How Ricardian Are We?*

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Abstract

Not very. To answer this question, we conjecture that households might be non-Ricardian because they do not have rational expectations over their future tax burden. From this assumption, we derive a behavioral consumption function, where households act as if bonds are net wealth, and consume out of taxes and transfers. The coefficient on taxes is determined by the attenuation present in households' behavioral expectations. This consumption function also nests other causes of non-Ricardianism, including liquidity constraints and overlapping generations. To estimate the coefficient, we derive a Bayesian limited information method that uses a large number of macroeconomic shocks from the literature as instrumental variables. We find that households internalize only 1/3 to 2/3 of their future taxes, depending on the estimation specification. In a general equilibrium model, these low values imply that public borrowing substantially crowds out private investment.

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"... the people who pay the taxes never so estimate them, and therefore do not manage their private affairs accordingly."

— David Ricardo (1820)

1 Introduction

Neoclassical theory predicts that *ceteris paribus* private consumption should be unaffected by government borrowing if we are *Ricardian* (Barro, 1974). But, how Ricardian are we? What share of future taxes do households save to pay for? The answer is critical for the design of major macroeconomic policies – e.g. fiscal stimulus, public finance, and crisis response – and yet we have little idea what the number is.

We address this crucial question by bringing modern methods to bear on a classic problem: estimating the consumption function. A large literature in the 1980s investigated the Ricardian question by using aggregate time series regressions to estimate how taxes affect consumption on average.[1] However, the effect of taxes on consumption is unlikely to be identified in these regressions (Feldstein, 1982; Cebula et al., 1996; Cardia, 1997). This is because demand shocks (i.e. omitted variables in the consumption function) affect consumption directly, but can also affect taxes, income, and other determinants. Mainstream work with this strategy largely ceased, with the Ricardian question unanswered.

Time series evidence is necessary. After the aggregate consumption function approach was abandoned, microeconomic studies flourished. Studies using interpersonal variation in taxes, transfers, and consumption are valuable for many reasons, but because of the *missing intercept problem*, they cannot (nor do they claim to) answer whether US households are Ricardian on average. Micro data are useful for estimating an individual's marginal propensity to consume (MPC), but not the aggregate *MPC out of debt-financed transfers* (MPC-DFT). To do so, macro evidence must be incorporated, either through full general equilibrium modeling (e.g. Angeletos et al. (2024)) or some semi-structural approach (e.g. Wolf (2023)). We adopt a minimal structure by assuming a single structural equation: a behavioral consumption function.

Our strategy is to estimate the consumption function using a battery of macroeconomic shocks as instrumental variables (IV), by drawing on careful identification in the recent applied macro literature. A valid IV approach will resolve the endogeneity problems that

[1] Well-known examples include Barro and Feldstein (1978), Tanner (1979), Seater and Mariano (1985), and especially Kormendi (1983), which spawned a decade of comments and replies in the American Economic Review (Barth et al., 1986; Modigliani and Sterling, 1986; Kormendi and Meguire, 1986; Feldstein and Elmendorf, 1990; Modigliani and Sterling, 1990; Kormendi and Meguire, 1990; Graham, 1995; Kormendi and Meguire, 1995).

prevented identification from traditional regressions using aggregate time series. This approach is inspired by Barnichon and Mesters (2020), who suggest using exogenous shocks to estimate structural macroeconomic equations. The consumption function is a valuable application, and we build on their method in order to do so. Specifically, we develop **B-HIVE** the **B**ayesian **H**ybrid **IV E**stimator. **B-HIVE** is a Bayesian limited information framework for using many external instruments to estimate macro models. This framework is a valuable enhancement for three reasons. First, we have designed it to accommodate a large number of instruments. This is important because, in contrast to the original Barnichon-Mesters application, the consumption function features many endogenous regressors. Second, the set of well-identified potential instruments from the literature have a wide range of data coverages and frequencies. Our Bayesian method easily accommodates mixed frequencies and periods with missing data. Third, we can leverage all the usual strengths of Bayesian estimation, among which the most relevant is the use of informed priors. Macroeconomic shocks are notoriously weak instruments (Barnichon and Mesters, 2020; Lewis and Mertens, 2025) so disciplining the parameter space with a Bayesian prior is valuable. For example, while there is uncertainty about size of the coefficient on taxes in the consumption function, most theories predict that it should be bounded by zero and one.

To derive our consumption function, we assume that Ricardian equivalence fails because of a behavioral friction: agents do not forecast their future taxes with rational expectations. Instead, they discount future taxes with a behavioral factor, similar to a cognitive discounting bias (Gabaix, 2020). This behavioral approach is useful for letting the data identify the degree of Ricardianism without prejudice. Other mechanisms that break Ricardian equivalence – such as finite lifetimes (Blanchard, 1985) or liquidity constraints (Campbell and Mankiw, 1989) – give clear predictions about the coefficient on taxes in the consumption function. Microeconomic evidence implies strong priors about the sizes of these particular frictions, but not about the quantitative effects of non-rational expectations. However, we also show that models featuring an alternative mechanism for the Ricardian equivalence failure imply an isomorphic consumption function to ours. Thus we interpret our estimates as describing non-Ricardianism in general, independent of the fundamental cause.[2]

We find that US consumers are far from Ricardian. The relevant parameter is the share of future taxes that households internalize in their consumption function. When households are rational, this share is one, and Ricardian equivalence holds. In contrast, our results imply that households internalize only a fraction of future taxes. In our baseline estimate with aggregate consumption, the point estimate is 68%. However many alternative

[2]However, with additional assumptions on parameter values, it is possible to attribute non-Ricardian behavior to different mechanisms. When we do so, we find that both discounting wedges and non-rational expectations are relevant. Eichenbaum et al. (2025) draw the same conclusion in an experiment where survey respondents may randomly receive an explanation of the tax implications from a hypothetical transfer.

specifications give smaller estimates; for example using non-durable consumption implies 19%. Simultaneously, our Bayesian method estimates the marginal propensity to consume out of debt-financed transfers (MPC-DFT); for Ricardian households this would be zero, but we estimate roughly 4%. In contrast, the generic quarterly MPC is 7%. This reveals a micro-macro disagreement: this amount is somewhat smaller than estimates from recent one-off fiscal transfers (Parker et al., 2013, 2022; Baker et al., 2023). It is also smaller than the careful survey-based thought experiments: Colarieti et al. (2024) estimate 16%, while Eichenbaum et al. (2025) estimate 14%.

Finally, we embed our mechanism in a general equilibrium model with capital; we learn that the severe non-Ricardianism we estimate implies that government borrowing substantially crowds our private investment, and households treat a large share of bond holdings as net wealth. The model features a variety of structural shocks, which we use to illustrate the previously discussed econometric challenges in a Monte Carlo simulation. When households feature demand shocks (stochastic residuals in the Euler equation) OLS estimates of the consumption function are biased. Estimates of consumption responses to structural tax shocks also do not recover the relevant coefficient. And when demand shocks are serially correlated, the classic strategy of using lagged aggregates as instruments fails as well. However, our strategy of using many structural shocks as IVs – even when measured with error – consistently estimates the consumption function.

Literature: The theory in this paper joins a revitalized literature studying the causes and consequences of non-Ricardian behavior. The most closely related models are Gabaix (2020), Brzoza-Brzezina et al. (2025) and Eichenbaum et al. (2025), who study cognitive discounting and show that partial myopia amplifies the effects of fiscal policy. Other mechanisms used to study non-Ricardian behavior by relaxing full information rational expectations include finite planning horizons (Woodford, 2019; Woodford and Xie, 2022; Lustenhouwer and Mavromatis, 2023), level-k thinking (Bianchi-Vimercati et al., 2024), and adaptive learning (Evans et al., 2012; Eusepi and Preston, 2018; Branch and Gasteiger, 2023). Woodford (2013) reviews older results along these lines. Other recent work has applied modern quantitative methods to tradition non-Ricardian mechanisms including finite lifetimes (Aguiar et al., 2023; Angeletos et al., 2024), constrained hand-to-mouth agents Galí et al. (2007); Nisticò (2016); Orchard et al. (2023), heterogeneous agents with borrowing constraints (Hagedorn et al., 2019; Auclert et al., 2024) and distortionary taxation (Bianchi and Melosi, 2022).

Our **B-HIVE** method has its roots in likelihood-based treatments of instrumental variable-based inference going back to Anderson and Rubin (1949, 1950), who introduced the limited information maximum likelihood (LIML) method. A Bayesian treatment of this approach was first discussed by Drèze (1976) and has since been extended in many directions (Kleibergen and Zivot, 2003; Chao and Phillips, 2002; Koop et al., 2012). Early work recognized endogeneity problems in the estimation of the consumption function and made some attempts to resolve them using lagged aggregate variables as IVs. See for example Hayashi (1982) or Feldstein (1982). Seater and Mariano (1985) argued that lagged aggregates are not valid IVs; we concur and demonstrate as much in our Monte Carlo exercise. Using instrumental variables to estimate one equation of an equilibrium model, where lagged observables are the instruments, has been popular beyond the consumption function papers we have mentioned above, in particular in the New Keynesian literature – see, for example, Galí and Gertler (1999); Sbordone (2002); Mavroeidis et al. (2014). The approach of using lagged observables as instruments has also been criticized there (Nason and Smith, 2008; Mavroeidis, 2005). We instead use instruments for structural shocks, following the lead of Barnichon and Mesters (2020), who introduce this idea in the context of estimating a single structural equation. Several frequentist approaches instrument for multiple endogenous regressors in a structural macroeconomic equation: Caldara and Kamps (2017) do so to estimate a fiscal policy rule by IV, while Adams and Barrett (2025) estimate multiple Taylor-type monetary policy rules by IV. Lewis and Mertens (2022) extend the Barnichon and Mesters (2020) approach using forecast errors and additional instrument lags to add statistical power.

The remainder of the paper is organized as follows. Section 2 lays out the theoretical framework and derives the behavioral consumption function. Section 3 describes our Bayesian limited information estimator. Section 4 describes the data and estimation results. Section 5 explores the macroeocnomic implications of our findings. Finally, Section 6 concludes.

2 The Consumption Function

This section derives the consumption function from the relevant equilibrium conditions. This is useful to do before proceeding to the full model in Section 5, because it clarifies how general our result is.

In Section 2.1 we derive a generic consumption function that is determined by only two equations that are featured in many models: a household budget constraint and an Euler equation pricing non-contingent bonds.

Then in Section 2.2 we derive a specific *behavioral* form of the consumption function that we can plausibly estimate in the data. This form uses two additional ingredients: the government budget constraint and a behavioral relationship between agents' expectations and the rational expectation.

2.1 The Generic Consumption Function

Consider an economy which satisfies, among other things, the following two equilibrium conditions. First is the representative household's budget constraint:

$$B_{t-1} + R_t^K K_{t-1} + Y_t^N = C_t + T_t + Q_t B_t + K_t \tag{1}$$

where B_{t-1} is risk-free government debt acquired in the previous period, K_{t-1} is capital (and/or other financial assets) with R_t^K the net-of-depreciation return.[3] Y_t^N is non-financial income, C_t is consumption, T_t is taxes, and Q_t is the price of new government debt. T_t represents the total taxes paid by households, which appears in the budget constraint whether taxes are lump-sum or distortionary.

The second equation is the household's Euler equation for pricing the debt:

$$Q_t = \beta \tilde{\mathbb{E}}_t \left[\frac{u'(C_{t+1})}{u'(C_t)} \right] + Z_t^d \tag{2}$$

where $\tilde{\mathbb{E}}_t[\cdot]$ is a (possibly non-rational) expectation operator, $u'(C_t)$ denotes a household's marginal utility of consumption, and Z_t^d is an exogenous intertemporal wedge.

The linearized forms (not *log*-linearized) of these two equations are

$$n_{t-1} + y_t = c_t + \tau_t + q_t \overline{B} + \beta n_t \tag{3}$$

$$q_t = \beta \tilde{\mathbb{E}}_t [\gamma \frac{1}{\overline{C}} (c_t - c_{t+1})] + z_t^d \tag{4}$$

where lower-case variables denote deviations from the steady state. $y_t = y_t^N + \overline{K} r_t^k$ represents *net* income, while financial wealth n_t is defined as

$$n_t \equiv b_t + \overline{R^k} k_t \tag{5}$$

with the assumption that $\overline{R^k} = 1/\beta$. Finally, $\gamma \equiv -\frac{u''(\overline{C})\overline{C}}{u'(\overline{C})}$ denotes the steady state coefficient of relative risk aversion.

The consumption function is most concise with some recursive notation. The linearized tax present value equation is

$$\tilde{v}_t^\tau = \tau_t + \beta \tilde{\mathbb{E}}_t [\tilde{v}_{t+1}^\tau]$$

Similarly, define a present value equation for the remaining income component

$$\tilde{v}_t^y = y_t + \beta \tilde{\mathbb{E}}_t [\tilde{v}_{t+1}^y] \tag{6}$$

[3] Specifically, R_t^K is the gross financial return, so it includes the original capital value plus net capital income. For example, in Section 5's behavioral RBC model with rental rate R_t, the return is $R_t^K = R_t + 1 - \delta$.

for government spending

$$\tilde{v}_t^g = g_t + \beta\tilde{\mathbb{E}}_t[\tilde{g}_{t+1}^y] \tag{7}$$

and the present value (or "console value") of future one-period bonds by

$$\tilde{v}_t^q = q_t + \beta\tilde{\mathbb{E}}_t[\tilde{v}_{t+1}^q] \tag{8}$$

We also use this approach to define an exogenous "demand" factor from the intertemporal wedges, which affects the consumption equation:

$$\zeta_t = -\frac{\overline{C}}{\gamma} z_t^d + \beta\tilde{\mathbb{E}}_t[\zeta_{t+1}] \tag{9}$$

The present value variables are written with tildes to denote that they depend on the behavioral expectation $\tilde{\mathbb{E}}$. If expectations are rational ($\mathbb{E}$) then we write them without the tilde, e.g. v_t^τ. As yet, we make no assumptions about the subjective expectations operator $\tilde{\mathbb{E}}_t$ other than linearity and that agents know current variables with certainty, e.g. $\tilde{\mathbb{E}}_t[n_t] = n_t$.

Proposition 1 *The linear consumption function is*

$$c_t = (1-\beta)\left(n_{t-1} + \tilde{v}_t^y - \tau_t - \beta\tilde{\mathbb{E}}_t[\tilde{v}_{t+1}^\tau]\right) + \left(\frac{\overline{C}}{\gamma} - (1-\beta)\overline{B}\right)\tilde{v}_t^q + \zeta_t \tag{10}$$

Proof: Appendix A

Proposition 1 is derived only using the household budget constraint and Euler equation on risk-free bonds. It holds in the lion's share of representative agent models. The Euler equation is the only one that is directly affected by expectations; this is the channel through which distorted beliefs enter the consumption function.

However, the generic consumption function (10) is not well-suited to be estimated directly. $\tilde{\mathbb{E}}_t[\tilde{v}_{t+1}^\tau]$ is not typically observed – if it was, we could directly estimate how $\tilde{\mathbb{E}}_t[\tilde{v}_{t+1}^\tau]$ depends on the rational forecast without bothering with the consumption function at all. So instead, we need an additional model equation to transform the consumption function into a form that can plausibly be estimated in the data.

2.2 A Behavioral Consumption Function

We now introduce a third model equation, the budget constraint for a government that issues non-contingent debt:[4]

$$B_{t-1} + G_t = T_t + Q_t B_t \tag{11}$$

where G_t is government expenditure. The linearized form is

$$b_{t-1} = \tau_t - g_t + \overline{B} q_t + \beta b_t \tag{12}$$

assuming that the steady state bond price is $\beta = \overline{Q}$.

We also now make an assumption about the relationship between the behavioral and rational expectation operators. Their forecasts for discounted future taxes is

$$\tilde{\mathbb{E}}_t[\tilde{v}^\tau_{t+1}] = \theta \mathbb{E}[v^\tau_{t+1}] \tag{13}$$

for some scalar θ. Crucially, the θ parameter only disciplines the expectations of *taxes*. We are agnostic about the biases in expectations for all other variables.

Proposition 2 *If the government budget constraint is given by equation* (12) *and expectations satisfy equation* (13)*, then the consumption function can be expressed as*

$$c_t = (1-\beta)\left(n_{t-1} - \theta b_{t-1} + \tilde{v}^y_t - (1-\theta)\tau_t - \theta v^g_t + \theta \overline{B} v^q_t\right) + \left(\frac{\overline{C}}{\gamma} - (1-\beta)\overline{B}\right)\tilde{v}^q_t + \zeta_t \tag{14}$$

Proof. Iterate the government budget constraint (12) and take rational expectations:

$$\begin{aligned} b_{t-1} &= \tau_t - g_t + \overline{B} q_t + \mathbb{E}_t\left[\sum_{j=1}^{\infty} \beta^j (\tau_{t+j} - g_{t+j} + \overline{B} q_{t+j})\right] \\ &= \tau_t - g_t + \overline{B} q_t + \beta \mathbb{E}_t\left[v^\tau_{t+1} - v^g_{t+1} + \overline{B} v^q_{t+1}\right] \\ &= \tau_t + \beta \mathbb{E}_t\left[v^\tau_{t+1}\right] - v^g_t + \overline{B} v^q_t \end{aligned}$$

Combine with equation (13) to find

$$\beta \tilde{\mathbb{E}}_t[\tilde{v}^\tau_{t+1}] = \theta\left(b_{t-1} - \tau_t + v^g_t - \overline{B} v^q_t\right)$$

then use this result to replace $\beta \tilde{\mathbb{E}}_t[\tilde{v}^\tau_{t+1}]$ in the consumption function (10). ∎

[4] The non-contingent assumption is not important. We make this assumption for clarity, so that readers do not wonder whether default is important for our non-Ricardianism. In Appendix D.1, we show that if debt is risky, the behavioral consumption function is unchanged.

