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 26% of their future taxes, implying a 19% marginal propensity to consume out of transfers. In a general equilibrium model, these values imply that public borrowing substantially crowds out private investment.

JEL-Codes: C11, C32, E21, E62, E70

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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 (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. 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 identified in the literature as instrumental variables (IV). A valid IV approach will resolve the endogeneity problems that 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 tempting application, and we build on their method in order to

[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).

do so. Specifically, we develop **B-HIVE** the Bayesian Hybrid IV Estimator. **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, many 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) – imply strong predictions about the coefficient on taxes in the consumption function. Microeconomic evidence gives clear evidence about the strengths of these particular effects, but not about the bias due to 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.

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 26% of future taxes. Simultaneously, our Bayesian method estimates the marginal propensity to consume out of transfers; for Ricardian households this would be zero, but we estimate roughly 19%. The amount is similar to estimates from recent one-off fiscal transfers (Johnson et al., 2006; Parker et al., 2013). It is also similar to values elicited from surveys for hypothetical economy-wide transfers by Eichenbaum et al. (2025).

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 studies are Gabaix (2020), Brzoza-Brzezina et al. (2024) 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; Lustenhouwer and Mavromatis, 2023) 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 Bayesian approach 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 net-of-depreciation return R_t^K, 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. 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

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

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:

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

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

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

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*

$$c_t = (1-\beta)\left(n_{t-1} - \theta b_{t-1} + \tilde{v}_t^y - (1-\theta)\tau_t - \theta v_t^g + \theta \overline{B} v_t^q\right) + \left(\frac{\overline{C}}{\gamma} - (1-\beta)\overline{B}\right)\tilde{v}_t^q + \zeta_t \quad (14)$$

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

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

$$= \tau_t - g_t + \overline{B}q_t + \beta\mathbb{E}_t\left[v_{t+1}^\tau - v_{t+1}^g + \overline{B}v_{t+1}^q\right]$$

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

Combine with equation (13) to find

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

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

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.

2.3 Alternative Justifications for the Behavioral Consumption Function

In this section, we show that alternative mechanisms for non-Ricardianism lead to similar conclusions regarding the consumption function as in our behavioral approach. Instead of non-rational expectations, we examine cases where: (1) households have a different discount rate than the government, and (2) some households are hand-to-mouth.

2.3.1 A Discounting Wedge

This section considers the case where households discount the future with a different factor than the government does. This 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) show that this mechanism leads to similar conclusions as in a full heterogeneous agents model. The wedge can also represent distortionary taxation.[2]

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*

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

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

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

where

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

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

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 necessarily close to 1 so equation (17) implies that the tax coefficient θ cannot be much less than 1 either.[3] 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.

2.3.2 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. A classic, tractable method of capturing this mechanism for non-Ricardianism is to introduce hand-to-mouth consumers (Campbell and Mankiw, 1989).[4] In this section, we 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

$$y_t = \lambda y_t^U + (1-\lambda) y_t^C \tag{18}$$

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

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

[4] 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).

function. The constrained consume

$$c_t^C = y_t^C - \tau_t \tag{19}$$

and aggregate consumption is given by

$$c_t = \lambda c_t^U + (1-\lambda) c_t^C \tag{20}$$

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 4 gives the aggregate consumption function when income is AR(1).

Proposition 4 *If households have rational expectations, then the aggregate consumption function in the two agent economy can be expressed as*

$$c_t = (1-\beta)\left(n_{t-1} - \lambda b_{t-1} + v_t^y - (1-\theta)\tau_t - \lambda v_t^g\right) + \lambda \frac{\overline{C}}{\gamma} \tilde{v}_t^q + \varsigma_t^C + \lambda \zeta_t \tag{21}$$

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 4 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 1).

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 1 *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 4. ■

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:

$$c_t = \phi_0 + \phi_n\, n_{t-1} + \phi_b\, b_{t-1} + \phi_\tau\, \tau_t + \sum_{j\in\{y,g,q\}} \tilde{\phi}_j\, v_t^j + \zeta_t, \tag{22}$$

   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 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 D.[5] 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

[5]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.

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.

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 D, E, and F 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), proxies for the variables that are possibly forecasted non-rationally (e.g. $\tilde{v}_t^y$) and many macroeconomic shocks to use as instruments.

Name	Variable	Data Source	FRED code	Range
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	PCE	1947:Q1-
Personal Taxes	τ_t	NIPA	W055RC1Q027SBEA	1947:Q1 -
Government Expenditures	g_t	NIPA	see note	1947:Q1 -
Personal Income	y_t	NIPA	PINCOME	1947:Q1 -
Inflation Forecast		Survey of Professional Forecasters		1968:Q4-
3-Month T-Bill Yield		Fed Financial Accounts	TB3MS	1934:M1-

Table 1: Time Series Data

Notes: Government Expenditures are net of government receipts not included in Personal Taxes. In terms of FRED codes, our expenditure measure is $GEXPND - (GRECPT - W055RC1Q027SBEA)$.

