These wealth levels correspond to the circles in Figure 1. Given the wealth distribution of households in the group (from the WAS), these thresholds determine the fraction of households in the group who like a monetary policy and a technology shock. We calibrate $\bar{\tau}_{im}$ and $\bar{\tau}_{iz}$ to match the fractions in Figure 4.

6.2 Estimated profiles

As in Section 2, we assume $\bar{v}_t = -\underline{v}_t$ and $\bar{\epsilon}_t = -\underline{\epsilon}_t$, so that under measurable risk and a uniform prior the shock would have zero expected value. We search for the time series profile of $\bar{v}_t$ and $\bar{\epsilon}_t$ that yields the time series profile of the regression coefficients in Figure 6. For each year t, we consider an "MIT" shock to uncertainty that hits the economy initially in a steady state. At year t and given a pair $\bar{v}_t$ and $\bar{\epsilon}_t$ we run the regression (25) on the cross sectional data simulated by the model and then search for the values of $\bar{v}_t$ and $\bar{\epsilon}_t$ that the regression coefficients in the model simulated regression are equal to the value reported in Figure 6 for the corresponding year t. The model matches exactly the estimated coefficients from the data. Figure 8 plots the resulting estimated profile of monetary policy uncertainty (panel a) and technology/economic uncertainty (panel b). Standard errors are calculated using delta-methods. Grey areas correspond to 90 percent confidence intervals. There is substantial variation over time in the two time series. Uncertainty about monetary policy and technology are just mildly correlated (correlation equal to -0.07) suggesting that they measure two largely orthogonal sources of uncertainty. Given the estimates for

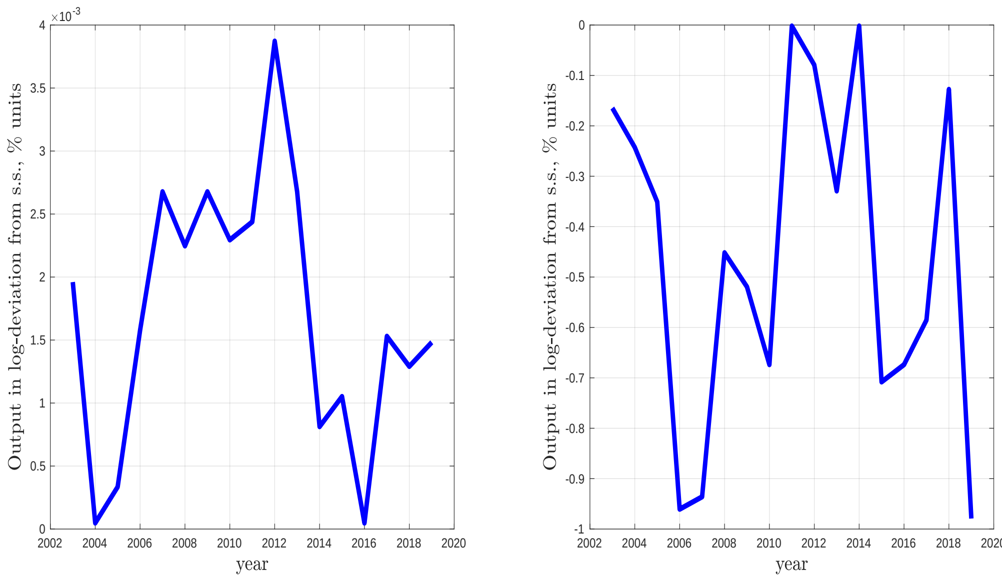
Figure 8: Monetary policy and economic uncertainty in the UK



(a) Monetary policy uncertainty: $\bar{v} - \underline{v}$ **(b) Economic uncertainty:** $\bar{\epsilon} - \underline{\epsilon}$

$\bar{v}_t$ and $\bar{\epsilon}_t$ we aggregate the consumption choices of all households in the economy and calculate by how much aggregate consumption and output would have changed (in general equilibrium) if households had processed uncertainty in the form of measurable risk with zero expected value. Figure 9 plots the resulting deviation of output due to monetary policy uncertainty (panel a) and technology uncertainty (panel b). Monetary policy uncertainty has little (essentially zero) effects on output while uncertainty due to technology is highly contractionary on output. This happens because a large proportion of UK households tend to dislike inflation so when faced with uncertainty about monetary policy households act on the basis of subjective beliefs that tend to overpredict future inflation, which is expansionary on aggregate demand and stimulates the economy. The converse is true for technology shocks since households generally prefer a technology expansion to a technology regression. The effects of economic uncertainty are sizable, with output be smaller by almost 1 percentage point at the beginning of the Great Recession and in the late years of the sample.