This form is useful for estimating Ricardianism, because the behavioral attenuation θ shows up directly in the coefficient on taxes τ_t. And it implies a straight-forward testable hypothesis: if agents are Ricardian, $\theta = 1$ so the coefficient on taxes is zero.

Moreover, the variables in the behavioral consumption function (14) can plausibly be observed. Consumption c_t, financial net worth n_{t-1}, government debt b_{t-1}, and taxes τ_t are all directly measured. $\tilde{v}_t^q$ is the market price of a console bond; it can be inferred with a model from the yield curve or simply approximated with long-term debt. v_t^q and v_t^g are rational expectations, which can be estimated. The most problematic variable is the household's expected discounted value of future net income $\tilde{v}_t^y$. One way to account for this variable is to include survey data on household income forecasts, although we will consider several alternative approaches.

Proposition 2's behavioral consumption function also illustrates why the missing intercept problem prevents the use of cross-sectional data to estimate Ricardian equivalence. As mentioned in the introduction, a large literature uses household-level variation to estimate how government transfers affect consumption. Comparing two households with different transfer receipts – but the same future tax burden – estimates the MPC $1-\beta$. This is useful information, but it is not informative about Ricardian equivalence. This is because the *MPC out of debt-financed transfers* (MPC-DFT) is $(1-\beta)(1-\theta)$. To ascertain if households are Ricardian, there must also be variation in their future tax burdens; this is why time series evidence will be essential for our application.

2.3 Alternative Justification for the Behavioral Consumption Function: Discounting Wedges

How important is the behavioral mechanism for our empirical work? Not particularly important: many alternative mechanisms for non-Ricardianism lead to similar conclusions regarding the consumption function. In this section, we show that a wedge between the household's and government's discount factors leads to the same reduced form as our behavioral consumption function. Then, in Appendix D, we show that this is true of other mechanisms, including hand-to-mouth households (Campbell and Mankiw, 1989).

A discounting wedge is a popular feature for modeling failures of Ricardian equivalence. For example, the wedge nests the inter-generational explanation for non-Ricardianism (Blanchard, 1985) whereby agents have some probability of death, after which they do not receive utility (or at least diminished utility from their dynasty). Alternatively, the wedge can capture occasionally binding liquidity constraints (Farhi and Werning, 2019); Angeletos et al. (2024) argue that this mechanism leads to similar conclusions as in a full heterogeneous agents model. The wedge can also represent distortionary taxation.[5]

[5]It is well known that distortionary taxation can break Ricardian equivalence, but not all distortionary

With a discounting wedge ω, the assumptions for the generic consumption function in Proposition 1 still hold, albeit with discount factor $\beta\omega$. But we relax the assumption that the steady state bond price β is equal to the household's discount factor, so Proposition 2 no longer follows and rational expectations households may not be Ricardian.

And yet, Proposition 3 states that the resulting consumption function is *isomorphic* to the behavioral consumption function from Proposition 2, under the assumption that the present value of taxes follows an AR(1) process as in Eichenbaum et al. (2025). The usual Ricardian coefficient $1-\theta$ – which captures the deviation from rational expectations in the rest of the paper – now measures how far the discounting wedge ω is from one. That is to say: households and governments discounting at different rates is equivalent to households misextrapolating future tax liabilities.

Proposition 3 *If the government discounts by β and the household discounts by $\beta\omega$, the present value of taxes is AR(1) given by*

$$v_t^\tau = \rho_\tau v_{t-1}^\tau + \varepsilon_t^\tau \tag{15}$$

and households have rational expectations, then the consumption function can be expressed as

$$c_t = (1-\beta\omega)\left(n_{t-1} - \theta b_{t-1} + \tilde{v}_t^y - (1-\theta)\,\tau_t - \theta v_t^g + \theta\overline{B}v_t^q\right) + \left(\frac{\overline{C}}{\gamma} - (1-\beta\omega)\overline{B}\right)\tilde{v}_t^q + \zeta_t \tag{16}$$

where

$$\theta = \omega\frac{1-\beta\rho_\tau}{1-\beta\omega\rho_\tau} \tag{17}$$

where for quantity x, v_t^x denotes the present value using the government's discount factor β, while $\tilde{v}_t^x$ denotes using the household's discount factor $\beta\omega$:

$$v_t^x = x_t + \beta\mathbb{E}_t[v_{t+1}^x] \qquad \tilde{v}_t^x = x_t + \beta\omega\mathbb{E}_t[\tilde{v}_{t+1}^x]$$

Proof: Appendix A

Given this equivalence, why do we bother with the behavioral expectations, when a household-government discounting wedge is already standard in our theories? Because a discounting wedge is too tightly disciplined by the microfoundations. For example, when the wedge is determined by the OLG structure so that ω represents the survival rate, ω is

taxes do so. Proposition 2 uses only budget constraints and an Euler equation to derive the behavioral consumption function; therefore, to distort consumption responses, the tax must distort intertemporal decision making through the Euler equation. For example, capital taxation can do so. However, as Trostel (1993) shows, labor taxation does not necessarily: reducing consumption solely by reducing income is not non-Ricardian.

necessarily close to 1 so equation (17) implies that the tax coefficient θ cannot be much less than 1 either.[6] In contrast, we have very loose priors about θ as a cognitive discounting coefficient. Therefore, with behavioral expectations as the source of non-Ricardianism, we are free to let the time series speak for themselves by choosing a relatively uninformed prior.

3 B-HIVE: the Bayesian Hybrid IV Estimator

In this section, we describe **B-HIVE**, a Bayesian limited information approach that allows us to estimate the parameters of our consumption function without having to take a stance on a full equilibrium model. To do this, we borrow insights from the literature on limited information maximum likelihood (Anderson and Rubin, 1949), and in particular Bayesian implementations of this idea (Drèze, 1976; Kleibergen and Zivot, 2003) - we discuss below how a Bayesian approach is natural in situations with possibly weak identification and small sample sizes. We cast our estimation in terms of a linear Gaussian state space model, which allows us to efficiently deal with different sample sizes for various variables as well as possibly mismeasured data. We next describe the state space model in detail before turning to specifics of the estimation.

3.1 The State Space Model

Our state space model consists of the following components, which we then map into observation equations that tell us how possibly unobserved variables relate to the variables we have data on, and state equations, which describe the dynamics of the possibly unobserved state variables.

1. A structural equation whose parameters we want to estimate. In our context, this is the consumption function, which we rewrite as follows to estimate its coefficients:

$$c_t = \phi_0 + \phi_n\, n_{t-1} + \phi_b\, b_{t-1} + \phi_\tau\, \tau_t + \sum_{j\in\{y,g,q\}} \tilde{\phi}_j\, v_t^j + \zeta_t, \tag{18}$$

   We assume that the forward looking terms are functions of a vector of variables X_t that we describe next. Alternatively, we can accommodate direct observations of these forward-looking terms or noisy measurements of said terms. The coefficients of the forward-looking terms v_t^j depend on the parameters governing X_t in a way that we describe next.

2. The dynamics of all variables that either enter the right hand-side of the consumption equation or are useful to predict those variables and form the forward-looking

[6] Angeletos et al. (2024) choose a liberal calibration, setting the OLG survival rate at $\omega = 0.865$.

terms v_t^j. We stack those variables in a vector X_t, which we assume follows a vector autoregression (VAR) of order p driven by the structural shocks ε_t:

$$X_t = \mu_X + A_1 X_{t-1} + \cdots + A_p X_{t-p} + G\varepsilon_t \quad , \quad \varepsilon_t \sim N(0, I)$$

We can then compute expected discounted sums of elements of X_t (the v_t^j terms) as

$$v_t^j = \sum_{j \in \{y,g,q\}} \phi_j \, s_j' \, (I_{mp} - \beta_j \, F)^{-1}$$

where β_j is a discount factor, ϕ_j is a scalar parameter, s_j is a selection vector, and F is the companion form matrix associated with the VAR, which is a function of $A_1, ..., A_p$ and whose construction we describe in Appendix F.[7] Importantly, we impose cross equation restrictions via this approach and take into account estimation uncertainty in the VAR dynamics encoded in F.

3. Measurement equations that describe how variables that are observed are linked to the state variables and whether the observables are measured with noise. This includes both elements of X_t (some of which could be completely unobservable) and instruments w_t that we assume are noise-ridden measurements of the structural shocks ε_t (Plagborg-Møller and Wolf, 2021):

$$w_t = \mu_w + M_X X_{t-1} + M\varepsilon_t + \eta_t$$

M is a matrix with exactly one non-zero element per row, M_X allows for contamination of the instrument by past observables, and $\eta_t \sim N(0, \Sigma_\eta)$ are measurement errors with a diagonal covariance matrix that are independent of all other shocks in the model. We describe the priors in detail in the appendix, but it is worth emphasizing that we use a uniform prior bounded between 0 and 1 on the parameter θ that controls the degree of non-Ricardian behavior in our consumption function.

We describe the state-space model in more detail in the appendix, where we also discuss various extensions. This state space model allows us to evaluate the likelihood even when data are missing, which is especially relevant in our setting because we use instruments that are available for different time periods. We use this likelihood function to conduct Bayesian inference.

[7] Technically, it is the companion form of the demeaned process $X_t - \mu_X$ since we include a constant in the consumption function. The construction of the forward-looking terms requires restrictions on the eigenvalues of F, which we impose in the estimation by setting the likelihood value for any parameter draw that does not satisfy these conditions to 0.

Why do we use a Bayesian approach? After all, the previous literature that has pioneered the use of structural shocks as instruments (Barnichon and Mesters, 2020) has used a frequentist approach. First, it transparently allows us to use all available information for the structural parameters via the use of priors. For example, if a parameter is bounded between 0 and 1, as will be the case for our key parameter that governs the degree of Ricardian behavior, then a natural assumption is a uniform prior between 0 and 1. Second, it allows for regularization, which is a natural requirement in macroeconomics, where sample sizes are often relatively small. Finally, the likelihood principle (Berger and Wolpert, 1988) states that everything that can be learned about a given parameter from the data (including any instruments) is contained in the likelihood function. As such, the shape of the posterior distribution summarizes all evidence about the parameters of the model, obfuscating the need to make specific assumptions about whether parameters are identified to obtain valid statistical inference or needing weak-identification robust methods. Naturally, there is a trade-off: In contrast to semi-parametric frequentist methods, we need to commit to a fully parametric model. However, our model need not be a fully structural model - instead we use a VAR for X_t, a model most macroeconomists will be comfortable with as a reasonable description of macroeconomic dynamics. Details on the construction of the likelihood function, the prior distributions we use, and the posterior sampling algorithm can be found in Appendices F, G, and H respectively.

4 Application

In this section we describe our time series data and macro shock instruments. Then we estimate the consumption function with **B-HIVE** and review the results, finding that consumers are non-Ricardian by a large margin.

4.1 Data

In order to estimate the behavioral consumption function (14), we require data on the directly observed variables (e.g. c_t), additional macro variables for a variety of robustness checks, and many macroeconomic shocks to use as instruments.

4.1.1 Directly Observed Variables

Our main time series come from the national accounts. We consistently take the approach of selecting variables that most closely match objects with which households interact directly, e.g. y_t is mapped to *personal income* rather than GDP. Taxes τ_t are *personal taxes*, which mainly includes income taxes, but excludes corporate and production taxes and tariffs.

Name	Variable	Data Source	FRED code	Range
Main Time Series				
Household Net Worth	n_t	Fed Financial Accounts	TNWBSHNO	1945:Q4 -
Market Value of Federal Debt	b_t	Dallas Fed	MVMTD027MNFRBDAL	1942:M1 -
Consumption	c_t	NIPA	PCEC	1947:Q1-
Personal Taxes	τ_t	NIPA	see note	1947:Q1 -
Government Expenditures	g_t	NIPA	see note	1947:Q1 -
Personal Income	y_t	NIPA	see note	1947:Q1 -
Additional Time Series				
Inflation Forecast		Survey of Professional Forecasters		1968:Q4-
3-Month T-Bill Yield		Fed Financial Accounts	TB3MS	1934:M1-
Non-Durable Consumption		NIPA	PCND	1947:Q1 -
Hours		BLS	HOANBS	1941:Q1 -
Average Income Tax Rate		Urban-Brookings Tax Policy Center		1979 - 2020
Hand-to-Mouth Income Share		Survey of Consumer Finances		select years

Table 1: Time Series Data

Notes: Personal Taxes are net of Personal Transfer Receipts. In terms of FRED codes, our net taxes measure is $\tau = W055RC1Q027SBEA - A577RC1Q027SBEA$. Government Expenditures are net of government receipts not included in net taxes. In terms of FRED codes, our expenditure measure is $g = GEXPND - (GRECPT - \tau)$. Personal Income must then be modified to exclude transfer income, which we measure in terms of FRED codes as $y = PINCOME - A577RC1Q027SBEA$.

To be consistent with this tax definition, we take g_t as government expenditures net of receipts that are not included in personal taxes. As usual, c_t is personal consumption expenditures. We take household net worth n_t directly from the financial accounts, which includes household ownership of government bonds but not their future tax liability. For government debt b_t, we use the market value of federal debt calculated by the Dallas Fed, which we deseasonalize to match the other data. The main time series are quarterly, so we calculate real interest rates using three-month Treasury bills and subtracting the CPI inflation forecast from the Survey of Professional Forecasters.

The nominal consumption time series is detrended and deflated by dividing by the CBO's estimate of nominal potential GDP. We do the same for all other nominal level variables in data vector X_t (i.e. excluding nominal yields and the inflation rate). This transforms them into real variables.

4.1.2 Rational Expectation Variables

The behavioral consumption function includes as arguments the rational expectation of the present discounted value of government spending v_t^g and future bond prices v_t^q. We can easily estimate these with a state space approach.

Consider a state vector X_t that includes current government spending g_t and one-period bond prices q_t. Suppose the state vector follows an AR(K) process:

$$X_t = \sum_{k=1}^{K} B_k X_{t-k} + \epsilon_t \tag{19}$$

where ϵ_t are i.i.d. unforecastable innovations. The h-period ahead rational expectation is given recursively by

$$\mathbb{E}_t[X_{t+h}] = \sum_{k=1}^{K} B_k \mathbb{E}_t[X_{t-k+h}]$$

The desired rational expectation variables are given by

$$v_t^g = \sum_{j=0}^{\infty} \beta^j e_g \mathbb{E}_t[X_{t+j}]$$

$$v_t^q = \sum_{j=0}^{\infty} \beta^j e_q \mathbb{E}_t[X_{t+j}]$$

where e_g and e_q denote the basis vector identifying the g_t and q_t entries of X_t.

4.1.3 Behavioral Expectation Variables

The behavioral consumption function also includes agents contemporary expectations of variables, which may not be rational and thus cannot be estimated ex post from realizations. To measure these variables – the *perceived* present discounted value of household income $\tilde{v}_t^y$ and future bond prices $\tilde{v}_t^q$ – we use multiple approaches.

In one method, we will suppose that agents' behavioral expectations are simply proportional to the rational expectation, which allows us to include the rational analogs v_t^y and v_t^q directly in our estimation equation.

In other methods, we use data from surveys and asset markets to augment the rational expectations. To do so, we assume that agents form expectations per a state space model that is analogous to equation (19), but possibly incorrectly specified.

For household income, we assume that households are simplistic forecasters, modeling y_t as AR(1) in lags of y_t alone. The *perceived* law of motion is

$$y_{t+1} = \tilde{B}^y y_t + \tilde{\epsilon}_{t+1}^y + \tilde{\nu}_t^y \tag{20}$$

The perceived coefficient $\tilde{B}^y$ is not necessarily the true autocorrelation. We allow households to receive a perceived iid news shock $\tilde{\nu}_t^y$, while the residual $\tilde{\epsilon}_{t+1}^y$ of the perceived PLM is not forecasted. The one-period ahead subjective expectation is

$$\tilde{\mathbb{E}}_t[y_{t+1}] = \tilde{B}^y y_t + \tilde{\nu}_t^y$$

Accordingly, the implied perceived present value of future income $\tilde{v}_t^y = \sum_{j=0}^{\infty} \beta^j \tilde{\mathbb{E}}_t[y_{t+j}]$ is

$$\tilde{v}_t^y = y_t + \frac{\beta}{1 - \beta \tilde{B}^y} f_t^y \tag{21}$$

where $f_t^y = \tilde{\mathbb{E}}_t[y_{t+1}]$ is a measurement of households' one-period ahead income forecasts. Crucially, this structure implies that $\tilde{v}_t^y - y_t$ is linear in f_t^y. Thus, we do not need to know the PLM in order to account for household expectations; we only need to include the one-period ahead forecasts, which we take from the Michigan Survey of Consumers.[8] Unfortunately, the Michigan Survey only begins asking for income forecasts in 1976:Q3, and we would prefer to estimate the consumption function using the entire post-war sample. Therefore, we use GNP forecasts from the Survey of Professional Forecasters (SPF) and Livingston Survey as noisy proxy variables to estimate unobserved household forecasts before 1976:Q3.

For expectations of future one-period bond prices, we turn to time series from the term structure of interest rates. The expectation hypothesis implies that demeaned (i.e. removing a constant risk premium) horizon-h nominal bond yields $i_t^{(h)}$ satisfy

$$i_t^{(h)} = \frac{1}{h} \sum_{j=0}^{h-1} \tilde{\mathbb{E}}_t \left[i_{t+j}^{(1)} \right]$$

and thus we can identify expected one-period yields from the term-structure by

$$\tilde{\mathbb{E}}_t \left[i_{t+h-1}^{(1)} \right] = h i_t^{(h)} - (h-1) i_t^{(h-1)}$$

A large literature tests these relationships under rational expectations, and find that they fail.[9] With our approach, we are implicitly taking the stance that such failures are due to expectations anomalies (Froot, 1989) or learning (Farmer et al., 2021), rather than time-varying risk premia (e.g. Wachter 2006).