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. 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. 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.

Consumption data c_t and all other elements of the data vector X_t (except for yields) are detrended by the CBO's estimate of nominal potential GDP. Since all non-yield variables in X_t and c_t are nominal, this also automatically turns 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:

$$X_t = \sum_{k=1}^{K} B_k X_{t-k} + \epsilon_t \tag{23}$$

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 (23), 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

$$y_{t+1} = \tilde{B}^y y_t + \tilde{\epsilon}^y_{t+1} + \tilde{\nu}^y_t \tag{24}$$

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

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

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

$$\tilde{v}^y_t = y_t + \frac{\beta}{1 - \beta \tilde{B}^y} f^y_t \tag{25}$$

where $f^y_t = \tilde{\mathbb{E}}_t[y_{t+1}]$ is a measurement of households' one-period ahead income forecasts. Crucially, this structure implies that $\tilde{v}^y_t - y_t$ is linear in f^y_t. 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.[6] 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 $i^{(h)}_t$ satisfy

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

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

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

A large literature tests these relationships under rational expectations, and find that they

[6]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.

fail.[7] 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 interest rate $i_{t+h}^{(1)}$ and the one-period-ahead inflation rate π_{t+h+1}:

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

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

$$\tilde{v}_t^q = -\overline{Q}^2\left(r_t^{(1)} + \sum_{j=1}^{\infty}\beta^j\tilde{\mathbb{E}}_t\left[r_{t+j}^{(1)}\right]\right) = -\overline{Q}^2\sum_{j=0}^{\infty}\beta^j\left(\tilde{\mathbb{E}}_t\left[i_{t+j}^{(1)}\right] - \tilde{\mathbb{E}}_t\left[\pi_{t+j+1}\right]\right)$$

$$\implies \tilde{v}_t^q = -\overline{Q}^2\left((1-\beta)\sum_{h=0}^{\infty}\beta^h(h+1)i_t^{(h+1)} - \sum_{h=0}^{\infty}\beta^h\pi_{t+1+h}\right) \tag{26}$$

4.1.4 Instruments

To build our dataset of macro instruments, we collected a large variety of structural shocks identified by the literature.[8] Altogether, we use more than 30 shocks from 26 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 form 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

[7] 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).

[8] 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	Surprises orthogonalized w.r.t. Greenbook	1991:M1-2009:M12
Bauer and Swanson (2023)	HFI	Uses Fed minutes and speeches	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
Ben Zeev and Pappa (2017)	SVAR	Defense spending news	1948:Q1-2007: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. (2019)	External	Patent filing news	1982:M10-2014:M12
Barsky and Sims (2011)	SVAR	TFP news	1961:Q1-2007:Q4
Ben Zeev and Khan (2015)	SVAR	IST news, IST surprise, TFP	1952:Q1-2012:Q1
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

political pressure shocks in a narrative sign-restricted SVAR (Antolín-Díaz and Rubio-Ramírez, 2018).

For government spending, we began with several 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, Ramey (2011) uses narrative military shocks constructed from periodicals, and Ben Zeev and Pappa (2017) use a SVAR with medium-run restrictions to identify defense spending news shocks. To these, we add three sources of non-defense government spending shocks, all using narrative 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 draw on the Barsky and Sims (2011) TFP news shocks estimed from an SVAR using medium-run restrictions, and the Ben Zeev and Khan (2015) investment-specific productivity shocks, which has both a news and surprise component. We also take innovations to the utilization-adjusted TFP series from Fernald (2014), which is regularly updated. Finally, we include the technology news shocks from Miranda-Agrippino et al. (2019), 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). For instrumental variables, we use a reliable yet broad subset of the shocks that cover all categories;

this group is reported in Table 7.

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 $[0, 1.5]$ interval, because while theory gives little guidance on the exact value of θ, all mechanisms for Ricardian non-equivalence discussed in Section 2.3 predict that it will be positive. Most suggest that it falls between zero and one, but we allow for a somewhat larger value in case consumers "overextrapolate" as in Angeletos et al. (2021). The posterior density is overwhelmingly less than 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 (22). The second panel corresponds to $\phi_n = 1-\beta$, the marginal propensity to consume (MPC) out of wealth. Reassuringly, it 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 transfers.* This value is smaller than the generic MPC, but not by much because people are far from Ricardian.