Figure 9: Effects of uncertainty on output (relative to measurable risk)



(a) Monetary policy uncertainty: $\bar{\epsilon} - \underline{\epsilon}$ **(b) Economic uncertainty:** $\bar{v} - \underline{v}$

7 Conclusions

We found that under Knightian uncertainty, households base their actions on beliefs which are negatively distorted by their preferences, the more so the larger the amount of uncertainty they face. We used this insight to identify the amount of Knightian uncertainty about monetary policy and technology faced by UK households exploiting the Bank of England Inflation Attitudes Survey (BIAS). A key and unique feature of the BIAS is that it inquires households about both their expected inflation and their preferences about future inflation and nominal interest rates. We estimated the amount of Knightian uncertainty about monetary policy and technology using indirect inference, taking the regression coefficients for the effects of preferences on expected inflation as estimation targets. We find evidence that (i) Knightian uncertainty increases after major economic events such as the failure of Lehman Brothers or the referendum in favor of Brexit, (ii) it is driven partly by future monetary policy and partly by the economic environment, and (iii) it is only mildly correlated with other existing measures of uncertainty based on stock market volatility and counting of words in official reports or the social media. If households had treated uncertainty as measurable risk, consumption and output would have been substantially higher over the period 2012-2014. Most of the contractionary effects are due to uncertainty about technology with monetary policy playing virtually no effects on output. Our measure of Knightian uncertainty can be calculated in real time, which might help policy makers in intervening to ameliorate households' perception about uncertainty to convert it into risk. If successful, these interventions be highly expansionary especially when uncertainty is about the economy (technology) rather than about monetary policy.

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APPENDIX

Section A contains additional empirical results., Section B discusses computational details.

A Additional empirical results

Table A1: Descriptive statistics: Additional variables

VARIABLES	(1) mean	(2) sd	(3) N	(4) min	(5) max
Income below 9500	0.12	0.33	68,425.00	0.00	1.00
Income in 9500-17500 range	0.14	0.34	68,425.00	0.00	1.00
Income above 17500 below 25000	0.08	0.27	68,425.00	0.00	1.00
Income above 25000	0.66	0.47	68,425.00	0.00	1.00
Full or Part time employed	0.48	0.50	68,425.00	0.00	1.00
Dummy for male	0.47	0.50	68,425.00	0.00	1.00
Less than high school	0.25	0.43	68,425.00	0.00	1.00
High school degree	0.49	0.50	68,425.00	0.00	1.00
College degree or more	0.24	0.43	68,425.00	0.00	1.00
Dummy for age 15-24	0.13	0.33	68,425.00	0.00	1.00
Dummy for age 25-34	0.17	0.38	68,425.00	0.00	1.00
Dummy for age 35-44	0.17	0.37	68,425.00	0.00	1.00
Dummy for age 45-54	0.16	0.36	68,425.00	0.00	1.00
Dummy for age 55-64	0.14	0.35	68,425.00	0.00	1.00
Dummy for age 65+	0.24	0.43	68,425.00	0.00	1.00
Π^e brings forw. a major purchase	0.05	0.22	25,090.00	0.00	1.00
Π^e makes HH spend less	0.37	0.48	26,023.00	0.00	1.00
Π^e makes HH shop around more	0.48	0.50	26,259.00	0.00	1.00
Π^e makes HH push for pay increase	0.07	0.25	25,101.00	0.00	1.00
Π^e makes HH search for more inc.	0.13	0.34	25,383.00	0.00	1.00
Π^e makes HH save more in assets	0.09	0.29	25,205.00	0.00	1.00
Π^e makes HH do something else	0.30	0.46	24,973.00	0.00	1.00
Π^e makes HH takes no action	0.09	0.29	21,112.00	0.00	1.00
UK econ. needs high Π	0.08	0.27	68,425.00	0.00	1.00
UK econ. is indifferent on Π	0.21	0.41	68,425.00	0.00	1.00
UK econ. needs low Π	0.56	0.50	68,425.00	0.00	1.00
Dk whether UK needs Π	0.16	0.36	68,425.00	0.00	1.00
UK i should go up	0.18	0.38	68,425.00	0.00	1.00
UK i should go down	0.19	0.39	68,425.00	0.00	1.00
UK i should remain unchanged	0.36	0.48	68,425.00	0.00	1.00
UK i does no make anty difference	0.10	0.30	68,425.00	0.00	1.00
Dk whether UK needs change in i	0.18	0.38	68,425.00	0.00	1.00
BoE is independent	0.54	0.50	68,425.00	0.00	1.00
BoE sets i	0.67	0.47	68,425.00	0.00	1.00
HH knows Monetary Cmte.	0.33	0.47	68,425.00	0.00	1.00
Leaving in Northern Ireland	0.27	0.44	68,425.00	0.00	1.00
Leaving in Midlands	0.19	0.40	68,425.00	0.00	1.00
Leaving in Scotland	0.08	0.28	68,425.00	0.00	1.00
Leaving in Wales	0.13	0.34	68,425.00	0.00	1.00