Next, we can construct expectations for the real interest rate $r_{t+h}^{(1)}$ from the nominal

[8] The AR(1) structure is what allows the one-period-ahead forecast to be a sufficient statistic for the entire set of forecast horizons. We would prefer to assume a more flexible structure, but data availability prevents it. We would require data on household income forecasts over multiple horizons, which are not available in the Michigan Survey.

[9] Examples include Shiller (1979), Shiller et al. (1983), Fama (1984), Fama and Bliss (1987), and Campbell and Shiller (1991). However, even though yield curve-implied forecasts fail this test, that does not mean that they are necessarily bad forecasts. For example, these constructed forecasts have smaller forecast errors than those reported in the Survey of Professional Forecasters (Adams and Barrett, 2023).

interest rate $i^{(1)}_{t+h}$ and the one-period-ahead inflation rate π_{t+h+1}:

$$\tilde{\mathbb{E}}_t\left[r^{(1)}_{t+h}\right] = \tilde{\mathbb{E}}_t\left[i^{(1)}_{t+h}\right] - \tilde{\mathbb{E}}_t\left[\pi_{t+h+1}\right]$$

Finally, Appendix C implies that we can recover $\tilde{v}^q_t$ from expected yields by

$$\tilde{v}^q_t = -\overline{Q}^2\left(r^{(1)}_t + \sum_{j=1}^{\infty}\beta^j\tilde{\mathbb{E}}_t\left[r^{(1)}_{t+j}\right]\right) = -\overline{Q}^2\sum_{j=0}^{\infty}\beta^j\left(\tilde{\mathbb{E}}_t\left[i^{(1)}_{t+j}\right] - \tilde{\mathbb{E}}_t\left[\pi_{t+j+1}\right]\right)$$

$$\implies \tilde{v}^q_t = -\overline{Q}^2\left((1-\beta)\sum_{h=0}^{\infty}\beta^h(h+1)i^{(h+1)}_t - \sum_{h=0}^{\infty}\beta^h\pi_{t+1+h}\right) \tag{22}$$

4.1.4 Instruments

To build our dataset of macro instruments, we collected a large variety of structural shocks identified by the literature.[10] Altogether, we use more than 30 shocks from 24 different sources covering the post-war period in the US (albeit unbalanced and with gaps). We organize them into six categories.

Modern estimates of monetary policy shocks (MPS) are the most cleanly identified structural shocks; their main drawback is that they tend to be weak instruments, explaining only a fraction of aggregate variation. Four sources identify their shocks from high-frequency data around monetary policy events: Miranda-Agrippino and Ricco (2021), Jarociński and Karadi (2020) who estimate both an interest rate shock and a Fed information shock, Bauer and Swanson (2023) who expand the set of Fed events used to estimate the shocks, and Swanson (2024) who decomposes the high-frequency asset price movements into a target rate shock, a forward guidance shock, a large-scale asset purchase shock. Two other sources use narrative methods. Aruoba and Drechsel (2024) build on ideas in Romer and Romer (2004), using natural language processing of internal documents to capture the Fed's information set. Drechsel (2024) uses data on Presidential interactions with Fed Chairs to estimate political pressure shocks in a narrative sign-restricted SVAR (Antolín-Díaz and Rubio-Ramírez, 2018).

For government spending, we began with two series previously collected and harmonized by Ramey (2016). These series use military events in some way as a source of exogenous variation: Fisher and Peters (2010) estimate shocks from excess returns for defense contractor stocks, and Ramey (2011) uses narrative military shocks constructed from periodicals. To these, we add three sources of non-defense government spending shocks, all using nar-

[10]In related work, Adams and Barrett (2025) apply the monthly subset of these instruments, plus additional monetary shocks, to use an IV method to decompose how MPS depend on contemporaneous interest rate surprises versus news about future policy across many horizons.

Shock Source	Method	Notes	Range
Monetary Policy Shocks			
Jarociński and Karadi (2020)	HFI	2 shocks: target rate and Fed information	1990:M1-2016:M12
Miranda-Agrippino and Ricco (2021)	HFI	Orthogonalized w.r.t. Greenbook	1991:M1-2009:M12
Bauer and Swanson (2023)	HFI	Orthogonalized w.r.t. financial data	1988:M2-2023:M12
Swanson (2024)	HFI	3 types: FFR, forward guidance, & LSAP	1988:M2-2023:M12
Aruoba and Drechsel (2024)	Narrative	Natural language processing of Fed docs	1982:M10-2008:M10
Drechsel (2024)	SVAR	Political pressure on the Fed	1935:Q1-2016:Q4
Government Spending Shocks			
Fisher and Peters (2010)	External	Excess returns of defense contractors	1947:Q1-2008:Q4
Ramey (2016)	Narrative	Military news	1947:Q1-2013:Q12
Romer and Romer (2016)	Narrative	Social Security expansions	1951:M1-1991:M12
Fieldhouse et al. (2018)	Narrative	Government housing purchases	1952:M11-2014:M12
Fieldhouse and Mertens (2023)	Narrative	Government R&D expenditures	1947:Q1-2021:Q4
Tax/Borrowing Shocks			
Leeper et al. (2012)	External	Fiscal news from bond markets, SPF	1947:Q1-2007:Q4
Phillot (2025)	HFI	Futures yields & Treasury announcements	1998:M10-2020:M01
Mertens and Ravn (2012)	Narrative	Anticipated and unanticipated	1947:Q1-2007:Q4
Lieb et al. (2024)	Narrative	News from Presidents' speeches	1951:Q4-2007:Q3
Technology Shocks			
Fernald (2014)	External	Utilization-adjusted TFP	1947:Q2-2024:Q4
Miranda-Agrippino et al. (2025)	External	Patent filing news	1982:M10-2014:M12
Oil Shocks			
Kilian (2008)	External	OPEC conflict events	1971:Q1-2004:Q3
Känzig (2021)	HFI	Oil supply news	1975:M1-2023:M6
Baumeister and Hamilton (2019)	SVAR	Oil supply, consumption/inventory demand	1975:M2-2024:M3
Other Shocks			
Kim et al. (2025)	External	ACI severe weather shocks	1964:M4-2019:M5
Piffer and Podstawski (2018)	HFI	Uncertainty shocks from intraday gold prices	1979:M1-2025:M4
Chahrour and Jurado (2022)	SVAR	Noise shocks to TFP expectations	1948:Q2 - 2023:Q4
Adams and Barrett (2024)	SVAR	Shocks to inflation expectations	1979:M1-2024:M5

Table 2: Structural Shock Instruments

rative methods. Romer and Romer (2016) identify transfer shocks from social security expansions, Fieldhouse et al. (2018) use mortgage purchases from federal housing agencies, and Fieldhouse and Mertens (2023) use changes to federal R&D appropriations.

Two series of tax shocks are also sourced from the Ramey (2016) collection: Mertens and Ravn (2012) use records of the delay between passage and implementation of tax legislation to isolate anticipated vs. unanticipated tax changes; Leeper et al. (2012) estimate expected tax changes using spreads between federal and municipal bonds. In addition to these, we add the Lieb et al. (2024) tax shocks constructed from analysis of presidential speeches. We also include Federal borrowing shocks estimated by Phillot (2025) using high frequency data around news of treasury auction announcements.

To measure productivity shocks, we take innovations to the utilization-adjusted TFP series from Fernald (2014), which is regularly updated. To account for news, we include the technology news shocks from Miranda-Agrippino et al. (2025), which uses patent applications orthogonalized with respect to macroeconomic conditions as an instrument for future productivity.

Oil shocks come in three flavors. Kilian (2008) identifies oil supply shocks from conflicts in oil-producing countries. Baumeister and Hamilton (2019) use a Bayesian VAR incorporating prior information about elasticities to separately identify oil supply and demand shocks. Känzig (2021) uses high frequency asset price data around OPEC announcements to identify news shocks regarding future oil supply.

Finally, in order to cover as broad a set of macroeconomic forces as possible, we use several additional series that do not fit neatly into one of the above categories. Piffer and Podstawski (2018) estimate macroeconomic uncertainty shocks using high-frequency data on volatility in intraday gold prices around international financial and political events. Kim et al. (2025) estimate severe weather shocks that are relevant for the US macroeconomy. Chahrour and Jurado (2022) develop a method to estimate the effects of noise shocks to expectations over future TFP; we construct the implied series of noise shocks following the method in Adams (2023). And Adams and Barrett (2024) identify shocks to inflation expectations using a SVAR with appropriate restrictions on the co-movement between forecasts and future inflation.

4.2 Results

In our baseline specification, we treat behavioral expectations as simply proportional to the rational expectation by some unknown factor (as discussed in Section 4.1.3). We use all of the shocks in Table 2 as instruments, although we also conduct robustness checks using selected subsets of these shocks.

Figure 1 reports the posterior densities from our baseline specification. The first panel corresponds to the behavioral attenuation θ. Our prior on this parameter (the red line) is uniform on the unit interval, because while theory gives little guidance on the exact value of θ, all mechanisms for Ricardian non-equivalence discussed in Section **??** predict that it falls between zero and one. The posterior density is overwhelmingly far from one: consumers are not Ricardian.

The behavioral attenuation θ is implied by $\theta = 1 + \phi_\tau/\phi_n$, a transformation of reduced-form coefficients in the estimation equation (18). The second panel corresponds to $\phi_n = 1-\beta$, the marginal propensity to consume (MPC) out of wealth. The MPC prior is Gaussian with a large standard deviation (Table 6); the data are very informative so the posterior is relatively tight. Reassuringly, estimate MPC is positive but relatively small. The third panel corresponds to $\phi_\tau = -(1-\beta)(1-\theta)$. This is the direct effect of taxes on consumption.

And $-\phi_\tau$ is what we refer to as the *MPC out of debt-financed transfers* (MPC-DFT). The prior appears unusual because it is implied by the priors on θ and ϕ_n; again the data are very informative. The estimated MPC-DFT is smaller than the generic MPC, but not by much because people are far from Ricardian.

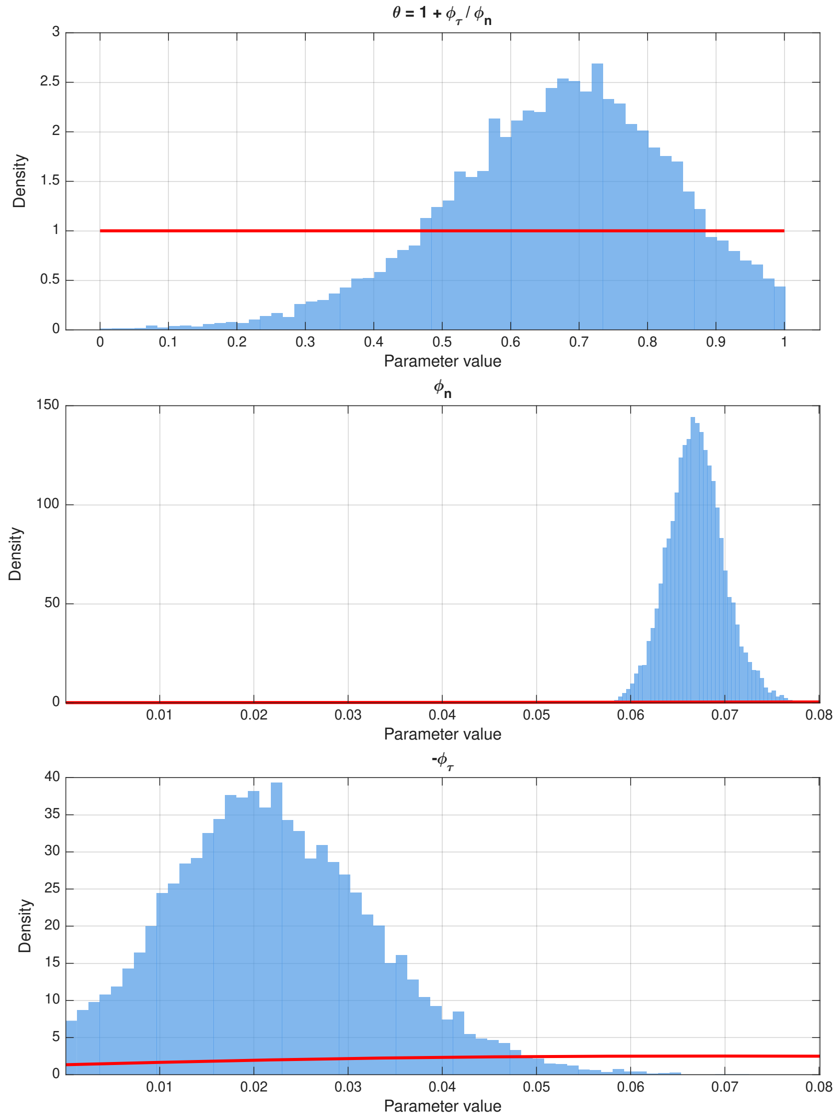


Figure 1: Marginal Posterior Densities for Three Consumption Function Parameters

We use a sequential Monte Carlo sampler (Herbst and Schorfheide, 2015) to approximate the posterior distribution of our model. The first panel plots the marginal posterior of θ, the behavioral attenuation. θ is determined from two coefficients in estimated equation (18): the coefficient on net worth (second panel) $\phi_n = 1 - \beta$, and the coefficient on taxes (third panel) $\phi_\tau = -(1-\beta)(1-\theta)$. The prior distributions are plotted in red; the priors on θ and ϕ_n are chosen (Table 6), and the prior on ϕ_τ is implied by the relationship between the three quantities.

Table 3 reports point estimates for the two quantities of interest. We calculate these as the medians of the posterior distributions, and also report the 90% credible interval. The first row gives the estimates from our baseline specification. The point estimate of the behavioral attenuation coefficient implies that consumers internalize only 68% of future taxes. 90% of the posterior mass appears in the $[37\%, 92\%]$ credible interval. This implies that the data soundly reject Ricardian equivalence: θ is clearly less than one. But the lower bound is also much greater than zero, i.e. households are not strictly myopic regarding their future tax burden. While there remains uncertainty about the exact value of θ, the marginal propensities to consume have relatively tight posteriors. The point estimate of the MPC ϕ_n is roughly 7%, which is somewhat smaller than the micro evidence from major government transfers (Parker et al., 2013, 2022; Baker et al., 2023), and much less than the largest estimates (Johnson et al., 2006; Hausman, 2016; Chetty et al., 2024). The point estimate of the MPC-DFT ($-\phi_\tau$) is roughly 4% with only modest uncertainty. In contrast, the MPC-DFT cannot be estimated from existing microeconomc studies because of the missing intercept problem.

Specification	Attenuation (θ)	MPC (ϕ_n)	MPC-DFT ($-\phi_\tau$)
Baseline	0.679 $[0.376, 0.921]$	0.067 $[0.062, 0.072]$	0.021 $[0.005, 0.041]$
Non-durable consumption	0.184 $[0.016, 0.491]$	0.027 $[0.021, 0.034]$	0.022 $[0.013, 0.030]$
Survey-based forecasts	0.456 $[0.049, 0.908]$	0.015 $[0.011, 0.019]$	0.008 $[0.001, 0.015]$
Non-separable utility	0.052 $[0.005, 0.295]$	0.065 $[0.059, 0.067]$	0.062 $[0.042, 0.066]$
Variable distortionary taxes	0.206 $[0.131, 0.253]$	0.036 $[0.033, 0.040]$	0.029 $[0.026, 0.032]$
Variable HtM income shares	0.154 $[0.048, 0.292]$	0.071 $[0.066, 0.077]$	0.060 $[0.049, 0.069]$
6 select instruments	0.348 $[0.048, 0.757]$	0.040 $[0.032, 0.051]$	0.026 $[0.010, 0.038]$

Table 3: Consumption Function Estimates (Posterior Medians)

Notes: Point estimates are medians of the marginal posterior distributions. Column values are related by $\theta = 1 + \phi_\tau/\phi_n$. Columns titles refer to the marginal propensity to consume (MPC) and MPC out of debt-financed transfers (MPC-DFT). The $[5\%, 95\%]$ credible intervals are reported in brackets. Section 4.3 describes the specifications.

4.3 Robustness

We conduct a variety of robustness checks, for which Table 3 also reports results.

First, we rerun our baseline method using non-durable consumption instead of the standard aggregate. This definition implies a substantially lower behavioral attenuation parameter θ, i.e. households appear to be less Ricardian. This is mainly because the estimated

MPC for non-durable consumption much lower (as expected), while the MPC-DFT is not. However, the credible set is much larger with this approach, so we do not interpret it as strong evidence that households are much less Ricardian than our baseline suggests.

Second, we relax the assumption that behavioral expectations are linear in the rational expectations. To do so, we use empirical surveys, following the method described in Section 4.1.3. This approach is very informative about both the MPC and MPC-DFT, which have tight marginal posteriors. However the point estimate of θ is poorly identified, as the marginal posterior for θ is relatively close to the prior distribution.

Our behavioral consumption function depends on three components: two budget constraints and an Euler equation. The latter introduces misspecification risk, so we consider three alternatives that address possible distortions to the Euler equation. First, we allow for the possibility that the marginal utility of consumption is affected by the labor-leisure choice. To do so, we include the present value of hours growth, which we justify and derive in Appendix D.2. Second, distortionary taxes may lead to non-Ricardian behavior if they enter the Euler equation; we show this in Appendix D.3 and account for it by including the present value of future marginal income tax rates. Third, Proposition 3 showed that our behavioral consumption function is isomorphic to the Angeletos et al. (2024) consumption function that approximates occasionally-binding liquidity constraints. But this is not true if there is a subset of households that are permanently hand-to-mouth if they also face a a different income process than the unconstrained households. We show in Appendix D.4 that we can account for this using the income of hand-to-mouth households, which we measure in the SCF following Kaplan and Violante (2014).[11] In all three of these cases, we estimate that households are less Ricardian than in our baselines, but only the distortionary taxation substantially changes our estimate of the MPC.