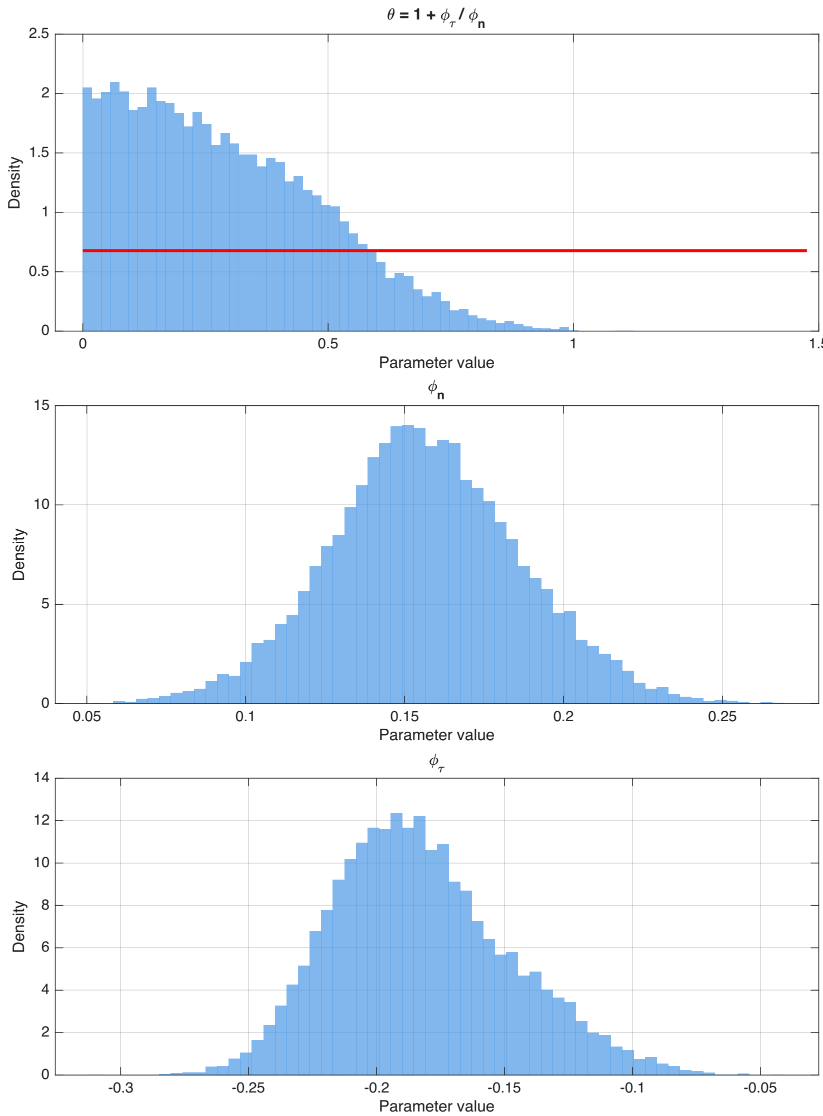


Figure 1: Marginal Posterior Densities for Three Consumption Function Parameters

The first panel plots the behavioral attenuation θ, with the prior distribution shown in red. θ is determined from two coefficients in estimated equation (22): the coefficient on net worth (second panel) $\phi_n = 1 - \beta$, and the coefficient on taxes (third panel) $\phi_\tau = -(1-\beta)(1-\theta)$.

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 26% of future taxes. The credible interval implies that the data soundly reject Ricardian equivalence: θ is clearly less than one. But there is also substantial mass away from zero, i.e. households are not strictly myopic regarding their future tax burden. The point estimate of the MPC out of transfers ($-\phi_\tau$) is roughly 19% with only modest uncertainty. This large value is consistent with micro evidence from major government transfers (Parker et al., 2013, 2022), although less than the largest estimates (Johnson et al., 2006; Hausman, 2016). We also show results for a specification where we use fewer instruments (1 from each of the 6 categories)[9] and find that the results are nearly unchanged.

Specification	Behavioral Attenuation θ	MPC Transfers ($-\phi_\tau$)
Baseline	0.259 $[0.024, 0.658]$	0.186 $[0.120, 0.234]$
Small Instrument Set	0.251 $[0.022, 0.702]$	0.184 $[0.116, 0.246]$

Table 3: Consumption Function Estimates (Posterior Medians)

Notes: Point estimates are medians of the marginal posterior distributions. The 5%-95% credible intervals are reported in brackets.

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.

[9]We use the instruments described in Fisher and Peters (2010); Aruoba and Drechsel (2024); Lieb et al. (2024); Känzig (2021); Barsky and Sims (2011); Piffer and Podstawski (2018), and summarized in Table 7.