Table A2: Table Calibration

NRS class × income × mortgage	Income (HH avg.)	Total Wealth (HH avg.)	NFA (HH avg.)	% who dislikes inflation	% who likes techn.	Mass of HHs
AB inc. <25 NO	0.17	5.96	5.20	0.76	0.42	0.09
AB inc. <25 YES	0.48	0.16	-1.74	0.58	0.82	0.02
AB inc. 25+ NO	2.27	9.31	7.21	0.69	0.48	0.04
AB inc. 25+ YES	2.39	-1.45	-4.07	0.60	0.80	0.10
C1 inc. <25 NO	0.16	3.27	2.80	0.72	0.59	0.13
C1 inc. <25 YES	0.46	-0.06	-1.81	0.57	0.86	0.03
C1 inc. 25+ NO	1.73	4.30	3.33	0.63	0.61	0.06
C1 inc. 25+ YES	2.06	-1.88	-3.83	0.55	0.83	0.14
C2 inc. <25 NO	0.19	1.94	1.33	0.67	0.66	0.14
C2 inc. <25 YES	0.47	-0.48	-2.71	0.56	0.87	0.03
C2 inc. 25+ NO	1.68	3.49	2.16	0.60	0.67	0.03
C2 inc. 25+ YES	1.78	-0.81	-4.43	0.50	0.86	0.04
DE inc. <25 NO	0.15	0.73	0.65	0.62	0.80	0.11
DE inc. <25 YES	0.40	-1.09	-2.26	0.54	0.88	0.01
DE inc. 25+ NO	1.66	1.14	0.91	0.52	0.76	0.01
DE inc. 25+ YES	1.54	-1.97	-2.62	0.48	0.84	0.02

Values are expressed as a fraction of average Annual net labor income of households in the economy (sum of employee income plus self-employed income) . Values are obtained from the Wealth and Assetts Suvey wave 3 (years 2010-2012). The fraction of households who likes technology corresponds to the fraction of households who dislikes inflation and likes low nominal interest rates among the population of households who dislikes inflation.

Table A3: Effects of Preferences on expected inflation: coefficients on controls

VARIABLES	(1) Π^e	(2) Π^e	(3) Π^e	(4) Π^e
Full or Part time employed		-0.06***	-0.06***	-0.05**
		(0.02)	(0.02)	(0.02)
Dummy for male		0.03**	0.04**	0.07***
		(0.02)	(0.02)	(0.02)
Less than high school		0.28***	0.29***	0.23***
		(0.07)	(0.07)	(0.07)
High school degree		0.17***	0.19***	0.16**
		(0.07)	(0.07)	(0.07)
College degree or more		0.06	0.08	0.08
		(0.07)	(0.07)	(0.07)
Dummy for age 25-34		-0.06*	-0.08**	-0.06*
		(0.03)	(0.03)	(0.03)
Dummy for age 35-44		0.15***	0.13***	0.18***
		(0.03)	(0.03)	(0.03)
Dummy for age 45-54		0.27***	0.27***	0.33***
		(0.03)	(0.03)	(0.03)
Dummy for age 55-64		0.29***	0.30***	0.38***
		(0.03)	(0.03)	(0.04)
Dummy for age 65+		0.13***	0.16***	0.27***
		(0.03)	(0.03)	(0.04)
Income below 9500		0.06	0.05	0.02
		(0.04)	(0.04)	(0.04)
Income in 9500-17500 range		0.05	0.04	0.02
		(0.03)	(0.04)	(0.03)
Income above 25000		-0.02	-0.03	-0.03
		(0.03)	(0.03)	(0.03)
Leaving in Northern Ireland		-0.02	-0.03	-0.04*
		(0.02)	(0.02)	(0.02)
Leaving in Midlands		0.00	0.01	-0.00
		(0.02)	(0.02)	(0.02)
Leaving in Scotland		-0.12***	-0.11***	-0.12***
		(0.03)	(0.03)	(0.03)
Leaving in Wales		-0.07**	-0.07**	-0.08***
		(0.03)	(0.03)	(0.03)
Observations	47,273	47,273	45,715	45,715
Method	OLS	OLS	OLS	OLS
R^2	0.08	0.09	0.09	0.10