B-HIVE requires that our instruments satisfy the exclusion restriction, but there may be concerns that some instruments do not, especially when we use so many. Therefore, we repeat our baseline specification using different subsets of instruments, listed in Table 8. In our baseline, we chose to be conservative by excluding all SVAR-based shocks, which may covary with other macro shocks if their identifying assumptions fail. When we incorporate the SVAR IVs, we find a similar estimate for θ, with much tighter credible intervals. Next, we adopt a maximally conservative approach using only one state-of-the-art instrument per shock type.[12]. Again, this alternative specification implies that households are substantially less Ricardian than in our baseline, mainly because the estimated MPC is smaller.

[11] Appendix E contains further details.

[12] The six instruments are Fieldhouse and Mertens (2023); Aruoba and Drechsel (2024); Lieb et al. (2024); Känzig (2021); Fernald (2014); Piffer and Podstawski (2018)

4.4 Non-Rational Expectations vs. Discounting

In Section 2, we argued that multiple different causes of non-Ricardian behavior lead to the same reduced-form consumption function, which we estimated without regard to the underlying cause.

However, with additional assumptions, we can separately attribute non-Ricardian behavior to two causes: non-rational expectations and a discounting wedge ω. This is because non-rational expectations only affects consumption out of future taxes, income and so forth. But a discounting wedge also affects consumption out of current financial net worth. To do this decomposition, we must take a stand on the specific form of expectations over taxes. We do so, assuming that households are either sophisticated or naive cognitive discounters.[13] We also assume that the present value of real taxes follows an AR(1), as in Section 2.3.

Proposition 8 in Appendix D.5 derives the consumption function in both of these cases: it matches the usual discounting wedge consumption function (Proposition 3) except the θ term becomes

$$\theta_{cd} = \begin{cases} \omega\lambda\frac{1-\beta\rho_\tau}{1-\beta\omega\lambda\rho_\tau} & \text{sophisticated cognitive discounting} \\ \omega\lambda\frac{1-\beta\rho_\tau}{1-\beta\omega\rho_\tau} & \text{naive cognitive discounting} \end{cases} \tag{23}$$

where λ is the cognitive discounting attenuation parameter. By taking a stance on the government discount factor β, and the autocorrelation of the present value of taxes ρ_τ, we can identify ω and λ from the estimated MPC $\phi_n = (1 - \beta\omega)$ and MPC-DFT $-\phi_\tau = (1 - \beta\omega)(1 - \theta_{cd})$.

Table 4 presents the results, setting $\beta = 0.995$ (to match a 2% long run real interest rate) and $\rho_\tau = 0.978$ (to match the quarterly autocorrelation of v_t^τ).[14] We derive the parameters using the point estimates from our baseline specification reported in Table 3. First, we report the attenuation value for naive cognitive discounting without any discounting wedge: this λ maps exactly to the reduced-form behavioral attenuation θ estimated previously. Second, we report the sophisticated cognitive discounting parameter, which is derived from θ in Appendix B; this value is much larger, because in order to be consistent with the behavioral attenuation θ, it must exponentially discount future taxes by λ, and future taxes have a very high autocorrelation. Third, we report the discounting wedge ω implied by the θ

[13] In both cases, cognitive discounting implies that future expectations are attenuated by a parameter λ. Sophisticated cognitive discounters recognize that they will form expectations in this way in the future, while naive households act as if they will have rational expectations in the future. See Appendix B for further details.

[14] We calculate v_t^τ as implied by the **B-HIVE** VAR structure in our baseline specification. In the model this is equivalent to the autocorrelation of debt, but in reality real debt is not riskless (which we address in Appendix D.1) so it is more appropriate to estimate the present discounted value of taxes directly.

Mechanism	Aggregate Consumption		Non-Durable Consumption	
	λ	ω	λ	ω
Naive Cognitive Discounting	0.69		0.19	
Sophisticated Cognitive Discounting	0.99		0.89	
Discounting Wedge + Rational		0.99		0.89
Discounting Wedge + Naive C.D.	2.43	0.94	0.34	0.98
Discounting Wedge + Sophisticated C.D.	1.05	0.94	0.91	0.98

Table 4: Implied Parameter Values for Different Non-Ricardian Mechanisms

Notes: Table reports values for the cognitive discounting parameter λ and discounting wedge ω implied by estimated MPCs, given $\beta = 0.995$ and $\rho_\tau = 0.978$. The "Aggregate Consumption" columns denote the baseline specification; the "Non-Durable Consumption" columns is estimated using only non-durables. Proposition 8 derives the relationships that imply these outcomes. All values correspond to the baseline point estimates reported in Table 3.

estimate per Proposition 3, without imposing a value of β to use any information from the estimated MPC $(1 - \beta\omega)$; this value is exactly equivalent to the second row. Finally, we use equation (23) to derive joint estimates of the ω and λ parameters for both behavioral assumptions. Again, because the autocorrelation of taxes is so high, the sophisticated cognitive discounting parameter must be much larger than the naive parameter.

These results show that the specification matters for decomposing observed non-Ricardianism across potential causes. In our baseline specification, θ is relatively large, and either behavioral expectations or a discounting wedge can fully explain the behavior. Indeed, if a discounting wedge is chosen to match the MPC estimate, households need to *over*-extrapolate ($\lambda > 1$) to be consistent with the MPC-DFT. However, if we use estimate the model using non-durable instead of aggregate consumption, it implies a much smaller values for the behavioral attenuation θ. In this case, households must have both λ and ω substantially less than one to match both MPCs. This is true for the other specifications (and regions of the credible set) reported in Table 3 that have low θ estimates and large MPCs.

5 Macroeconomic Implications

In this section, we explore the macroeconomic implications of our results in a general equilibrium economy. Because tax cuts increase consumption by non-Ricardian households, they also reduce savings. Thus, government borrowing crowds out private capital.

We also use the model to illustrate the econometric challenges in a Monte Carlo simulation. When the consumption function features demand shocks, OLS is biased, but structural shocks can be used as instruments to consistently estimate the consumption function.

5.1 Model Assumptions

We study a standard real business cycle model modified with behavioral expectations.[15] Government finances exogenous spending with taxes and risk-free debt. Taxation follows a fiscal rule subject to exogenous shocks. We include a variety of additional shocks in order to both challenge our Monte Carlo estimation and construct valid instruments: TFP, IST, government spending, risk, and demand shocks.

5.1.1 Households

The representative household's preferences over current and future consumption are represented by

$$\tilde{\mathbb{E}}_t \left[\sum_{s=0}^{\infty} \beta^s u(C_{t+s}) \right] \tag{24}$$

where C_t is the household's consumption in period t, β is its discount factor, $u(\cdot)$ is a strictly concave utility function, and $\tilde{\mathbb{E}}_t$ is the household's subjective expectation.

The household earns two kinds of income. It inelastically works L_t units of time, for which it is paid real wage W_t. And it rents capital K_{t-1} at rental rate R_t. The household can save by purchasing risk-free bonds B_t, which pay one unit of the numeraire and cost Q_t. It can buy and sell capital K_t at stochastic cost Z_t^k, and capital depreciates at rate δ. The household spends its remaining income on consumption C_t and taxes T_t. The household's budget constraint is

$$W_t L_t + R_t K_{t-1} + Z_t^k (1-\delta) K_{t-1} + B_{t-1} = C_t + T_t + Q_t B_t + Z_t^k K_t \tag{25}$$

The household's savings decisions are characterized by two Euler equations. The Euler equation for bonds is:

$$Q_t = \beta \tilde{\mathbb{E}}_t \left[\frac{u'(C_{t+1})}{u'(C_t)} \right] + Z_t^d \tag{26}$$

while the Euler equation for capital is

$$1 = \beta \tilde{\mathbb{E}}_t \left[\frac{u'(C_{t+1})}{u'(C_t)} R_{t+1}^K \right] + Z_t^d + Z_t^r \tag{27}$$

where

$$R_{t+1}^K \equiv \frac{R_{t+1} + Z_{t+1}^k (1-\delta)}{Z_t^k}$$

[15] The model is solved using BEET (Adams, 2024), a toolkit for dynamic models with behavioral expectations.

denotes the return on capital. We introduce two ad hoc exogenous wedges to the Euler equations. The stochastic Z_t^d is an intertemporal wedge that affects both; the stochastic Z_t^r is a risk wedge the affects only capital demand.

5.1.2 Future Taxes

We write the perceived present value of current and future taxes as

$$\tilde{V}_t^T = \tilde{\mathbb{E}}_t \left[\sum_{s=0}^{\infty} P_{t,t+s} T_{t+s} \right] \tag{28}$$

where $P_{t,t+s} \equiv \prod_{r=0}^{s-1} Q_{t+r}$ denotes the relative price between consumption in different periods, with $P_{t,t} \equiv 1$. The perceived tax burden $\tilde{V}_t^T$ follows a recursive law of motion:

$$\tilde{V}_t^T = T_t + Q_t \tilde{\mathbb{E}}_t [\tilde{V}_{t+1}^T] \tag{29}$$

5.1.3 Production

Competitive firms rent capital and labor from the household. They produce generic output using a constant returns to scale production function. For the representative firm, output is given by

$$Y_t = A_t F(K_{t-1}, L_t) \tag{30}$$

where A_t is total factor productivity. The firm's factor demand functions are

$$A_t F_K(K_{t-1}, L_t) = R_t \tag{31}$$

$$A_t F_L(K_{t-1}, L_t) = W_t \tag{32}$$

Output is used for consumption, government spending, and investment. The economy-wide resource constraint is:

$$Y_t = C_t + G_t + Z_t^K (K_t - (1 - \delta) K_{t-1}) \tag{33}$$

5.1.4 Government

The government must finance exogenous government expenditures G_t, and does so by taxing and issuing risk-free bonds B_t at price Q_t. The government's budget constraint is

$$G_t = T_t + Q_t B_t - B_{t-1} \tag{34}$$

and define deficits D_t by

$$D_t \equiv G_t - T_t$$

which implies that the government's lifetime budget constraint can be written

$$B_{t-1} = -\sum_{s=0}^{\infty} P_{t,t+s} D_{t+s}$$

or

$$B_{t-1} = \sum_{s=0}^{\infty} P_{t,t+s} T_{t+s} - \sum_{s=0}^{\infty} P_{t,t+s} G_{t+s}$$

Taxes T_t and government spending G_t are both exogenous.

5.1.5 Equilibrium Definition

A *behavioral expectations equilibrium* is a stationary series of 3 prices (Q_t, W_t, R_t), 5 quantities $(Y_t, K_t, B_t, C_t, T_t)$ and exogenous time series $(A_t, L_t, G_t, Z_t^u, Z_t^k)$, satisfying 8 equations:

1. Households maximize expected utility: their Euler equations (26) and (27) hold.
2. Firms produce by (30) and satisfy factor demands (31) and (32)
3. Fiscal variables follow the government budget constraint (34)
4. The resource constraint (33) is satisfied

5.1.6 Linearized Equilibrium Conditions

We linearize the model around the deterministic steady state. In the linear equations, lowercase letters denote deviations (except for taxes, whose deviation is denoted by τ_t) from the steady state, while uppercase with bars denote steady state values.

The budget constraint becomes

$$w_t \overline{L} + r_t \overline{K} + \overline{R}^k k_{t-1} + b_{t-1} = c_t + \tau_t + q_t \overline{B} + \beta b_t + k_t$$

which uses $\overline{R^k} = \overline{R} + 1 - \delta$.[16]

The Euler equations (26) and (27) become

$$q_t = \beta \tilde{\mathbb{E}}_t [\gamma \frac{1}{\overline{C}} (c_t - c_{t+1})] + z_t^d \tag{35}$$

[16] To map this budget constraint to the generic form expressed in equation (3), define net worth as $n_t = \beta^{-1} k_t + b_t$ and use $\overline{R}^k = \beta^{-1}$.

$$0 = \beta\tilde{\mathbb{E}}_t[\gamma\frac{1}{\bar{C}}(c_t - c_{t+1}) + r_{t+1} + (1-\delta)z^k_{t+1}] - z^k_t + z^d_t + z^r_t \tag{36}$$

where $\gamma = \frac{u''(\overline{C})\overline{C}}{u'(\overline{C})}$ is the steady state coefficient of relative risk aversion. The second equation uses that $r^k_t = r_t + (1-\delta)z_t - \overline{R}^k z_{t-1}$, as well as $\overline{Z}^k = 1$ and $\overline{R}^k = 1/\beta$.

With inelastic labor supply, output (equation (30)) is given by

$$y_t = \overline{Y}a_t + \overline{R}k_{t-1} \tag{37}$$

with steady state productivity normalized to $\overline{A} = 1$. Similarly, the capital demand (31) is linearized as

$$r_t = \overline{R}a_t + \bar{F}_{KK}k_{t-1} \tag{38}$$

and the labor demand (32) is linearized as

$$w_t = \overline{W}a_t + \bar{F}_{LK}k_{t-1} \tag{39}$$

The government budget constraint (34) is

$$b_{t-1} = \tau_t - g_t + q_t\bar{B} + \beta b_t \tag{40}$$

The resource constraint (33) is

$$y_t = c_t + g_t + k_t - (1-\delta)k_{t-1} + \delta\overline{K}z^k_t \tag{41}$$

with the normalization $\overline{Z}^k = 1$.

The consumption function in this model follows the general behavioral consumption function in Proposition 2.

We assume that the exogenous terms follow AR(1) processes. The linearized stochastic wedges are given by

Demand	$\zeta_t = \rho_\zeta\zeta_{t-1} + \epsilon^\zeta_t$	(42)
TFP	$a_t = \rho_a a_{t-1} + \epsilon^a_t$	(43)
IST	$z^k_t = \rho_k z^k_{t-1} + \epsilon^k_t$	(44)
Risk	$z^r_t = \rho_r z^r_{t-1} + \epsilon^r_t$	(45)
Gov. Spending	$g_t = \rho_g g_{t-1} + \epsilon^g_t$	(46)

where $(\epsilon^\zeta_t, \epsilon^a_t, \epsilon^k_t, \epsilon^r_t\epsilon^g_t)$ are independent Gaussian shocks. The present value of taxes v^τ_t is also AR(1):

$$\text{P.V. Taxes} \qquad v_t^\tau = \rho_\tau v_{t-1}^\tau + \epsilon_{t-1}^\tau \tag{47}$$

which depends on the *lagged* tax shock ϵ_{t-1}^τ, because if there is zero steady-state debt ($\overline{B} = 0$), the government budget constraint implies $b_{t-1} = v_t^\tau$, so v_t^τ must not depend on time t shocks. Lastly, $v_t^\tau = \tau_t + \beta \mathbb{E}[v_{t+1}^\tau]$ implies that the exogenous tax process τ_t satisfies

$$\text{Current Taxes} \qquad \tau_t = \rho_\tau \tau_{t-1} - \beta \epsilon_t^\tau + \epsilon_{t-1}^\tau \tag{48}$$

5.1.7 Expectations

We assume that households have rational expectations about most exogenous processes, i.e. recognizing that they follow equations (42) - (46). However, they forecast taxes with behavioral attenuation θ:

$$\tilde{\mathbb{E}}_t[\tau_{t+1}] = \theta \mathbb{E}_t[\tau_{t+1}]$$

At further horizons, we also assume that θ attenuates the recursive forecast $\tilde{\mathbf{E}}_{t,t+j}[\tau_{t+j+1}] = \tilde{\mathbb{E}}_t \tilde{\mathbb{E}}_{t+1} ... \tilde{\mathbb{E}}_{t+j}\,[\tau_{t+j+1}]$:

$$\tilde{\mathbf{E}}_{t,t+j}[\tau_{t+j+1}] = \theta \mathbb{E}_t[\tau_{t+j+1}] \tag{49}$$

These expectations are referred to as *naive cognitive discounting*, because θ is only applied once instead of recursively.[17] This structure recovers the relationship assumed in Section 2 (equation (13)).

Why do we follow this attenuation on tax forecasts instead of applying behavioral expectations more broadly? We want to emphasize that this source of non-Ricardianism is not specific to behavioral models, but can justify non-Ricardian behavior in more general settings, including those where agents are otherwise rational. We only apply the non-rational bias to taxes, but this friction can easily be extended to other shocks as well. Additionally, we choose the naive behavioral expectations for clarity, because the non-Ricardian parameter θ from Section 2 appears directly. Appendix B shows that if we used the sophisticated representation, whereby the attenuation is applied recursively, we would still have the desired behavioral consumption function, but the mapping from the attenuation parameter to θ is more complicated.

5.2 The Effects of Tax Shocks

To quantify how Ricardianism is affected by a consumer's behavioral expectations, we consider an unexpected tax shock ϵ_t^τ that does not affect government spending.

[17] Appendix B describes how we represent these expectations when solving the model.

Parameter	Symbol	Value
Discount factor	β	0.99
Capital share	α	0.4
Depreciation rate	δ	0.02
Relative risk aversion	γ	1
Steady state debt	$\bar{B}$	0
Shock autocorrelation	$\rho_\zeta, \rho_a, \rho_k, \rho_r, \rho_\tau$	0.5
Std. dev. of shocks	$\sigma_\zeta, \sigma_a, \sigma_k, \sigma_r, \sigma_\tau$	1
Std. dev. of IV errors	$\sigma_{\xi,1}, \sigma_{\xi,2}$	$0.1, 0.2$

Table 5: Parameter Values for the Quarterly Business Cycle Model

The model is intended to be illustrative, so we choose a generic quarterly parameterization (Table 5), but do not attempt to estimate or discipline the time series properties of the exogenous wedges. When conducting the Monte Carlo study, we will vary the shock variances and the behavioral attenuation θ. In this section, we let $g_t = 0$ and $\bar{B} = 0$ so that the government budget constraint simplifies to

$$b_{t-1} = \tau_t + \beta b_t$$

Changes to taxes can affect consumption because households are able to substitute from consumption to savings. Market clearing implies that any decline in consumption is offset by an investment increase. Under Ricardian equivalence, tax shocks have no effect on consumption, because agents know that current tax changes will be paid by (or pay for) future tax changes. However, when households are not Ricardian, then tax changes distort the consumption/savings decision.