5.1 Model Assumptions

We study a standard real business cycle model modified with behavioral expectations.[10] 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

$$\tilde{\mathbb{E}}_t \left[\sum_{s=0}^{\infty} \beta^s u(C_{t+s}) \right] \tag{27}$$

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

$$W_t L_t + R_t K_{t-1} + Z_t^k (1-\delta) K_{t-1} + B_{t-1} = C_t + T_t + Q_t B_t + Z_t^k K_t \tag{28}$$

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

$$Q_t = \beta \tilde{\mathbb{E}}_t \left[\frac{u'(C_{t+1})}{u'(C_t)} \right] + Z_t^d \tag{29}$$

while the Euler equation for capital is

$$1 = \beta \tilde{\mathbb{E}}_t \left[\frac{u'(C_{t+1})}{u'(C_t)} R_{t+1}^K \right] + Z_t^d + Z_t^r \tag{30}$$

where

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

denotes the return on capital. We introduce two ad hoc exogenous wedges to the Euler

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

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

$$\tilde{V}_t^T = \tilde{\mathbb{E}}_t \left[\sum_{s=0}^{\infty} P_{t,t+s} T_{t+s} \right] \tag{31}$$

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:

$$\tilde{V}_t^T = T_t + Q_t \tilde{\mathbb{E}}_t [\tilde{V}_{t+1}^T] \tag{32}$$

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

$$Y_t = A_t F(K_{t-1}, L_t) \tag{33}$$

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

$$A_t F_K(K_{t-1}, L_t) = R_t \tag{34}$$

$$A_t F_L(K_{t-1}, L_t) = W_t \tag{35}$$

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

$$Y_t = C_t + G_t + Z_t^K (K_t - (1-\delta) K_{t-1}) \tag{36}$$

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

$$G_t = T_t + Q_t B_t - B_{t-1} \tag{37}$$

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 (29) and (30) hold.
2. Firms produce by (33) and satisfy factor demands (34) and (35)
3. Fiscal variables follow the government budget constraint (37)
4. The resource constraint (36) 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 $\overline{R^k} = \overline{R} + 1 - \delta$.[11]

The Euler equations (29) and (30) become

$$q_t = \beta \tilde{\mathbb{E}}_t [\gamma \frac{1}{\bar{C}} (c_t - c_{t+1})] + z_t^d \tag{38}$$

$$0 = \beta \tilde{\mathbb{E}}_t [\gamma \frac{1}{\bar{C}} (c_t - c_{t+1}) + r_{t+1} + (1-\delta) z_{t+1}^k] - z_t^k + z_t^d + z_t^r \tag{39}$$

[11] 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 $\overline{R}^k = \beta^{-1}$.

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 (33)) is given by

$$y_t = \overline{Y}a_t + \overline{R}k_{t-1} \tag{40}$$

with steady state productivity normalized to $\overline{A} = 1$. Similarly, the capital demand (34) is linearized as

$$r_t = \overline{R}a_t + \bar{F}_{KK}k_{t-1} \tag{41}$$

and the labor demand (35) is linearized as

$$w_t = \overline{W}a_t + \bar{F}_{LK}k_{t-1} \tag{42}$$

The government budget constraint (37) is

$$b_{t-1} = \tau_t - g_t + q_t\bar{B} + \beta b_t \tag{43}$$

The resource constraint (36) is

$$y_t = c_t + g_t + k_t - (1-\delta)k_{t-1} + \delta\overline{K}z^k_t \tag{44}$$

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	$\zeta_t = \rho_\zeta\zeta_{t-1} + \epsilon^\zeta_t$	(45)
TFP	$a_t = \rho_a a_{t-1} + \epsilon^a_t$	(46)
IST	$z^k_t = \rho_k z^k_{t-1} + \epsilon^k_t$	(47)
Risk	$z^r_t = \rho_r z^r_{t-1} + \epsilon^r_t$	(48)
Gov. Spending	$g_t = \rho_g g_{t-1} + \epsilon^g_t$	(49)

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):

P.V. Taxes	$v^\tau_t = \rho_\tau v^\tau_{t-1} + \epsilon^\tau_{t-1}$	(50)

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

$$\text{Current Taxes} \qquad \tau_t = \rho_\tau \tau_{t-1} - \beta\epsilon^{\tau}_t + \epsilon^{\tau}_{t-1} \tag{51}$$

5.1.7 Expectations

We assume that households have rational expectations about most exogenous processes, i.e. recognizing that they follow equations (45) - (49). 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 $\tilde{\mathbf{E}}_{t,t+j}[\tau_{t+j+1}] = \tilde{\mathbb{E}}_t\tilde{\mathbb{E}}_{t+1}...\tilde{\mathbb{E}}_{t+j}\,[\tau_{t+j+1}]$:

$$\tilde{\mathbf{E}}_{t,t+j}[\tau_{t+j+1}] = \theta\mathbb{E}_t[\tau_{t+j+1}] \tag{52}$$

These expectations are referred to as *sophisticated cognitive discounting*, because θ is only applied once instead of recursively.[12] 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 sophisticated behavioral expectations for clarity, because the non-Ricardian parameter θ from Section 2 appears directly. Appendix B shows that if we used the naive 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^{τ}_t that does not affect government spending.