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.10

The table reports the coefficients of a regression where dependent variable is expected inflation and regressors are listed by rows. The last row the p-value for the null hypothesis that all preference coefficients are equal to zero.

Table A4: Effects of Preferences on expected interest rates, Ordered Logit (No controls)

VARIABLES	(1) ie_down	(2) ie_equal	(3) ie_up
HH prefers i up	0.01***	0.04***	-0.05***
	(0.00)	(0.00)	(0.01)
HH prefers i down	-0.02***	-0.06***	0.09***
	(0.00)	(0.00)	(0.01)
Observations	44,284	44,284	44,284
Method	Ordered Logit	Ordered Logit	Ordered Logit
Variables	No Controls	No Controls	No Controls
Wald test	0.00	0.00	0.00

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.10

The table reports the average marginal effects on the probability of the future dynamics of (nominal) interest rates. The last row reports the p-value for the null hypothesis that all preference coefficients are all equal to zero.

Table A5: Effects of Preferences on expected interest rates, Ordered Probit

VARIABLES	(1) ie_down	(2) ie_equal	(3) ie_up
HH prefers i up	0.01***	0.02***	-0.03***
	(0.00)	(0.00)	(0.01)
HH prefers i down	-0.02***	-0.04***	0.06***
	(0.00)	(0.00)	(0.01)
Observations	44,284	44,284	44,284
Method	Ordered Probit	Ordered Probit	Ordered Probit
Variables	Yes Controls	Yes Controls	Yes Controls
Wald test	0.00	0.00	0.00

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.10

The table reports the average marginal effects on the probability of the future dynamics of (nominal) interest rates. The last row reports the p-value for the null hypothesis that all preference coefficients are all equal to zero. The controls are the same as in column 4 in Table 4.

Table A6: Effects of Preferences on expectations: Heterogeneity

VARIABLES	(1) Π^e	(2) Π^e
HH prefers high Π for low income	-0.17***	
	(0.06)	
HH prefers high Π for below median income	-0.12**	
	(0.05)	
HH prefers high Π for above median income	-0.15***	
	(0.02)	
HH prefers high Π for less than High School		-0.15***
		(0.05)
HH prefers high Π for High School		-0.13***
		(0.03)
HH prefers high Π for College Degree		-0.15***
		(0.04)
Observations	47,273	47,273
Method	OLS	OLS
R^2	0.10	0.10
Wald test for heterogeneity	0.82	0.88

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.10

The table reports the coefficients of a regression where dependent variable is expected inflation and regressors are listed by rows. Preferences for inflation varies by education, age and income. All regressions include as controls the same variables as in column (5) of Table 4.

B Solving the model

The household supplies one unit of labor, $\ell_{it} = 1$ for each i and t. The optimal consumption/saving decision of household i is such that

$$(w_t + r_{t-1}\, a_{it} - a_{it+1} + \tau_{it})^{-\sigma} = E_{it}\left[\beta r_{t+1}\, (w_{t+1} + r_{t+1} a_{it+1} - a_{it+2} + \tau_{it+1})^{-\sigma}\right] \tag{26}$$