Figure 2 plots the impulse responses to a *negative* tax shock (e.g. a surprise rebate) for a variety of θ values. When $\theta < 1$, agents expect that future taxes will be smaller than the rational expectation, and so would like to increase consumption (Panel 2a). GDP is fixed on impact, so this must reduce investment, and the capital stock shrinks (Panel 2b). Consol values (Panel 2c) fall as consumers expect lower interest rates, in line with their perceived path of declining consumption. As θ shrinks, households are less Ricardian, and want to increase consumption by even more. This leads to a deeper macroeconomic contraction. In all these cases, the tax cut increases government debt (Panel 2d). Thus, when $\theta < 1$, *government debt crowds out capital.*

5.3 Monte Carlo Simulation

In this section we simulate the model in order to demonstrate the challenges involved in estimating Ricardianism, why OLS fails, and how IVs can resolve the problem.

We maintain the specialized assumptions that government spending is fixed ($g_t = 0$) and steady state debt is $\bar{B} = 0$. With these assumptions, the behavioral consumption function is even simpler than in Proposition 2:

Corollary 1 *If government spending is constant ($g_t = 0$), steady state debt is $\overline{B} = 0$, and perceived future taxes are proportional to the rational expectation by $\tilde{\mathbb{E}}_t[v^\tau_{t+1}] = \theta \mathbb{E}_t[v^\tau_{t+1}]$, then the consumption function can be written in terms of financial assets n_{t-1}, government debt b_{t-1}, taxes τ_t, console values $\tilde{v}^q_t$, and perceived non-financial wealth $\tilde{v}^y_t$ as:*

$$c_t = (1-\beta)\left(n_{t-1} - \theta b_{t-1} + \tilde{v}^y_t - (1-\theta)\tau_t\right) + \frac{\overline{C}}{\gamma}\tilde{v}^q_t + \zeta_t \tag{50}$$

Proof: Appendix A

Are government bonds net wealth? Behavioral households act as if they are. Corollary 1 implies that if households do not have rational expectations, current bond holdings b_{t-1} affect consumption, *ceteris paribus*. Bonds appear in financial assets n_{t-1}, but households only net out the share θ of their bond holdings when making their consumption decision.

We can estimate the consumption function (50) in the simulated data, but the residual ζ_t introduces an omitted variable problem. Even if the econometrician observes n_{t-1}, b_{t-1}, v^y_t, τ_t, and v^q_t, the demand shock ζ_t will affect both consumption and time t endogenous variables, so OLS estimates will be biased. And even though taxes are entirely exogenous, omitted variable bias still affects the coefficient on τ_t because we are estimating the effect of variation in τ_t orthogonal to the other regressors.

Thus, classic OLS estimates of the consumption function (50) can go wrong. Figure 3a demonstrates how, by plotting the estimated coefficient on τ_t from a regression of c_t on n_{t-1}, b_{t-1}, v^y_T, τ_t, and v^q_t. The true coefficient is $-(1-\beta)(1-\theta)$, so we transform the estimated coefficients using the true β to give an estimate $\hat{\theta}$, so that axes are directly comparable. The solid blue line shows how the estimated coefficient varies with the behavioral factor θ when there are no demand shocks. When households are Ricardian ($\theta = 1$), taxes have no effect on consumption. As households become less Ricardian, taxes have larger effects on consumption; when households are myopic ($\theta = 0$), taxes reduce consumption by the entire MPC $1-\beta$. Coefficients on the blue line identify the Ricardian factor, because there is no unobserved demand shock. But the dashed red line and dotted yellow lines plot regression coefficients when ζ_t has a small and large variance, respectively. These lines diverge from the blue line: the estimates are biased. The higher the variance of the unobserved shock, the worse the omitted variable bias.

Applied macroeconomists have identified plausibly exogenous tax shocks with a number of methods (e.g. Mertens and Ravn, 2012 and Leeper et al., 2012). These shocks should be orthogonal to the demand shocks that create the omitted variable bias documented in

Figure 3a. Can the behavioral factor θ be identified by simply regressing consumption on exogenous tax shocks? No. Tax shocks are orthogonal to demand shocks, but also affect consumption through other channels (e.g. interest rates). And with this approach, those other channels become omitted variables. Accordingly, the OLS regression of consumption on tax shocks is biased, except in the case of exact Ricardianism ($\theta = 1$). Figure 3b demonstrates: the estimated coefficients are not affected by the presence of demand shocks, but the OLS estimates are attenuated towards Ricardianism compared to the true value of θ (the blue line from Figure 3a).

Using lagged macroeconomic variables as instruments does not work either. Early in the Ricardian equivalence literature it was clear that OLS might be biased; Hayashi (1982) and Feldstein (1982) proposed estimating the consumption function by IV with lagged variables. This solution is valid if demand shocks are uncorrelated. But in the Monte Carlo model, demand shocks are autocorrelated. Figure 3c plots the estimated parameter using lagged consumption, capital, and console values to instrument for the endogenous regressors. The method is consistent when there are no demand shocks (blue line), but when the demand shock variance increases, the method's bias does as well.

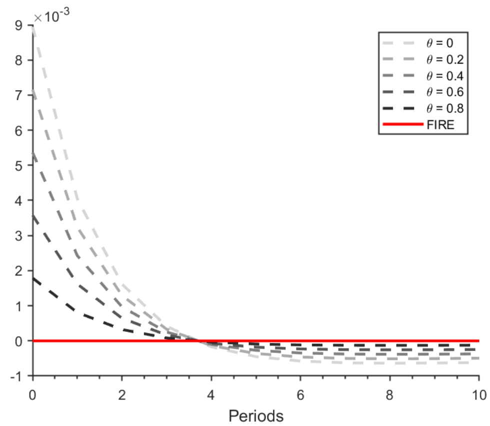
Macro shocks as instrumental variables can resolve the problem. The Monte Carlo model's consumption function (50) has three endogenous variables (n_{t-1}, $\tilde{v}_t^y$, and $\tilde{v}_t^q$) and two exogenous variables (b_{t-1} and τ_t) so three non-collinear exogenous instruments are needed. We use productivity a_t, the capital cost (IST) z_t^k, and the risk premium z_t^r as IVs. These IVs affect the endogenous variables, but not taxes τ_t, debt b_{t-1}, nor demand shocks ζ_t. Then the consumption function is estimated by two stage least squares. Figure 3d reports the estimated coefficients on τ_t from this exercise. Regardless of the presence of demand shocks, the IV estimation recovers the correct effect of a tax change.

6 Conclusion

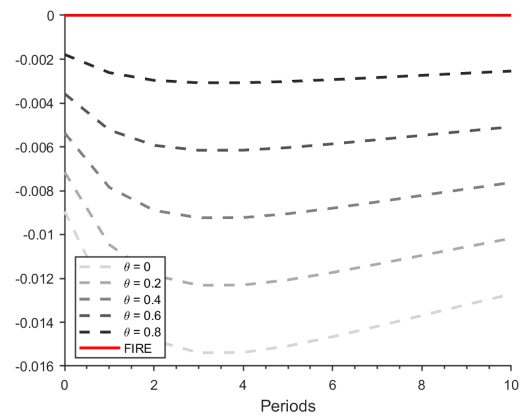
How Ricardian are we? Our time series estimates suggest: not very Ricardian. This is a challenging question to answer because it requires estimating the consumption function, for which microeconomic evidence is insufficient due to the missing intercept problem, while macroeconomic evidence suffers from omitted variables. To address these challenges, we derived a Bayesian limited information method that used structural macroeconomic shocks as IVs.

Our treatment of non-Ricardianism has broad implications. Because taxes distort consumption and investment, the degree of non-Ricardianism matters for public debt management, business cycle smoothing, optimal tax planning, monetary policy, and an endless variety of further topics. Moreover, our behavioral method of modeling non-equivalence is easily embedded into other macroeconomic models that feature other frictions and are not necessarily behavioral.

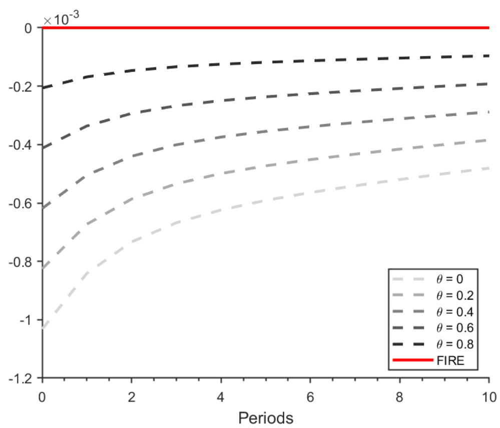
Our **B-HIVE** estimation method has broad applicability as well. The method is flexible out of the box, easily accommodating data with intermittent coverage and missing observations. It also handles expectations elegantly; rational expectations are internally consistent or can be proxied by external forecast data. And the Bayesian framework allows for informative priors based on theory – which we leveraged to estimate θ – plus all the usual benefits of Bayesian statistics. This method will be valuable for estimating structural macroeconomic equations in many contexts, either using the structural shocks that we have collected or by augmenting our dataset with further instruments.



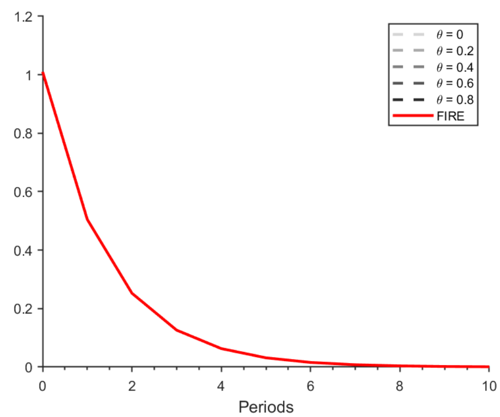
(a) Consumption



(b) Capital



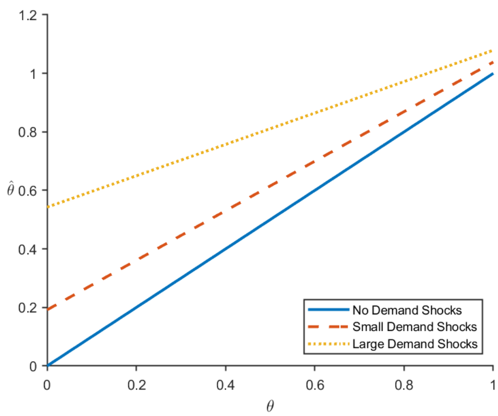
(c) Consol Value



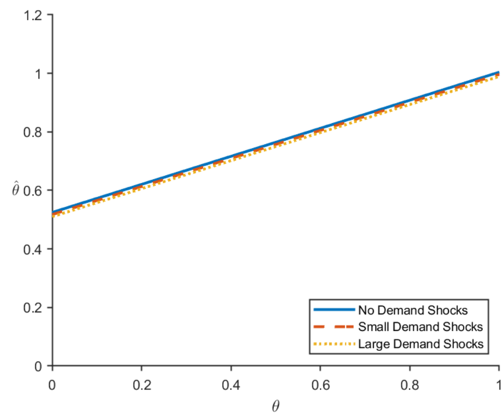
(d) Government Debt

Figure 2: Non-Ricardian Responses to a Negative Tax Shock

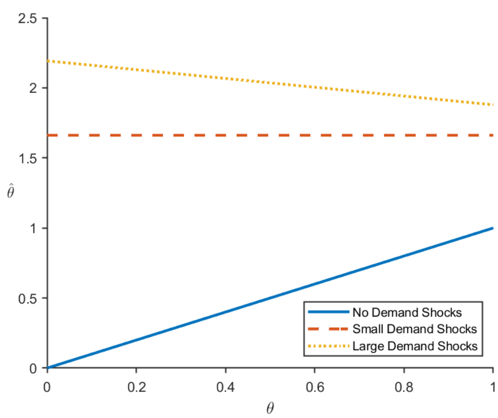
Impulse response functions for a negative unit tax shock. Each panel plots a different response variable, where "Consol Value" denotes the value of a console bond v_t^q. The solid red lines denote the case with rational consumers ($\theta = 1$). Each dashed line reports the outcome for a different behavioral attenuation parameter θ.



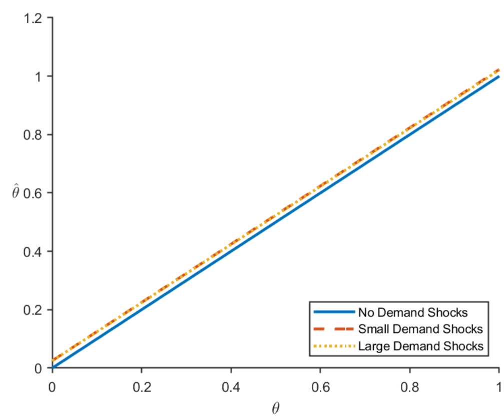
(a) OLS



(b) OLS: Tax shocks Only



(c) IV (Lagged Variables)



(d) IV (TFP, IST, and Risk Shocks)

Figure 3: Monte Carlo Estimates of the Consumption Effects of Tax Shocks

Each panel plots the result of a different estimation method for the consumption function in the general equilibrium model. In each case the sample size is 10 million periods, so that reported estimates are close to large sample limits. The x-axis corresponds to the true θ value, which varies across Monte Carlo simulations. The solid blue lines ("No Demand Shocks") set $\sigma_\zeta = 0$, the dashed red lines ("Small Demand Shocks") set $\sigma_\zeta = 1$, and the dotted yellow lines ("Large Demand Shocks") set $\sigma_\zeta = 2$. Each method directly estimates $-(1-\beta)(1-\theta)$, so each estimate is transformed into an implied estimate $\hat{\theta}$, plotted on the y-axis.

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A Proofs

Proof of Proposition 1. Shift the budget constraint (3) forward one period and take expectations:

$$n_t + \tilde{\mathbb{E}}_t[y_{t+1}] = \tilde{\mathbb{E}}_t[c_{t+1} + \tau_{t+1} + \overline{B}q_{t+1} + \beta n_{t+1}]$$

$\tilde{\mathbf{E}}_{t,t+j}[x_{t+j+1}]$ denotes the iterated expectation (see Appendix B):

$$\tilde{\mathbf{E}}_{t,t+j}[x_{t+j+1}] = \tilde{\mathbb{E}}_t\tilde{\mathbb{E}}_{t+1}\tilde{\mathbb{E}}_{t+2}...\tilde{\mathbb{E}}_{t+j}\left[x_{t+j+1}\right]$$

iterate this equation forward and multiply by β:

$$\beta n_t + \sum_{j=1}^{\infty}\beta^j\tilde{\mathbf{E}}_{t,t+j-1}[y_{t+j}] = \sum_{j=1}^{\infty}\beta^j\tilde{\mathbf{E}}_{t,t+j-1}\left[c_{t+j} + \tau_{t+j} + \overline{B}q_{t+j}\right]$$

then replace βn_t in the time-t constraint (3) to get:

$$n_{t-1} + y_t + \sum_{j=1}^{\infty}\beta^j\tilde{\mathbf{E}}_{t,t+j-1}[y_{t+j}] = c_t + \tau_t + \overline{B}q_t + \sum_{j=1}^{\infty}\beta^j\tilde{\mathbf{E}}_{t,t+j-1}\left[c_{t+j} + \tau_{t+j} + \overline{B}q_{t+j}\right]$$

Substituting with $\tilde{v}_t^y$ and $\tilde{\mathbb{E}}_t[\tilde{v}_{t+1}^\tau]$ simplifies the budget constraint to

$$n_{t-1} + \tilde{v}_t^y = c_t + \tau_t + \beta\tilde{\mathbb{E}}_t[\tilde{v}_{t+1}^\tau] + \overline{B}q_t + \sum_{j=1}^{\infty}\beta^j\tilde{\mathbf{E}}_{t,t+j-1}\left[c_{t+j} + \overline{B}q_{t+j}\right]$$

Then, use the Euler equation (4) to write expectations of future consumption in terms of current consumption and bond prices:

$$\tilde{\mathbb{E}}_t[c_{t+1}] = c_t - \frac{\overline{C}}{\beta\gamma}q_t + \frac{\overline{C}}{\beta\gamma}z_t^d$$

$$\implies [j > 1]: \qquad \tilde{\mathbf{E}}_{t,t+j-1}\left[c_{t+j}\right] = c_t + \frac{\overline{C}}{\beta\gamma}(z_t^d - q_t) + \frac{\overline{C}}{\beta\gamma}\sum_{i=1}^{j-1}\tilde{\mathbf{E}}_{t,t+i-1}(z_{t+i}^d - q_{t+i})$$

thus the discounted sum of future consumption can be written as

$$\sum_{j=1}^{\infty}\beta^j\tilde{\mathbf{E}}_{t,t+j-1}\left[c_{t+j}\right] = \frac{\beta}{1-\beta}c_t + \frac{\overline{C}}{\gamma}\frac{1}{1-\beta}(z_t^d - q_t) + \frac{\overline{C}}{\gamma}\frac{1}{1-\beta}\sum_{j=1}^{\infty}\beta^j\tilde{\mathbf{E}}_{t,t+j-1}\left[(z_{t+j}^d - q_{t+j})\right]$$

so the budget constraint becomes

$$
\begin{aligned}
n_{t-1} + \tilde{v}_t^y = \frac{1}{1-\beta} c_t + \tau_t + \beta \tilde{\mathbb{E}}_t[\tilde{v}_{t+1}^\tau] \\
+ \left(\overline{B} - \frac{\overline{C}}{\gamma}\frac{1}{1-\beta}\right) q_t + \sum_{j=1}^{\infty} \beta^j \tilde{\mathbf{E}}_{t,t+j-1}\left[\left(\overline{B} - \frac{\overline{C}}{\gamma}\frac{1}{1-\beta}\right) q_{t+j}\right] \\
+ \frac{\overline{C}}{\gamma}\frac{1}{1-\beta} z_t^d + \sum_{j=1}^{\infty} \beta^j \tilde{\mathbf{E}}_{t,t+j-1}\left[\frac{\overline{C}}{\gamma}\frac{1}{1-\beta} z_{t+j}^d\right]
\end{aligned}
$$

and substitute in with $\tilde{v}_t^q$ and ζ_t :

$$
n_{t-1} + \tilde{v}_t^y = \frac{1}{1-\beta} c_t + \tau_t + \beta \tilde{\mathbb{E}}_t[\tilde{v}_{t+1}^\tau] + \left(\overline{B} - \frac{\overline{C}}{\gamma}\frac{1}{1-\beta}\right) \tilde{v}_t^q - \frac{1}{1-\beta}\zeta_t
$$