The model is intended to be illustrative, so we choose a generic quarterly parameterization (Table 4), 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

[12] 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 4: Parameter Values for the Quarterly Business Cycle Model

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:

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

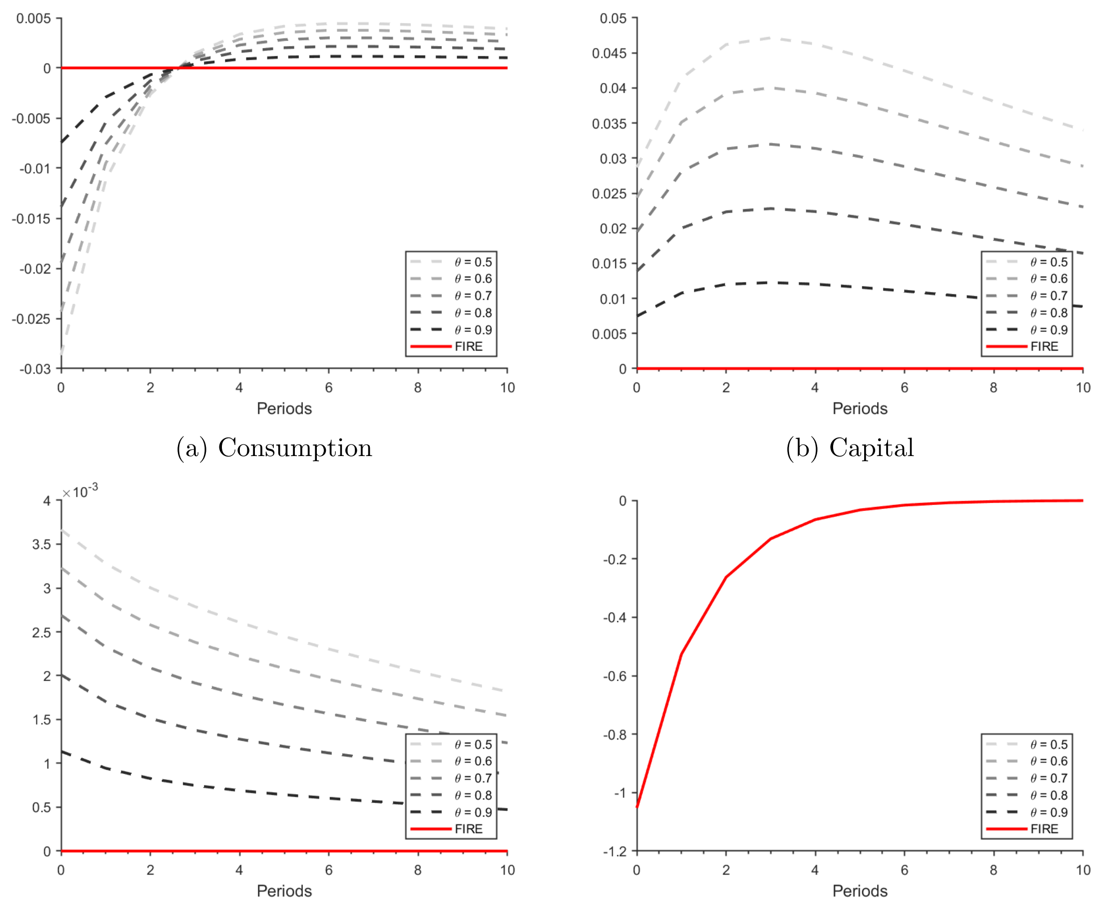
Changes to taxes can affect consumption because households are able to substitute from consumption to savings. Market clearing implies that any decline in consumption is offset by an investment increase. Under Ricardian equivalence, tax shocks have no effect on consumption, because agents know that current 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 tax shock u_t for a variety of θ values. When $\theta < 1$, agents expect that future taxes will be higher than the rational expectation, and so would like to decrease consumption (Panel 2a). The unconsumed GDP is instead used for investment, so the capital stock accumulates (Panel 2b). Because there is savings vehicle, consol values (Panel 2c) do not need to rise nearly as much as in the capital-less mode. As θ shrinks, households are less Ricardian, and want to decrease consumption by even more. This leads to greater capital accumulation. In all these cases, the tax increase reduces 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:



(a) Consumption (b) Capital

(c) Consol Value (d) Government Debt

Figure 2: Non-Ricardian Responses to Tax Shocks

Impulse response functions for a 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.