The first order condition for the firm pricing problem at each t implies the following new-keynesian Phillips curve:

$$1 - \kappa_0\, \Pi_t\, (\Pi_t - 1) + \kappa_0\, E_t \left[\Pi_{t+1}\, (\Pi_{t+1} - 1) \frac{1}{r_{t+1}} \frac{Y_{t+1}}{Y_t}\right] = \theta\, (1 - s_t) \tag{27}$$

where

$$s_t = \frac{w_t^{\alpha} e^{-\alpha\, z_t}}{\alpha^{\alpha}(1-\alpha)^{1-\alpha}}$$

is the real marginal cost of production. We notice that a first order approximation to (27) gives:

$$\pi_t = \beta\, E_t \pi_{t+1} + \kappa\, [\hat{w}_t - z_t], \tag{28}$$

where $\hat{w}_t = \ln w_t - \ln \bar{w}$ and $\kappa = \theta\alpha/\kappa_0$. The optimal input demand is given by

$$x_{it} = x_t = \frac{1-\alpha}{\alpha}\, w_t. \tag{29}$$

Using the production function, equilibrium output is given by

$$y_{it} = Y_t = e^{\alpha\, z{-}t} x_t^{1-\alpha}. \tag{30}$$

The real interest rate is given by

$$r_t = R_{t-1}/\Pi_t. \tag{31}$$

The equilibrium at $t \geq 1$ Let $\bar{\tau}_t = \int \tau_{it} di$ denote the aggregate transfer to households at time t. At $t \geq 1$ there is perfect foresight and (26) implies an equilibrium condition for the path of wages:

$$w_t = (\beta r_{t+1})^{\frac{1}{\sigma}}\, w_{t+1} + (\beta r_{t+1})^{\frac{1}{\sigma}}\, \bar{\tau}_{t+1} - \bar{\tau}_t + A\left[(\beta r_{t+1})^{\frac{1}{\sigma}}\, (r_{t+1} - 1) - (r_t - 1)\right], \tag{32}$$

where we have used that the supply of bonds provided by the government is constant, so that in equilibrium $\int a_{it} di = A$. Equations (32), (27), (29), (30) and (31) determine the equilibrium dynamics of w_t, Π_t, x_t, Y_t and r_t at $t \geq 1$ given the interest rate rule for R_t in (4), the realizations of the shocks v_1 and ϵ_1, and the law of motions of z_t and m_t.

The equilibrium at $t = 0$ Assume that the economy is in steady state at $t = 0$ with no foreseen shocks, i.e. expectations are such that $v_t = \epsilon_t = 0$ for all t. After firms have set their price at $t = 0$ the economy is hit by an uncertainty/ambiguity shock about the possibility that z_1 or v_1 may be different from zero. In particular, $z_1 \in [\underline{z}, \bar{z}]$ or $v_1 \in [\underline{v}, \bar{v}]$, while $v_t = \epsilon_t = 0$ for all $t > 1$. We solve for the equilibrium of the economy in response to one uncertainty shock at the time. Index the type of shock by $u = \{v, z\}$. Given firms set prices before the uncertainty shock has realized we have $\Pi_0 = 1$, implying $r_0 = 1/\beta$ and $R_0 = 1/\beta$. Equations (29) and (30) determine x_0 and Y_0 for given w_0. Hence we are left to determine w_0. This achieved by using (26). In particular, conditional on each type of uncertainty shocks about $u = v_1$ or $u = z_1$, we consider two types households, those that have degenerate beliefs such that $u = \bar{u}$ and those that degenerate beliefs such that $u = \underline{u}$ with probability 1. Combining (26) with the household budget constraint at $t \geq 1$ optimal consumption and asset demand by household i is given by

$$c_{it} = \frac{\left[r_t a_{it} + \sum_{T=t}^{\infty} q_{tT}\ (w_T + \tau_{iT})\right]}{\sum_{T=t}^{\infty} (q_{tT})^{1-\frac{1}{\sigma}}\ \beta^{\frac{T-t}{\sigma}}} \tag{33}$$

$$a_{it+1} = r_t a_{it} + w_t + \tau_{it} - c_{it} \tag{34}$$

where $q_{tt} = 1$ and $q_{tT} = \left(\prod_{n=t+1}^{T} r_n\right)^{-1}$. This immediately implies that we can express c_{i1} as

$$c_{i1}^u = \tilde{w}^u + \tilde{\tau}_i^u + a_{i1}\,\tilde{r}^u \tag{35}$$

where

$$\tilde{w}^u = \frac{\sum_{T=1}^{\infty} q_{1T}^u\ w_T^u}{\sum_{T=1}^{\infty} (q_{1T}^u)^{1-\frac{1}{\sigma}}\ \beta^{\frac{T-1}{\sigma}}} \tag{36}$$