Rearrange to isolate consumption:

$$
c_t = (1-\beta)\left(n_{t-1} + \tilde{v}_t^y - \tau_t - \beta \tilde{\mathbb{E}}_t[\tilde{v}_{t+1}^\tau]\right) + \left(\frac{\overline{C}}{\gamma} - (1-\beta)\overline{B}\right) \tilde{v}_t^q + \zeta_t
$$

■

Proof of Proposition 3. Proposition 1 implies that with rational expectations and discount factor $\beta\omega$, the consumption function is

$$
c_t = (1-\beta\omega)\left(n_{t-1} + \tilde{v}_t^y - \tau_t - \beta\omega \mathbb{E}_t[\tilde{v}_{t+1}^\tau]\right) + \left(\frac{\overline{C}}{\gamma} - (1-\beta\omega)\overline{B}\right) \tilde{v}_t^q + \zeta_t
$$

The government budget constraint implies

$$
\begin{aligned}
b_{t-1} &= \tau_t - g_t + \overline{B} q_t + \sum_{j=1}^{\infty} \beta^j \mathbb{E}_t[\tau_{t+j} - g_{t+j}] \\
&= \tau_t - g_t + \overline{B} q_t + \beta \mathbb{E}_t\left[v_{t+1}^\tau - v_{t+1}^g + \overline{B} v_{t+1}^q\right] \\
&= \tau_t + \beta \mathbb{E}_t\left[v_{t+1}^\tau\right] - v_t^g + \overline{B} v_t^q
\end{aligned}
$$

Rearrange to write neatly as

$$
\beta \mathbb{E}_t[v_{t+1}^\tau] = b_{t-1} - \tau_t + v_t^g - \overline{B} v_t^q \tag{51}
$$

By definition $\tau_t = v_t^\tau - \beta \mathbb{E}_t[v_{t+1}] = \tilde{v}_t^\tau - \beta\omega \mathbb{E}_t[\tilde{v}_{t+1}^\tau]$. This implies that v_t^τ and $\tilde{v}_t^\tau$ are related by

$$
\tilde{v}_t^\tau = \sum_{j=0}^{\infty} (\beta\omega)^j \mathbb{E}_t\left[v_{t+j}^\tau - \beta v_{t+1+j}^\tau\right]
$$

which, per equation (69), simplifies to

$$= \frac{1-\beta\rho_\tau}{1-\beta\omega\rho_\tau} v_t^\tau$$

Combined with equation (72), this implies that $\beta\omega\mathbb{E}_t[\tilde{v}_{t+1}^\tau]$ can be written

$$\beta\omega\mathbb{E}_t[\tilde{v}_{t+1}^\tau] = \omega\frac{1-\beta\rho_\tau}{1-\beta\omega\rho_\tau}\left(b_{t-1}-\tau_t+v_t^g-\overline{B}v_t^q\right)$$

then use this result to replace $\beta\omega\mathbb{E}_t[\tilde{v}_{t+1}^\tau]$ in the consumption function. ■

Proof of Corollary 1. With constant government spending and zero steady-state debt, the government budget constraint (40) implies

$$\beta b_t = \beta\mathbb{E}_t[v_{t+1}^\tau]$$

Plugging into equation (10):

$$c_t = (1-\beta)\left(n_{t-1}+\tilde{v}_t^y-\tau_t-\theta\beta b_t\right)+\frac{\overline{C}}{\gamma}\tilde{v}_t^q+\zeta_t$$

the constraint $b_{t-1}=\tau_t+\beta b_t$ implies

$$c_t = (1-\beta)\left(n_{t-1}-\theta b_{t-1}+\tilde{v}_t^y-(1-\theta)\tau_t\right)+\frac{\overline{C}}{\gamma}\tilde{v}_t^q+\zeta_t$$

■

B Naive and Sophisticated Expectations

The behavioral expectations literature treats recursive expectations in multiple ways. This section elaborates, and clarifies the distinction between "naive" and "sophisticated" expectations that we adopt in the model.

In general, we define recursive behavioral expectations as

$$\tilde{\mathbf{E}}_{t,t+j}[x_{t+j+1}] \equiv \tilde{\mathbb{E}}_t\tilde{\mathbb{E}}_{t+1}\tilde{\mathbb{E}}_{t+2}...\tilde{\mathbb{E}}_{t+j}\left[x_{t+j+1}\right] \tag{52}$$

for some random variable x_{t+j+1}. How the behavioral expectation operators $\tilde{\mathbb{E}}_t$, $\tilde{\mathbb{E}}_{t+1}$, etc. interact is not defined without further assumptions, unlike the rational case where the law of iterated expectations always holds. Two common assumptions are naive and sophisticated expectations.

When using cognitive discounting with parameter $\lambda < 1$, the representations are clear:

$$\tilde{\mathbf{E}}_{t,t+j}[x_{t+j+1}] = \begin{cases} \lambda\mathbb{E}_t[x_{t+j+1}] & \text{(naive expectations)} \\ \lambda^{j+1}\mathbb{E}_t[x_{t+j+1}] & \text{(sophisticated expectations)} \end{cases} \tag{53}$$

In the Section 5 model, we assumed that households had naive expectations so that $\lambda = \theta$, the non-Ricardian parameter in the consumption function (14). The following result shows that with sophisticated expectations, there is also a mapping from λ to θ:

Lemma 1 *If households are sophisticated cognitive discounters with parameter λ, then the attenuation factor defined in equation* (13) *for the present value of taxes is*

$$\theta = \lambda \frac{1 - \beta\rho_\tau}{1 - \beta\lambda\rho_\tau}$$

Proof. Per equation (48), the process for taxes is

$$\tau_t = \rho_\tau \tau_{t-1} - \beta\epsilon_t^\tau + \epsilon_{t-1}^\tau$$

The expected present value of future taxes is

$$\tilde{v}_t^\tau = \tau_t + \sum_{j=1}^{\infty} \beta^j \tilde{\mathbf{E}}_{t,t+j-1}[\tau_{t+j}]$$

With sophisticated cognitive discounting

$$\tilde{\mathbf{E}}_{t,t+j-1}[\tau_{t+j}] = \lambda^j \mathbb{E}_t[\tau_{t+j}]$$

and the rational expectation is

$$\mathbb{E}_t[\tau_{t+j}] = \rho_\tau^j \tau_t + \rho_\tau^{j-1}\epsilon_{t+j-1}^\tau$$

Therefore

$$\begin{aligned}\tilde{v}_t^\tau &= \tau_t + \sum_{j=1}^{\infty} \beta^j \lambda^j (\rho_\tau^j \tau_t + \rho_\tau^{j-1}\epsilon_{t+j-1}^\tau) \\ &= \tau_t + \frac{\beta\lambda\rho_\tau}{1 - \beta\lambda\rho_\tau}\tau_t + \frac{\beta\lambda}{1 - \beta\lambda\rho_\tau}\epsilon_t^\tau\end{aligned}$$

Therefore the perceived present value of future taxes is $\frac{\beta\lambda\rho_\tau}{1-\beta\lambda\rho_\tau}\tau_t + \frac{\beta\lambda}{1-\beta\lambda\rho_\tau}\epsilon_t^\tau$ and the rational expectation is the same albeit with $\lambda = 1$. Thus the ratio is

$$\frac{\tilde{\mathbb{E}}_t[\tilde{v}_{t+1}^\tau]}{\mathbb{E}[v_{t+1}^\tau]} = \lambda \frac{1 - \beta\rho_\tau}{1 - \beta\lambda\rho_\tau}$$

■

Lemma 1 implies that, given values for β and ρ_τ, and an estimate θ, the implied parameter λ is

$$\lambda = \frac{\theta}{1 - \beta\rho_\tau(1 - \theta)}$$

B.1 Actual and Perceived Law of Motion

We use an actual law of motion (ALM) and perceived law of motion (PLM) approach to implement behavioral expectations in the general equilibrium model while maintaining internal consistency. The model admits a state space solution of the form

$$x_t = Px_{t-1} + Qz_t$$

where x_t is a vector of endogenous state variables and z_t is a vector of exogenous state variables. z_t follows

$$[ALM]: \qquad z_{t+1} = Nz_t + \vec{\epsilon}_{t+1}$$

where $\vec{\epsilon}_{t+1}$ is a vector of shocks. A rational expectations solution satisfies the linear equilibrium conditions given this ALM, as in Uhlig (2001). However, under behavioral expectations, we instead impose that expectations in the equilibrium conditions are formed based on

$$[PLM]: \qquad z_{t+1} = \tilde{N}z_t + \vec{\epsilon}_{t+1}$$

with $N \neq \tilde{N}$. The solution under this PLM is the behavioral equilibrium. Adams (2024) gives further details.

B.2 Representing Naive and Sophisticated Expectations with a PLM

In the general equilibrium model of Section 5, households are naive cognitive discounters regarding taxes only (equation (49)). To implement this representation, we write the exogenous state vector to include both τ_t and v_t^τ. Then the relevant row of the transition matrix N encodes

$$\tau_t = (1 - \beta\rho_v)v_t^\tau - \beta\epsilon_t^\tau$$

Therefore, the appropriate PLM is to write $\tilde{N}$ encoding N everywhere, except with coefficient θ on the entry mapping v_t^τ to τ_t (recall that v_t^τ is predetermined in this model, so it appears in the vector z_{t-1}).

If instead we were to model sophisticated cognitive discounting over taxes, $\tilde{N}$ would rescale by λ the ρ_τ entry mapping v_t^τ to v_{t+1}^τ. If we were to model sophisticated cognitive discounting over all time series (the usual case) we would rescale by λ the entire matrix N.

C Consol Values and Yields

The market value of a consol bond (one period before any coupon payment) is given by equation (8). The analogous rational value of a consol bond is thus

$$v_t^q = q_t + \beta\mathbb{E}_t[v_{t+1}^q]$$

Why does this describe the value of a consol bond? A consol bond pays a constant coupon in perpetuity. Equivalently, the consol pays a one-period bond every period in advance of the associated coupon payment.

We can also relate the value of the consol to the yields at different horizons. The price Q_t of a one-period bond is related to its yield $R_t^{(1)}$ by

$$Q_t = \frac{1}{1 + R_t^{(1)}}$$

which is linearized as

$$q_t = -\overline{Q}^2 r_t^{(1)}$$

Thus the consol value maps to yields by:

$$v_t^q = -\overline{Q}^2 r_t^{(1)} + \beta \mathbb{E}_t[v_{t+1}^q]$$

$$\propto \sum_{h=0}^{\infty} \beta^h r_{t+h}^{(1)}$$

D Additional Model Extensions

D.1 Risky Debt

In this section, we relax the assumption that governments issue risk-free real debt. For example, this is important if governments issue risk-free nominal debt but the economy features inflation risk. We show that this extension yields the same behavioral consumption function as in Proposition 2.

Now we write risky debt $B_t^\dagger$ to denote the notional end-of-period real debt which grows by a risky factor R_{t+1}^B in the next period. The household's budget constraint (1) becomes

$$R_t^B B_{t-1}^\dagger + R_t^K K_{t-1} + Y_t^N = C_t + T_t + B_t + K_t \tag{54}$$

while the government's budget constraint (11) becomes

$$R_t^B B_{t-1}^\dagger + G_t = T_t + B_t^\dagger \tag{55}$$

The household's Euler equation (2) now prices the risky debt:

$$1 = \beta \tilde{\mathbb{E}}_t \left[\frac{R_{t+1}^B u'(C_{t+1})}{u'(C_t)} \right] + Z_t^d \tag{56}$$

When linearized, these equations become

$$n_{t-1} + r_t^B \bar{B}^\dagger + y_t = c_t + \tau_t + \beta n_t \tag{57}$$

$$\overline{R^B} b_{t-1}^\dagger + r_t^B \overline{B}^\dagger = \tau_t - g_t + b_t^\dagger \tag{58}$$

$$0 = \beta \tilde{\mathbb{E}}_t[r_{t+1}^B + \gamma \frac{1}{\bar{C}}(c_t - c_{t+1})] + z_t^d \tag{59}$$

where financial net worth is now defined $n_t \equiv \overline{R^B} b_t + \overline{R^k} k_t$ with the assumption that $\overline{R^B} = \overline{R^K} = \beta^{-1}$.

Finally, define the risky debt console value as

$$\tilde{v}_t^q = \beta \tilde{\mathbb{E}}_t[r_{t+1}^B] + \beta \tilde{\mathbb{E}}_t[\tilde{v}_{t+1}^q] \tag{60}$$

and similarly for the rational expectations analog v_t^q.

The following Proposition shows that the behavioral consumption function is largely unchanged when government debt is risky. The only difference is that $\overline{R^B} b^{\dagger}_{t-1}$ enters in place of b_{t-1}, as expected: they both represent the time t value of outstanding debt.

Proposition 4 *If government debt is risky with budget constraint* (58) *and expectations satisfy equation* (13)*, then the consumption function is given by equation* (14) *albeit with* $\overline{R^B} b^{\dagger}_{t-1}$ *in place of* b_{t-1}.

Proof. The household equations (57) and (59) are equivalent to equations (3) and (4) by mapping $\beta \tilde{\mathbb{E}}_t[r^B_{t+1}] \to -q_t$ and $\beta \overline{B}^{\dagger} \to \overline{B}$. Therefore the consumption function in Proposition 1 still holds.

Next, iterate the government budget constraint, take rational expectations, and use $\overline{R^B} = \beta^{-1}$:

$$\overline{R^B} b^{\dagger}_{t-1} = \tau_t - g_t - \overline{B}^{\dagger} r^B_t + \mathbb{E}_t \left[\sum_{j=1}^{\infty} \beta^j (\tau_{t+j} - g_{t+j} - \overline{B}^{\dagger} r^B_{t+j}) \right]$$

Use the risky debt definition for the console value v^q_t:

$$= \tau_t - g_t - \overline{B}^{\dagger} r^B_t + \beta \mathbb{E}_t \left[v^\tau_{t+1} - v^g_{t+1} + \overline{B} v^q_{t+1} \right]$$

$$= \tau_t + \beta \mathbb{E}_t \left[v^\tau_{t+1} \right] - v^g_t + \overline{B} v^q_t$$

Combine with equation (13) to find

$$\beta \tilde{\mathbb{E}}_t[\tilde{v}^\tau_{t+1}] = \theta \left(\overline{R^B} b^{\dagger}_{t-1} - \tau_t + v^g_t - \overline{B} v^q_t \right)$$

then use this result to replace $\beta \tilde{\mathbb{E}}_t[\tilde{v}^\tau_{t+1}]$ in the consumption function (10). ■

D.2 Non-Separable Utility

In the baseline model we assumed that the marginal utility of consumption only depended on consumption. Sometimes, the utility function is thought to be non-separable in consumption C_t and labor L_t. In that case, the behavioral consumption function introduces an additional term that depends on the growth rate of labor.

Proposition 5 *If the utility function* $u(C_t, L_t)$ *is non-separable in labor* L_t*, then the behavioral consumption function becomes*

$$c_t = (1-\beta) \left(n_{t-1} - \theta b_{t-1} + \tilde{v}^y_t - (1-\theta)\tau_t - \theta v^g_t + \theta \overline{B} v^q_t \right) + \left(\frac{\overline{C}}{\gamma} - (1-\beta)\overline{B} \right) \tilde{v}^q_t + \alpha^\ell \beta \tilde{\mathbb{E}}_t[\tilde{v}^{d\ell}_{t+1}] + \zeta_t$$

where $\tilde{v}^{d\ell}_t$ *denotes the perceived present discounted value of future labor growth:*

$$\tilde{v}^{d\ell}_t = \ell_t - \ell_{t-1} + \beta \tilde{v}^{d\ell}_{t+1}$$

and $\alpha^\ell \equiv -\frac{\bar{C}}{\gamma} \left(\frac{u_{CL}(\overline{C}, \overline{L})}{u_C(\overline{C}, \overline{L})} \right)$.

Proof. Instead of (2), the Euler equation with non-separable utility is given by

$$Q_t = \beta\tilde{\mathbb{E}}_t\left[\frac{u'(C_{t+1}, L_{t+1})}{u'(C_t, L_t)}\right] + Z_t^d \tag{61}$$

which linearizes as

$$q_t = \beta\tilde{\mathbb{E}}_t[\gamma\frac{1}{\overline{C}}(c_t - c_{t+1} + \alpha(l_t - l_{t+1}))] + z_t^d \tag{62}$$

Then, the derivation of Proposition 1 still applies, except where ever z_t^d appears, there is now an additional $\beta\tilde{\mathbb{E}}_t[\gamma\frac{1}{\overline{C}}\alpha^\ell(\ell_t - \ell_{t+1}))]$ term. Therefore the consumption function (10) still holds, except wherever $\zeta_t = -\frac{\overline{C}}{\gamma}z_t^d + \beta\tilde{\mathbb{E}}_t[\zeta_{t+1}]$ appears, there is now an additional $\alpha\beta\tilde{\mathbb{E}}_t[\tilde{v}_{t+1}^{d\ell}]$ term. Thus the consumption function is given by

$$c_t = (1-\beta)\left(n_{t-1} + \tilde{v}_t^y - \tau_t - \beta\tilde{\mathbb{E}}_t[\tilde{v}_{t+1}^\tau]\right) + \left(\frac{\overline{C}}{\gamma} - (1-\beta)\overline{B}\right)\tilde{v}_t^q + \alpha^\ell\beta\tilde{\mathbb{E}}_t[\tilde{v}_{t+1}^{d\ell}] + \zeta_t$$

Then following the same steps as the proof of Proposition 2 gives the desired result. ■

D.3 Distortionary Taxation

In the baseline, taxes appear in the budget constraints, and may distort the economy, but do not distort the intertemporal decision. In this section, we extend the model to allow for such effects.