Corollary 2 *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 $\tilde{\mathbb{E}}_t[v_{t+1}^\tau] = \theta \mathbb{E}_t[v_{t+1}^\tau]$, 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 $\tilde{v}_t^q$, and perceived non-financial wealth $\tilde{v}_t^y$ as:*

$$c_t = (1-\beta)\left(n_{t-1} - \theta b_{t-1} + \tilde{v}_t^y - (1-\theta)\tau_t\right) + \frac{\overline{C}}{\gamma}\tilde{v}_t^q + \zeta_t \tag{53}$$

Proof: Appendix A

Are government bonds net wealth? Behavioral households act as if they are. Corollary 2 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 (53) 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_t^y, τ_t, and v_t^q, 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 (53) 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_T^y, τ_t, and v_t^q. 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) proposed estimation 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.

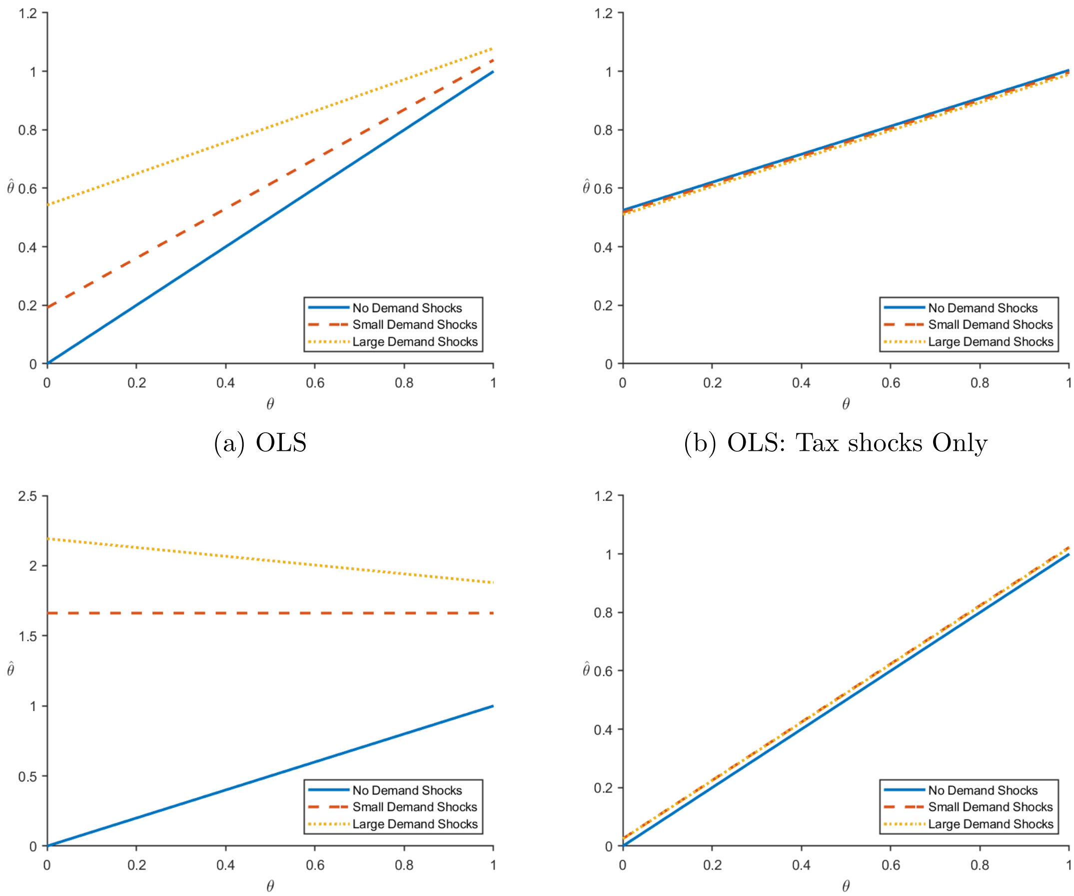
Macro shocks as instrumental variables can resolve the problem. The Monte Carlo model's consumption function (53) has three endogenous variables (n_{t-1}, $\tilde{v}_t^y$, and $\tilde{v}_t^q$) and two exogenous variables (b_{t-1} and τ_t) so three non-collinear exogenous instruments are needed. We use 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) 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

$$
\beta \mathbb{E}_t[v_{t+1}^\tau] = b_{t-1} - \tau_t + v_t^g - \overline{B} v_t^q \tag{54}
$$

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 (15), simplifies to

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

Combined with equation (54), this implies that $\beta\omega\mathbb{E}_t[\tilde{v}_{t+1}^{\tau}]$ can be written