$$\tilde{\tau}_i^u = \frac{\sum_{T=1}^{\infty} q_{1T}^u\ \tau_{iT}^u}{\sum_{T=1}^{\infty} (q_{1T}^u)^{1-\frac{1}{\sigma}}\ \beta^{\frac{T-1}{\sigma}}} \tag{37}$$

$$\tilde{r}^u = \frac{r_1^u}{\sum_{T=1}^{\infty} (q_{1T}^u)^{1-\frac{1}{\sigma}}\ \beta^{\frac{T-1}{\sigma}}} \tag{38}$$

where the superscript u indexes each function by the realization of the shock $u = v$ or $u = z$. We obtain $\tilde{w}^u$, $\tilde{\tau}_i^u$ and $\tilde{r}^u$ from the solution of the model at $t \geq 1$. Then using (26) at $t = 0$ conditional on agent i having degenerate beliefs that $u = v$ or $u = z$, we obtain

$$c_{i0}^u = (\beta\, r_1^u)^{-\frac{1}{\sigma}}\ (\tilde{w}^u + \tilde{\tau}_i^u + a_{i1}\,\tilde{r}^u)\,.$$

Then we use the budget constraint in period $t = 0$ to solve for a_{i1}:

$$a_{i1}^u = \left[1 + (\Pi_1^u)^{\frac{1}{\sigma}}\,\tilde{r}^u\right]^{-1} \left[\frac{a_{i0}}{\beta} + w_0 - \tilde{w}^u\ (\Pi_1^u)^{\frac{1}{\sigma}} + \tau_{i0} - \tilde{\tau}_i^u\ (\Pi_1^u)^{\frac{1}{\sigma}}\right] \tag{39}$$

For given worst-case beliefs associated to each household i, we then obtain an equilibrium condition for w_0 by integrating the demand of assets and requiring it to equal the supply:

$$A = \int \frac{\frac{A}{\beta} + w_0 + \bar{\tau}_0}{1 + \left(\Pi_1^{u(i)}\right)^{\frac{1}{\sigma}} \tilde{r}^{u(i)}} di - \int \frac{\tilde{w}^{u(i)} \left(\Pi_1^{u(i)}\right)^{\frac{1}{\sigma}}}{1 + \left(\Pi_1^{u(i)}\right)^{\frac{1}{\sigma}} \tilde{r}^{u(i)}} di - \int \frac{\tilde{\tau}^{u(i)} \left(\Pi_1^{u(i)}\right)^{\frac{1}{\sigma}}}{1 + \left(\Pi_1^{u(i)}\right)^{\frac{1}{\sigma}} \tilde{r}^{u(i)}} di. \tag{40}$$

Equilibrium worst-case beliefs We are left to determine the equilibrium worst-case beliefs, i.e. the mapping from i to the degenerate beliefs about the realization of u. The continuation value of household i conditional on the realization u of the shock at $t = 1$ is given by

$$V_i^u = \sum_{t=1}^{\infty} \beta^{t-1} \frac{(c_{it}^u)^{1-\sigma}}{1-\sigma}$$

where using the inter-temporal Euler equation we have that for all $t > 1$

$$c_{it}^u = \left(\prod_{T=2}^{t} \beta \, r_T^u \right)^{\frac{1}{\sigma}} c_{i1}^u = \beta^{\frac{t-1}{\sigma}} (q_{1t}^u)^{-\frac{1}{\sigma}} c_{i1}^u \tag{41}$$

implying

$$V_i^u = \frac{(c_{i1}^u)^{1-\sigma}}{1-\sigma} \sum_{t=1}^{\infty} \beta^{\frac{t-1}{\sigma}} (q_{1t}^u)^{1-\frac{1}{\sigma}} = \frac{(c_{i1}^u)^{1-\sigma}}{1-\sigma} \frac{r_1^u}{\tilde{r}^u}.$$

where c_{i1}^u is given by (35) together with (39) determining a_{i1} for given degenerate beliefs about u. For each household i we can then compute the value of V_i^u associated to each realization of the shock u at $t = 1$. The worst-case beliefs of agent i will be the ones that minimize V_i^u over the possible realizations of u.