Specifically, we allow for taxes on interest income, which enters the Euler equation for government bonds (2). Define $1 + i_t^b = Q_t^{-1}$ so that i_t^b denotes the pretax real interest rate on the bond. Interest income is taxed at rate τ_t^i, so the after-tax gross return is $1+(1-\tau_t^i)i_t^b$.

With non-zero steady state taxes, there will be a discounting wedge ω relative to the government.[18] Thus the Euler equation becomes

$$\left(1 + (1-\tau^i)i_t^b\right)^{-1} = \beta\tilde{\mathbb{E}}_t\left[\frac{u'(C_{t+1})}{u'(C_t)}\right] + Z_t^d \tag{63}$$

or in terms of the bond price Q_t:

$$\frac{Q_t}{\tau_t^i Q_t + 1 - \tau_t^i} = \beta\omega\tilde{\mathbb{E}}_t\left[\frac{u'(C_{t+1})}{u'(C_t)}\right] + Z_t^d$$

Proposition 6 *If there are taxes on interest such that the Euler equation is given by* (63)*, then the behavioral consumption function is*

$$c_t = (1-\beta\omega)\left(n_{t-1} - \theta b_{t-1} + \tilde{v}_t^y - (1-\theta)\tau_t - \theta v_t^g + \theta\overline{B}v_t^q\right) + \left(\frac{\overline{C}}{\gamma} - (1-\beta)\overline{B}\right)\alpha^q\tilde{v}_t^q - \alpha^i\tilde{v}_t^i + \zeta_t$$

[18] Strictly speaking, the household's discount factor $\beta\omega$ is the primitive parameter, and the government's steady state discount factor $\beta = \overline{Q}$ is determined by steady state taxes, but we stick to the wedge notation in order to be consistent with the rest of the paper.

where $\tilde{v}^i_t$ denotes the household's present discounted value of future taxes on interest:

$$\tilde{v}^i_t = \tau^i_t + \beta\omega\mathbb{E}_t[\tilde{v}^i_{t+1}]$$

and $\alpha^i \equiv -\frac{\bar{C}}{\gamma}\beta\frac{1-\beta}{1-\overline{\tau}^i}$*,* $\alpha^q \equiv \omega\left(1-\beta\omega\overline{\tau}^i\right)$*, and the steady state household discounting wedge is given in terms of the government's discount factor* β *by*

$$\omega = \frac{1}{1-\overline{\tau}^i(1-\beta)}$$

Proof. To linearize around the deterministic steady state, use $\frac{\overline{Q}}{\overline{\tau}^i\overline{Q}+1-\overline{\tau}^i} = \beta\omega$. The government's discount factor is $\beta = \overline{Q}$, implying that the household wedge is $\omega = \frac{1}{1-\overline{\tau}^i(1-\beta)}$. The left-hand side linearizes as

$$\frac{1}{\overline{\tau}^i\overline{Q}+1-\overline{\tau}^i}\left(q_t - \frac{\overline{Q}}{\overline{\tau}^i\overline{Q}+1-\overline{\tau}^i}\overline{\tau}^i q_t - \frac{\overline{Q}}{\overline{\tau}^i\overline{Q}+1-\overline{\tau}^i}(\overline{Q}-1)\tau^i_t\right)$$
$$= \omega\left(1-\beta\omega\overline{\tau}^i\right)q_t + \beta\omega^2(1-\beta)\tau^i_t$$

so the linearized Euler equation is

$$\omega\left(1-\beta\omega\overline{\tau}^i\right)q_t = \beta\omega\tilde{\mathbb{E}}_t[\gamma\frac{1}{\overline{C}}(c_t - c_{t+1})] - \beta\omega^2(1-\beta)\tau^i_t + z^d_t \tag{64}$$

Therefore, in the derivation of the consumption function (Proposition 3) wherever q_t appears it now has the coefficient $\omega\left(1-\beta\omega\overline{\tau}^i\right)$. And wherever z^d_t appears, it is joined by $-\beta\omega^2(1-\beta)\tau^i_t$.

Following the same logic as in the proof of Proposition 5, the behavioral consumption function becomes

$$c_t = (1-\beta\omega)\left(n_{t-1} - \theta b_{t-1} + \tilde{v}^y_t - (1-\theta)\tau_t - \theta v^g_t + \theta\overline{B}v^q_t\right) + \left(\frac{\overline{C}}{\gamma} - (1-\beta)\overline{B}\right)\alpha^q\tilde{v}^q_t - \alpha^i\tilde{v}^i_t + \zeta_t$$

■

When taxes on interest are $\overline{\tau}^i = \tau^i_t = 0$ then this reduces to the standard consumption function.

D.4 Liquidity Constraints

Liquidity constraints can also break Ricardian equivalence. This is because the consumption function (Proposition 1) is derived by iterating over future Euler equations, but when an agent is constrained, the Euler equation does not hold. Angeletos et al. (2024) argue that the discounting wedge from Section 2.3 is a good approximation of occasionally-binding liquidity constraints. But what if some agents are perpetually constrained?

A classic, tractable method of capturing this mechanism for non-Ricardianism is to introduce hand-to-mouth consumers (Campbell and Mankiw, 1989).[19] In this section, we

[19] This method is still used in modern two-agent New Keynesian (TANK) models (Galí et al., 2007), which approximate non-Ricardian behavior in richer heterogeneous agent models (Auclert et al., 2024).

describe a simple two-agent model, and show that the consumption function test of Ricardianism applies to this setting as well.

There is a measure λ of unconstrained consumers, and a measure $1-\lambda$ of constrained consumers. For simplicity, we assume government spending is constant with zero steady-state debt, both types of consumers receive the same tax and income processes, and have rational expectations.

The unconstrained households' income y_t^U and the constrained households' income y_t^C may follow different processes. They add up to aggregate income by

$$y_t = \lambda y_t^U + (1-\lambda) y_t^C \tag{65}$$

We write the present discounted values of these income streams as $v_t^{y,U}$ and $v_t^{y,C}$ respectively.

The unconstrained choose consumption c_t^U satisfying the Proposition 1 consumption function. The constrained consume

$$c_t^C = y_t^C - \tau_t \tag{66}$$

and aggregate consumption is given by

$$c_t = \lambda c_t^U + (1-\lambda) c_t^C \tag{67}$$

Similarly, the unconstrained hold assets n_t^U while the constrained hold zero assets. Thus household-level assets are related to total assets by

$$n_t^U = \frac{n_t}{\lambda}$$

and similarly for bonds.

With this structure, Proposition 7 gives the aggregate consumption function when income is AR(1).

Proposition 7 *If households have rational expectations, then the aggregate consumption function in the two agent economy can be expressed as*

$$c_t = (1-\beta)\left(n_{t-1} - \lambda b_{t-1} + v_t^y - (1-\theta)\tau_t - \lambda v_t^g\right) + \lambda \frac{\overline{C}}{\gamma} \tilde{v}_t^q + \varsigma_t^C + \lambda \zeta_t \tag{68}$$

where the non-Ricardian parameter is now given by

$$\theta = 1 - \frac{1-\lambda}{1-\beta}$$

and $\varsigma_t^C \equiv (1-\lambda)\left(y_t^C - (1-\beta) v_t^{y,C}\right)$ *is a term that depends on the constrained income process.*

Proof: Appendix A

Unlike in the case of a discounting wedge, Proposition 7 shows that the consumption function in the two agent economy is similar but not quite equivalent to the behavioral consumption function from Proposition 2. Different restrictions relate the coefficients of the right-hand-side variables. And there is now a ζ_t^C term which depends on the income process of the constrained households. We can estimate including this term directly, but it may also be convenient to focus on one of several special cases where the ζ_t^C term is irrelevant (Corollary 2).

The crucial similarity is that taxes feature the usual Ricardian coefficient $1-\theta$. Except now, this coefficient captures the degree to which households are constrained, rather than the deviation from rational expectations. When there are no constrained households $\lambda = 1$ so $\theta = 1$, and households are Ricardian. This shows one reason why we focus on the impact of current taxes to measure Ricardianism. In the behavioral consumption function, θ also appeared as a coefficient on existing debt b_{t-1}. But debt has a different coefficient in the two agent economy; $\lambda \neq 1-\theta$, so if we want to be agnostic about the causes of non-Ricardianism, we cannot rely on restrictions to discipline the coefficients on taxes and debt.

Corollary 2 *If constrained households receive constant income $y_t^C = \bar{y}^C$ then the aggregate consumption function in the two agent economy reduces to*

$$c_t = (1-\beta)\left(n_{t-1} - \lambda b_{t-1} + v_t^y - (1-\theta)\tau_t - \lambda v_t^g\right) + \lambda \frac{\overline{C}}{\gamma} \tilde{v}_t^q + \lambda \zeta_t$$

Proof. When constrained income is constant, then its present discounted value is given by

$$v_t^{y,C} = \bar{y}^C + \beta \bar{y}^C + \beta^2 \bar{y}^C + ... = \frac{\bar{y}^C}{1-\beta}$$

thus ς_t^C is given by

$$\varsigma_t^C = (1-\lambda)\left(y_t^C - (1-\beta) v_t^{y,C}\right) = (1-\lambda)\left(\bar{y}^C - (1-\beta)\frac{\bar{y}^C}{1-\beta}\right) = 0$$

and the result follows from Proposition 7. ■

D.5 Discount Wedges without Rational Expectations

This section derives the consumption function when households have both a discount wedge relative to the government, and non-rational expectations. If the present value of taxes are AR(1) and households are cognitive discounters, Proposition 8 derives explicit expressions for the MPC and taxes coefficient.

Proposition 8 *If the government discounts by β and the household discounts by $\beta\omega$, the present value of taxes is AR(1) given by*

$$v_t^\tau = \rho_\tau v_{t-1}^\tau + \varepsilon_t^\tau \tag{69}$$

and households are sophisticated or naive cognitive discounters with behavioral attenuation

λ, then the consumption function can be expressed as

$$c_t = (1 - \beta\omega)\left(n_{t-1} - \theta_{cd} b_{t-1} + \tilde{v}_t^y - (1 - \theta_{cd})\,\tau_t - \theta_{cd} v_t^g + \theta_{cd}\overline{B} v_t^q\right) + \left(\frac{\overline{C}}{\gamma} - (1 - \beta\omega)\overline{B}\right)\tilde{v}_t^q + \zeta_t \quad (70)$$

where

$$\theta_{cd} = \begin{cases} \omega\lambda\frac{1-\beta\rho_\tau}{1-\beta\omega\lambda\rho_\tau} & \textit{sophisticated cognitive discounting} \\ \omega\lambda\frac{1-\beta\rho_\tau}{1-\beta\omega\rho_\tau} & \textit{naive cognitive discounting} \end{cases} \quad (71)$$

and where for quantity x, v_t^x denotes the present value using the government's discount factor β and rational expectations $\mathbb{E}_t$, while $\tilde{v}_t^x$ denotes using the household's discount factor $\beta\omega$ and expectations $\tilde{\mathbb{E}}_t$:

$$v_t^x = x_t + \beta\mathbb{E}_t[v_{t+1}^x] \qquad \tilde{v}_t^x = x_t + \beta\omega\tilde{\mathbb{E}}_t[\tilde{v}_{t+1}^x]$$

Proof of Proposition 8. Proposition 1 implies that with discount factor $\beta\omega$, the consumption function is

$$c_t = (1 - \beta\omega)\left(n_{t-1} + \tilde{v}_t^y - \tau_t - \beta\omega\mathbb{E}_t[\tilde{v}_{t+1}^\tau]\right) + \left(\frac{\overline{C}}{\gamma} - (1 - \beta\omega)\overline{B}\right)\tilde{v}_t^q + \zeta_t$$

The government budget constraint implies

$$\begin{aligned} b_{t-1} &= \tau_t - g_t + \overline{B}q_t + \sum_{j=1}^{\infty}\beta^j\mathbb{E}_t[\tau_{t+j} - g_{t+j}] \\ &= \tau_t - g_t + \overline{B}q_t + \beta\mathbb{E}_t\left[v_{t+1}^\tau - v_{t+1}^g + \overline{B}v_{t+1}^q\right] \\ &= \tau_t + \beta\mathbb{E}_t\left[v_{t+1}^\tau\right] - v_t^g + \overline{B}v_t^q \end{aligned}$$

Rearrange to write neatly as

$$\beta\mathbb{E}_t[v_{t+1}^\tau] = b_{t-1} - \tau_t + v_t^g - \overline{B}v_t^q \quad (72)$$

By definition $\tau_t = v_t^\tau - \beta\mathbb{E}_t[v_{t+1}^\tau] = \tilde{v}_t^\tau - \beta\omega\tilde{\mathbb{E}}_t[\tilde{v}_{t+1}^\tau]$. And the AR(1) assumption implies $\tau_t = (1 - \beta\rho_\tau)v_t^\tau$.

If households are sophisticated cognitive discounters with attenuation λ, then $\tilde{\mathbb{E}}_t[\tilde{v}_{t+1}^\tau] = \lambda\mathbb{E}_t[\tilde{v}_{t+1}^\tau]$. Therefore

$$\text{[sophisticated]} \qquad \tilde{v}_t^\tau = (1 - \beta\rho_\tau)v_t^\tau + \beta\omega\lambda\mathbb{E}_t[\tilde{v}_{t+1}^\tau] = \frac{1 - \beta\rho_\tau}{1 - \beta\omega\lambda\rho_\tau}v_t^\tau$$

Combined with equation (72), this implies that $\beta\omega\tilde{\mathbb{E}}_t[\tilde{v}_{t+1}^\tau]$ can be written

$$\text{[sophisticated]} \qquad \beta\omega\tilde{\mathbb{E}}_t[\tilde{v}_{t+1}^\tau] = \omega\lambda\frac{1 - \beta\rho_\tau}{1 - \beta\omega\lambda\rho_\tau}\left(b_{t-1} - \tau_t + v_t^g - \overline{B}v_t^q\right)$$

then use this result to replace $\beta\omega\tilde{\mathbb{E}}_t[\tilde{v}^\tau_{t+1}]$ in the consumption function.

If households are naive cognitive discounters, then $\tilde{\mathbb{E}}_t[\tilde{v}^\tau_{t+1}] = \lambda \mathbb{E}_t[v^\tau_{t+1}]$. Therefore,

$$[\text{naive}] \qquad \tilde{\mathbb{E}}_t[\tilde{v}^\tau_{t+1}] = \lambda \sum_{j=0}^{\infty} (\beta\omega)^j \mathbb{E}_t[\tau_{t+1+j}]$$

$$= \lambda \sum_{j=0}^{\infty} (\beta\omega)^j \mathbb{E}_t[(1-\beta\rho) v^\tau_{t+1+j}] = \lambda \frac{1-\beta\rho_\tau}{1-\beta\omega\rho_\tau} \mathbb{E}_t[v^\tau_{t+1}]$$

Combined with equation (72), this implies that $\beta\omega\tilde{\mathbb{E}}_t[\tilde{v}^\tau_{t+1}]$ can be written

$$[\text{naive}] \qquad \beta\omega\tilde{\mathbb{E}}_t[\tilde{v}^\tau_{t+1}] = \omega\lambda \frac{1-\beta\rho_\tau}{1-\beta\omega\rho_\tau} \left(b_{t-1} - \tau_t + v^g_t - \overline{B} v^q_t \right)$$

then use this result to replace $\beta\omega\tilde{\mathbb{E}}_t[\tilde{v}^\tau_{t+1}]$ in the consumption function. ■

E Data Details for Model Extensions

In our robustness checks, we use several additional time series, whose construction we describe here.

When relaxing the baseline assumption that perceived present discounted values are proportional to rational ones (e.g. $\tilde{v}^y_t \propto v^y_t$) we incorporate survey forecasts as described in Section 4.1.3. To construct a forecast for future personal income, we take the expected household income growth reported in the Michigan Survey of Consumers, and use it to scale current personal income.

When constructing the Hand-to-Mouth (HtM) income process, we follow established practices as closely as possible. Using the U.S. Survey of Consumer Finances (SCF) for the years 1983 through 2022, we calculate the ratio of the average annual income of households classified as HtM to that of all households in the survey. First, we classify households as HtM and omit certain observations by closely following Kaplan and Violante (2014). We consolidate all varieties of hand-to-mouth agents in their research into one HtM classification, determined by a household's biweekly income, net liquid wealth, and monthly credit limit. These variables are carefully constructed using the U.S. SCF full public dataset and the specifications provided by Kaplan and Violante. To construct average income measures, we weight the income for each household using the weights provided in the U.S. SCF dataset and calculate the average income within the desired groups accordingly. We limit our analysis to the years 1992 onward due to the non-uniform survey methodology used in the 1983 to 1989 surveys.

When accounting for non-separable labor income, the relevant variable is labor growth, but theory is agnostic about how it is transformed in the consumption function (it enters from the utility function, in contrast to other observables which enter through budget constraints.) Therefore we can measure labor growth as log differences, which is convenient as this series doe snot need to be detrended. We use non-farm business hours as our labor measurement.