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

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

Proof of Corollary 2. With constant government spending and zero steady-state debt, the government budget constraint (43) 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

$$\tilde{\mathbf{E}}_{t,t+j}[x_{t+j+1}] \equiv \tilde{\mathbb{E}}_t\tilde{\mathbb{E}}_{t+1}\tilde{\mathbb{E}}_{t+2}...\tilde{\mathbb{E}}_{t+j}\left[x_{t+j+1}\right] \tag{55}$$

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:

$$\tilde{\mathbf{E}}_{t,t+j}[x_{t+j+1}] = \begin{cases} \lambda^{j+1}\mathbb{E}_t[x_{t+j+1}] & \text{(naive expectations)} \\ \lambda\mathbb{E}_t[x_{t+j+1}] & \text{(sophisticated expectations)} \end{cases} \tag{56}$$

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

Lemma 1 *If households are naive 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 (51), 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 naive 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

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

■

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

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

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 sophisticated cognitive discounters regarding taxes only (equation (52)). 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 naive 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 naive 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 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.

D.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

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

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:

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

D.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).

E Priors

Group	Parameters	Count	Prior	Hyperparameters / Notes
VAR dynamics	F (coefficients on lags of X_t)	$6 \times 6 \times 2 = 72$	Normal (Minnesota)	Mean/std per Minnesota prior (own/cross, lag decay)
Shock impacts on X	G (6×7)	42	Normal	$\mathcal{N}(0, 0.5^2)$ for all entries
VAR intercepts	μ_X	6	Normal	$\mathcal{N}(0, 1.0^2)$
Consumption intercept	ϕ_0	1	Normal	$\mathcal{N}(0, 1.0^2)$
Consumption rule	ϕ_n, ϕ_b, ϕ_τ	3	Mixed	$\phi_n, \phi_b \sim \mathcal{N}(0, 0.5^2)$; $\phi_\tau \mid \phi_n \sim$ Uniform$([-1 \cdot \phi_n, 0])$
Forward-looking coeffs	ϕ_y, ϕ_g, ϕ_q	3	Normal	$\mathcal{N}(0, 0.5^2)$
Consumption shock loading	h_c	1	Gamma	Gamma($k = 25$, $\theta = 0.02$) (mean 0.5, std 0.1)
Discount factors	β_y, β_g, β_q	3	Beta	Beta($\alpha = 31.5$, $\beta = 3.5$) (mean 0.9, std 0.05)
Instrument loadings on lags	M_X	$17 \times 6 = 102$	Normal	$\mathcal{N}(0, 0.1^2)$
Instrument intercepts	μ_w	17	Normal	$\mathcal{N}(0, 1.0^2)$
Shock impacts on instruments	M (restricted nonzeros)	17	Gamma	Gamma($k = 20$, $\theta = 0.05$) (mean 1.0, std ≈ 0.22)
Instrument meas. variances	Σ_η (diag)	17	Gamma	Gamma($k = 4$, $\theta = 0.05$) (mean 0.2, std 0.1)

Table 5: Estimated parameters and priors with $m = 6$, $p = 2$, and $n_{\text{inst}} = 17$, using the data transformation described in the text. Measurement error variances for X and c are fixed to zero (not estimated). A joint prior is applied to (ϕ_n, ϕ_τ): $\phi_\tau \in [-\phi_n, 0]$ with uniform density conditional on ϕ_n. This implies a $U[0, 1]$ prior for θ.

Our priors are summarized in Table 5. 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 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

$$\mathrm{Var}\big(F_{i,j}^{free,(\ell)}\big) = \begin{cases} \dfrac{\lambda_1^2}{\ell^2}, & i = j, \\ \dfrac{\lambda_2^2\,\lambda_1^2}{\ell^2} \cdot \dfrac{\hat{\sigma}_i^2}{\hat{\sigma}_j^2}, & i \neq j, \end{cases}$$

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.

F 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 6 shows the settings we use for our sampler, borrowing the notation from Herbst and Schorfheide (2015).

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

G Additional Results

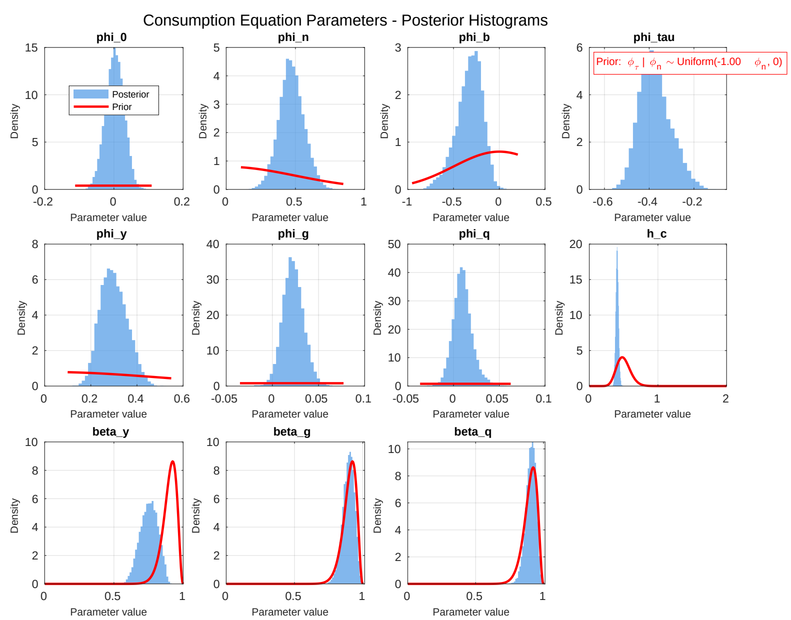

Figure 4: Priors and posteriors of the parameters of the consumption function.

Shock Source	Method	Baseline	All Shocks	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	✓	✓	✓	
Ben Zeev and Pappa (2017)	SVAR		✓		
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. (2019)	External		✓	✓	
Barsky and Sims (2011)	SVAR	✓	✓		✓
Ben Zeev and Khan (2015)	SVAR		✓		
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	✓	✓	✓	✓
Adams and Barrett (2024)	SVAR	✓	✓		

Table 7: Structural Shock Instruments Used in Estimation

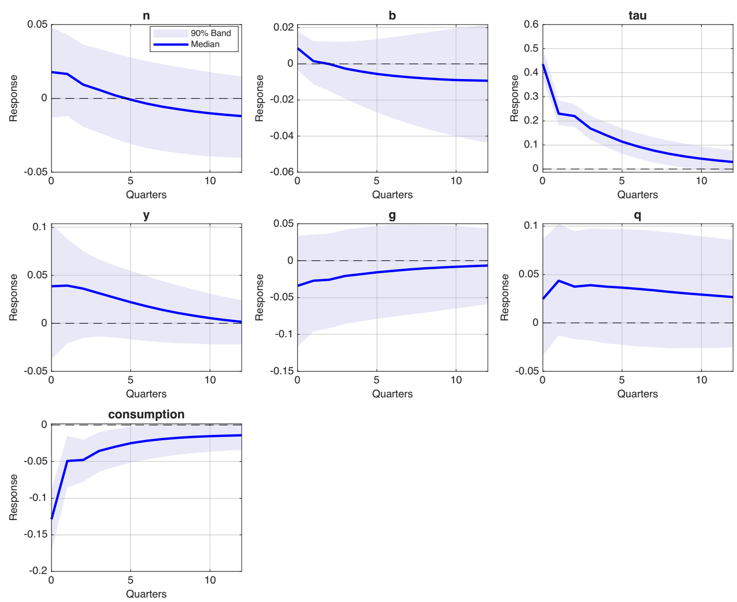

Figure 5: Impulse responses to a one standard deviation tax shock, all variables standardized.

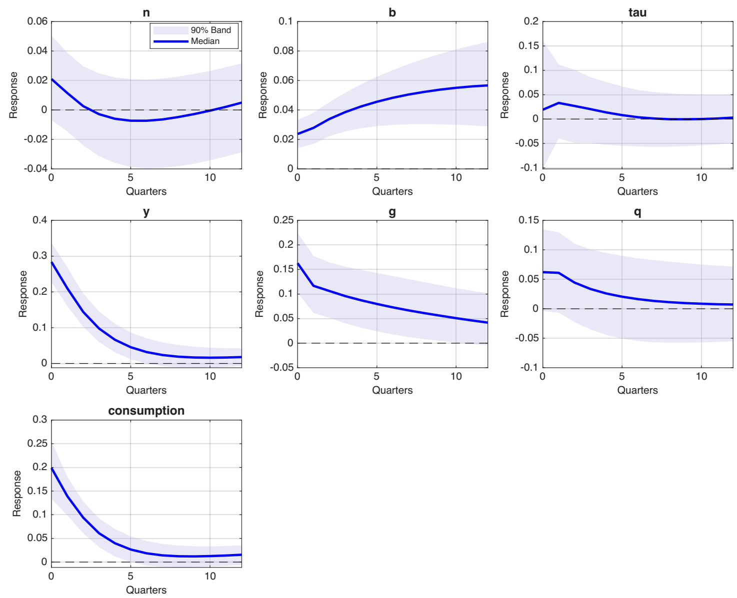

Figure 6: Impulse responses to a one standard deviation government spending shock, all variables standardized.