F The State Space Model

We now describe our state-space model in more detail. We do so in two steps - first we describe a state-space model where all variables are observed in every period. We then describe how we modify this representation to account for missing observations.

F.1 Some Preliminary Definitions and Expressions

- $X_t \in \mathbb{R}^m$ is the vector of observed predictors (does *not* include c_t - otherwise we would have two equations for c_t in the state space model).
- We assume a VAR(p) model for X_t:

$$X_t = \mu_X + A_1 X_{t-1} + \cdots + A_p X_{t-p} + u_t \quad , \quad u_t \sim N(0, \Sigma_u) \quad , \quad u_t = G\varepsilon_t$$

- We form the companion state $\overline{X}_t = \left(X_t', X_{t-1}', \ldots, X_{t-p+1}'\right)' \in \mathbb{R}^{mp}$. The resulting companion form is given by

$$\overline{X}_t = \overline{\mu} + F, \overline{X}_{t-1} + \overline{u}_t.$$

$$\overline{\mu} = \begin{pmatrix} \mu_X \\ 0 \\ \vdots \\ 0 \end{pmatrix} \in \mathbb{R}^{mp}, \qquad F = \begin{pmatrix} A_1 & A_2 & \cdots & A_{p-1} & A_p \\ I_m & 0 & \cdots & 0 & 0 \\ 0 & I_m & \cdots & 0 & 0 \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & \cdots & I_m & 0 \end{pmatrix} \in \mathbb{R}^{mp \times mp},$$

$$\overline{\Sigma}_u = \mathrm{Var}(\overline{u}_t) = \begin{pmatrix} \Sigma_u & 0 & \cdots & 0 \\ 0 & 0 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & 0 \end{pmatrix}.$$

- The joint shock vector $\varepsilon_t \in \mathbb{R}^{m+1}$ is standard normal, $\varepsilon_t \sim \mathcal{N}(0, I_{m+1})$. Its first element $\varepsilon_{c,t}$ is the consumption-equation residual; the remaining m elements represent other structural shocks.
- We stack into the full latent state

$$Z_t = \begin{pmatrix} \overline{X}_t \\ 1 \\ \varepsilon_t \end{pmatrix} \in \mathbb{R}^{mp+(m+1)}.$$

2. State Transition Equations

$$\widetilde{X}_t = \begin{pmatrix} \overline{X}_t \\ 1 \end{pmatrix}, \qquad Z_t = \begin{pmatrix} \widetilde{X}_t \\ \varepsilon_t \end{pmatrix}, \qquad \varepsilon_t \sim \mathcal{N}\big(0, I_{m+1}\big).$$

$$Z_t = A\, Z_{t-1} + B\, \varepsilon_t,$$

$$A = \begin{pmatrix} \widetilde{F} & 0_{(mp+1)\times(m+1)} \\ 0_{(m+1)\times(mp+1)} & 0_{(m+1)\times(m+1)} \end{pmatrix}, \quad B = \begin{pmatrix} \widetilde{G} \\ I_{m+1} \end{pmatrix},$$

$$\widetilde{F} = \begin{pmatrix} F & \mu_X \\ 0_{1\times mp} & 1 \end{pmatrix}, \qquad \widetilde{G} = \begin{pmatrix} G \\ 0_{1\times(m+1)} \end{pmatrix}.$$

3. Measurement Equations

We observe

$$y_t = \begin{pmatrix} X_t^{\mathrm{obs}} \\ c_t^{\mathrm{obs}} \\ w_t \end{pmatrix} = \underbrace{\begin{pmatrix} I_m & 0_{m\times 1} & 0_{m\times(m+1)} \\ H_c & \phi_0 & h_c \\ M_X H_\ell & \mu_w & M \end{pmatrix}}_{C} \underbrace{\begin{pmatrix} \overline{X}_t \\ 1 \\ \varepsilon_t \end{pmatrix}}_{Z_t} + \underbrace{\begin{pmatrix} v_{X,t} \\ v_{c,t} \\ \eta_t \end{pmatrix}}_{v_t},$$

where

$$H_c = \phi_n\, s_n' \;+\; \phi_b\, s_b' \;+\; \phi_\tau\, s_\tau' \;+ \sum_{j\in\{y,g,q\}} \phi_j\, e_j'\, (I_{mp} - \beta_j\, F)^{-1},$$

and

$$h_c = \big[1, 0, \ldots, 0\big]$$

picks out $\varepsilon_{c,t}$ from ε_t and s_j is a selection vector that picks variable j with the correct lag from $\overline{X}_t$. H_ℓ is the $m\times(mp)$ selection matrix that picks X_{t-1} out of $\overline{X}_t$. Finally, we assume the following distributions for the various measurement errors:

$$v_{X,t} \sim \mathcal{N}(0, \Sigma_X), \quad v_{c,t} \sim \mathcal{N}(0, \sigma_c^2), \quad \eta_t \sim \mathcal{N}(0, \Sigma_\eta).$$

F.2 Missing Observables

To account for missing observables, we need to modify the observation equation so that the matrix C linking observables and states and the covariance matrix of measurement errors v_t, which we call Σ_v, become time varying. In we set a specific row of C as well as the same row and column of Σ_v when the corresponding variable to 0 is not observed. We then replace the missing observable with 0, leading to the identity $0 = 0$ in the measurement equation. Such an equation does not influence the unobserved state estimates as well as the likelihood function computed via the Kalman filter (Durbin and Koopman, 2012).

G Priors

Our priors are summarized in Table 6. We impose a Minnesota-type prior on the free VAR coefficients in F (we denote the parameters in the first m rows of F as F^{free}), but center it

Group	Parameters	Count	Prior	Hyperparameters / Notes
VAR dynamics	F (coefficients on lags of X_t)	$6 \times 6 \times 4 = 144$	Normal (Minnesota)	Minnesota prior via `minnesota_prior`; $\lambda = [0.2, 0.5]$, prior mean uses `unit_root_MN`$= 0$
Shock impacts on X	G (6×7)	42	Mixed	$G_{ij} \sim \mathcal{N}(0,\, 0.5^2)$ except $G_{\tau,\varepsilon_\tau}$, G_{g,ε_g}, $G_{q,\varepsilon_q} \sim$ Uniform$(0, 2)$
VAR intercepts	μ_X	6	Normal	$\mathcal{N}(0,\, 1.0^2)$; rescaled by σ_{X_k}
Consumption intercept	ϕ_0	1	Normal	$\mathcal{N}(0,\, 1.0^2)$; rescaled by σ_c
Selection coeffs	ϕ_n, ϕ_b, ϕ_τ	3	Mixed	$\phi_b \sim \mathcal{N}(0,\, 0.5^2)$ rescaled; $\phi_n \mid \beta \sim$ Uniform$(1-\beta,\, 1)$; $\phi_\tau \mid \phi_n \sim$ Uniform$(-\phi_n,\, 0)$ (so $\theta = 1 + \phi_\tau/\phi_n \sim$ Uniform$(0, 1)$)
Forward-looking coeffs	ϕ_y, ϕ_g, ϕ_q	3	Normal	$\mathcal{N}(0,\, 0.5^2)$; rescaled by σ_c/σ_{X_k}
Consumption shock loading	h_c	1	Gamma	Gamma$(k = 25,\, \theta = 0.02)$ (mean 0.5, std 0.1); rescaled by σ_c
Discount factor (shared)	β	1	Beta	Beta(31.5, 3.5) (mean 0.9, std 0.05); shared across y, g, q
Instrument loadings on lags	M_X	$41 \times 6 = 246$	Normal	$\mathcal{N}(0,\, 0.1^2)$
Instrument intercepts	μ_w	41	Normal	$\mathcal{N}(0,\, 1.0^2)$
Shock impacts on instruments	M (restricted nonzeros)	41	Gamma	Gamma$(k = 20,\, \theta = 0.05)$ (mean 1.0, std ≈ 0.22); one nonzero per instrument under current mapping
Instrument meas. variances	Σ_η (diag)	41	Gamma	$\sigma^2_{\eta,i} \sim$ Gamma$(k = 1.4,\, \theta = 0.036)$ (targets $E[\sigma_{\eta,i}] \approx 0.2$, sd$(\sigma_{\eta,i}) \approx 0.1$)

Table 6: Estimated parameters and priors under the actual-data setup with $m = 6$, $p = 4$, and $n_{\text{inst}} = 41$. A joint prior is applied to (ϕ_n, ϕ_τ) with $\phi_\tau/\phi_n \sim \text{Uniform}(-1, 0)$, and ϕ_n is further restricted by $\phi_n \mid \beta \sim \text{Uniform}(1-\beta, 1)$. Priors for μ_X, ϕ_0, ϕ_b, ϕ_y, ϕ_g, ϕ_q, and h_c are rescaled by the pre-standardization standard deviations σ_c and σ_{X_k}. The prior support is additionally truncated by the stability condition $\max(\beta)\,\rho(F) < 1$ to ensure that the discounted expected sums in the consumption equation are finite.

at iid variables, as is common practice to impose a prior view that the variables are likely stationary (Koop and Korobilis, 2010):

$$\mathbb{E}[F^{free}] \;=\; \big[\underbrace{\texttt{unit\_root\_MN} \cdot I_m}_{\text{lag 1}} \quad \underbrace{0_{m \times m(p-1)}}_{\text{lags 2 to p}}\big].$$

The prior variance for coefficient on variable j at lag ℓ in equation i is

$$\operatorname{Var}\big(F^{free,(\ell)}_{i,j}\big) \;=\; \begin{cases} \dfrac{\lambda_1^2}{\ell^2}, & i = j, \\[2ex] \dfrac{\lambda_2^2\,\lambda_1^2}{\ell^2} \cdot \dfrac{\hat{\sigma}_i^2}{\hat{\sigma}_j^2}, & i \neq j, \end{cases}$$

where λ_1, λ_2 are hyperparameters, and $\hat{\sigma}_k^2$ is the residual variance from a univariate AR(p) of variable k (estimated equation-by-equation on the available data). In our baseline, $\lambda_1^2 = 0.2$, $\lambda_2^2 = 0.5$, and `unit_root_MN`=0.

H Posterior Sampling Algorithm

We use a sequential Monte Carlo sampler (Herbst and Schorfheide, 2015) to approximate the posterior distribution of our model. This algorithm is well suited to approximate possibly irregular posterior distributions with ridges in the likelihood function, making it well suited for models such as ours with cross-equation restrictions (remember that the VAR coefficients F enter the consumption function). Table 7 shows the settings we use for our sampler, borrowing the notation from Herbst and Schorfheide (2015).

I Additional Tables and Figures

Setting	Value
Particles	15000
Temperature steps (N_ϕ)	100
MH steps per stage (N_{MH})	5
ϕ schedule parameter (λ)	3
Resample threshold (fraction of effective sample size)	0.5
Resample method	stratified

Table 7: Sequential Monte Carlo settings used in the actual-data estimation.

Shock Source	Method	Baseline	Omit SVAR	Small Set
Monetary Policy Shocks				
Jarociński and Karadi (2020)	HFI	✓	✓	
Miranda-Agrippino and Ricco (2021)	HFI	✓	✓	
Bauer and Swanson (2023)	HFI	✓	✓	
Swanson (2024)	HFI	✓	✓	
Aruoba and Drechsel (2024)	Narrative	✓	✓	✓
Drechsel (2024)	SVAR	✓		
Government Spending Shocks				
Fisher and Peters (2010)	External	✓	✓	
Ramey (2016)	Narrative	✓	✓	
Romer and Romer (2016)	Narrative	✓	✓	
Fieldhouse et al. (2018)	Narrative	✓	✓	
Fieldhouse and Mertens (2023)	Narrative	✓	✓	✓
Tax/Borrowing Shocks				
Leeper et al. (2012)	External	✓	✓	
Phillot (2025)	HFI	✓	✓	
Mertens and Ravn (2012)	Narrative	✓	✓	
Lieb et al. (2024)	Narrative	✓	✓	✓
Technology Shocks				
Fernald (2014)	External	✓	✓	✓
Miranda-Agrippino et al. (2025)	External	✓	✓	
Oil Shocks				
Kilian (2008)	External	✓	✓	
Känzig (2021)	HFI	✓	✓	✓
Baumeister and Hamilton (2019)	SVAR	✓		
Other Shocks				
Kim et al. (2025)	External	✓	✓	
Piffer and Podstawski (2018)	HFI	✓	✓	✓
Chahrour and Jurado (2022)	SVAR	✓		
Adams and Barrett (2024)	SVAR	✓		

Table 8: Structural Shock Instruments Used in Estimation

Notes: Table reports the subsets of structural shocks used as instruments in different estimation specifications in Sections 4.2 and 4.3. The shocks are described in detail in Section 4.1.4.

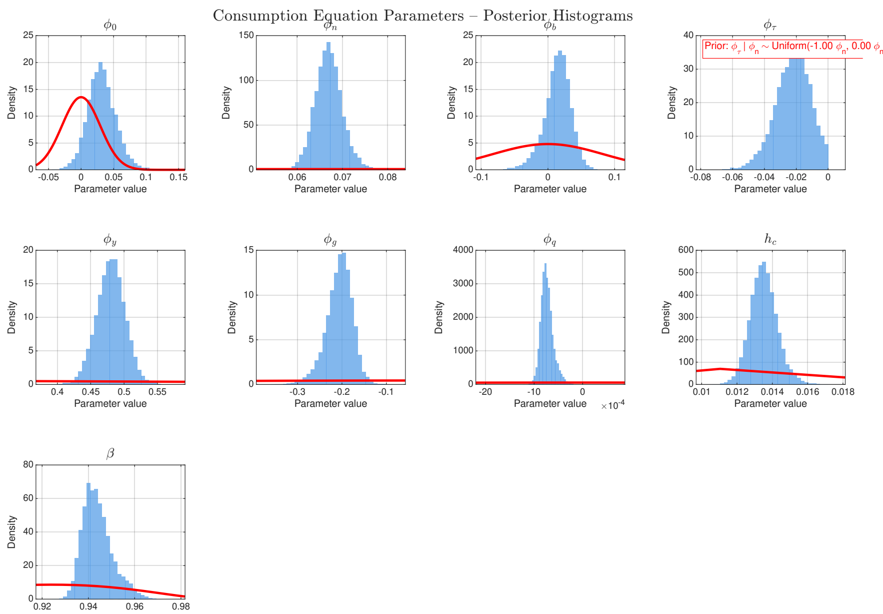

Figure 4: Priors and posteriors of the parameters of the consumption function.

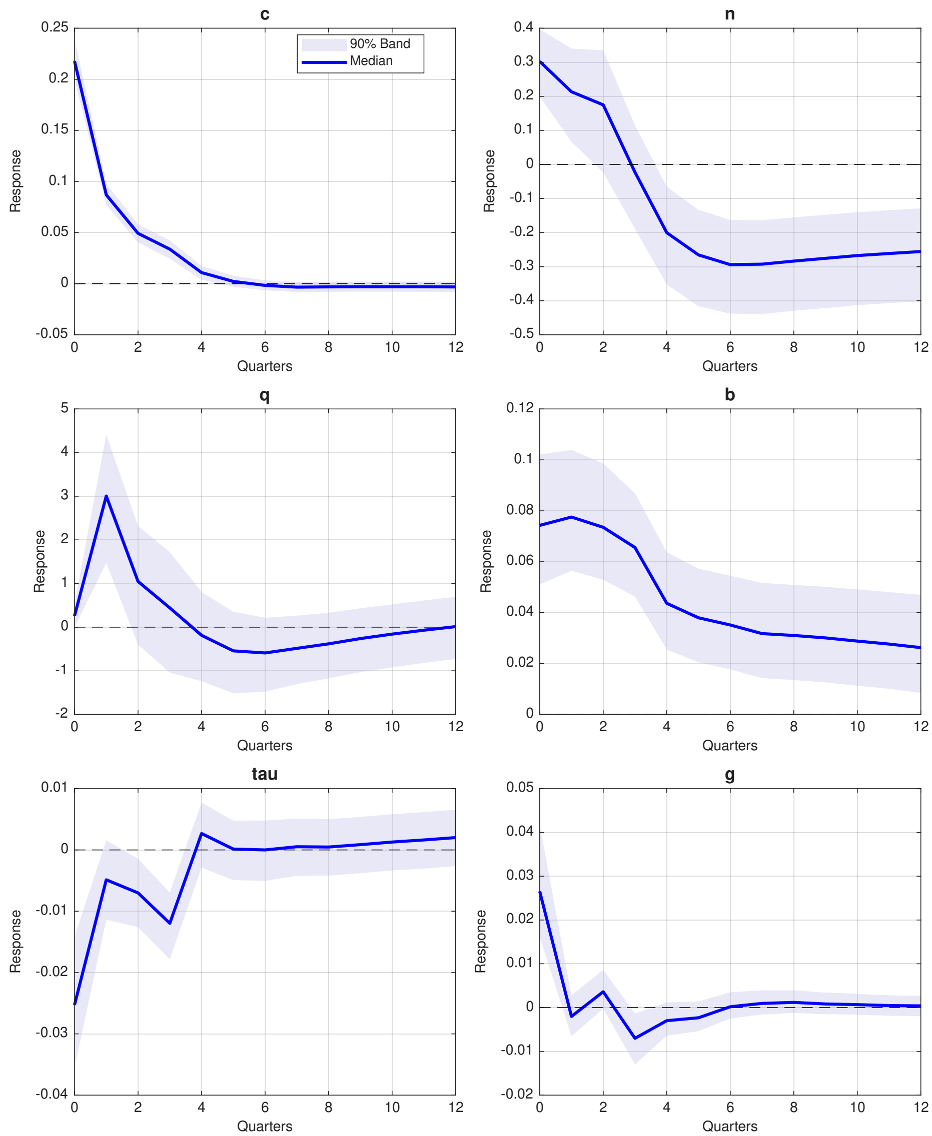

Figure 5: Impulse responses to a one standard deviation tax shock.