Reference-Dependent Utility over Prices and the Welfare Cost of Inflation*

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Abstract

Survey evidence documents anger and perceived unfairness among consumers facing rising prices. I study a mechanism through which these reactions can generate welfare losses by embedding reference-dependent demand in a New Keynesian model. When posted prices exceed reference prices formed from past purchases, the same physical consumption bundle delivers less utility. This generates a first-order welfare cost of inflation absent from standard models. I estimate the parameters governing these losses using a survey with hypothetical shopping scenarios that vary reference prices while holding posted prices fixed. Under the baseline calibration, welfare losses are about four times those in the standard model for cost-push shocks matched to a 1% peak in quarterly inflation. To quantify this cost during the recent inflation surge, I fit a heterogeneous-agent model with reference-dependent demand for frequently purchased goods to U.S. macroeconomic data from 2021–2023. The average household loses the equivalent of 5.3% of annual steady-state consumption, about one-fifth more than without reference dependence.

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1 Introduction

Conventional models imply modest welfare costs of inflation, yet the public expresses a deep aversion to rising prices. U.S. consumer sentiment fell to a historic low in 2022 during the recent inflation surge, with rising prices at the center of public frustration. Federal Reserve Chair Jerome Powell linked this dissatisfaction in part to consumers "paying much more for the basics of life" than they had two or three years earlier. Paying more than one is accustomed to can leave consumers feeling overcharged and less satisfied with the transaction (Thaler, 1985). This offers an explanation for the anger at higher prices documented in surveys of consumers' attitudes toward inflation.[1] This psychological cost is outside the scope of welfare calculations in standard macroeconomic models, which could lead to an underestimation of the losses households experience during inflationary episodes.

To quantify this cost, I integrate reference-dependent demand into a New Keynesian model. In this framework, consumers assess how good a deal each variety offers by comparing its posted price with a reference price formed from its past prices. Holding the posted price fixed, a lower reference price makes the purchase a worse deal, reducing both demand and utility. I show that reference-dependent demand generates a *first-order* cost of inflation that standard models fail to capture. I estimate the parameters governing this cost using a novel survey of U.S. consumers. To assess the importance of this mechanism during the recent inflation surge, I extend the framework to a rich heterogeneous-agent New Keynesian model with differences in consumption baskets, sticky wages, and a realistic wealth distribution. Fitting the model to U.S. data for 2021–2023, I find that the episode cost the average household 5.3% of its annual steady-state consumption. The cost of reference dependence is equivalent to 18% of the cost of the episode.

At the core of this framework is a CES consumption aggregator in which the gap between each variety's posted and reference prices enters as a taste shifter. Reference prices are weighted moving averages of each variety's past prices and coincide with posted prices at the zero-inflation steady state. I show that a second-order approximation of household utility around an efficient steady state contains a new term that is linear in the gap between posted and reference prices. Intuitively, in the symmetric equilibrium, inflation pushes posted prices above their references across all varieties, making every purchase feel like a worse deal. The household therefore derives less utility from a given consumption bundle.

Two parameters govern the magnitude of this cost: the reference-price elasticity, which is the elasticity of demand with respect to the reference price holding the posted price fixed, and the speed at which reference prices update. A larger reference-price elasticity implies a greater utility loss for a given gap between posted and reference prices. Slower updating of reference prices leads to more persistent gaps between posted and reference prices, increasing

[1] See Shiller (1997) and Stantcheva (2024).

the cumulative welfare loss. In its general form, the demand system allows a kink at the reference price: demand can respond more strongly to a price increase above the reference than to an equal-sized decrease below it. The reference-price elasticity can therefore differ between the loss side, where posted prices exceed their references, and the gain side, where they fall below. Because inflation generates an increase in prices relative to their references, the loss-side elasticity governs the resulting welfare costs.

I estimate the reference-price elasticities and the speed at which reference prices update with a survey of about 1,500 U.S. respondents conducted on Prolific in April 2026. To isolate the reference-price elasticity, the ideal experiment varies the reference price while holding the posted price, income and other prices fixed. I implement this through novel hypothetical questions where respondents consider various shopping scenarios. First, each respondent names a grocery product they buy often, reports the price they typically expect to pay for it, which I take as their initial reference price, and states how much they would buy at that price over the next month. At baseline, the posted price equals their initial reference price. Across the hypothetical shopping scenarios, next month's posted price remains fixed at the respondent's initial reference price.

The scenarios differ in what the product usually costs. In the loss scenario, the product usually sells for less, making next month's posted price a temporary increase. With income and all other prices held fixed, respondents report how much they would buy next month and the price they would typically expect to pay under the scenario, which I take as their reference price. The gap between the initial reference price and the scenario's usual price is randomized across respondents, generating exogenous variation in reference prices while the posted price remains unchanged. Respondents also answer a similar gain-side scenario, in which the item usually sells for more. Since stated quantities are discrete, I estimate the elasticities by Poisson pseudo-maximum likelihood. The same posted price elicits 0.87% less consumption when the reference price is 1% below it, but only 0.33% more when the reference price is 1% above it. I obtain a similar loss-side reference-price elasticity when estimating the same demand system using observational NielsenIQ scanner data for 22 grocery categories.

The speed of reference-price updating is identified through another hypothetical question, in which respondents encounter a 20% price increase after several shopping trips at their initial reference price. A randomly chosen half of respondents report the price that would feel normal (neither too high nor too low) on subsequent trips, while the other half report the price they would typically expect to pay. Using the normal-price responses for the baseline, I invert the reference-price law of motion to infer reference-price updating per shopping trip, then convert it to the quarterly level using each respondent's reported shopping frequency. The mean quarterly persistence is 0.53: just over half of a gap between posted and reference prices remains after a quarter.

I use these estimates to quantify the welfare cost of a cost-push shock in the baseline New

Keynesian model with reference-dependent demand. The estimated kink in demand at the reference price makes the model non-standard in two ways: the firm's optimality conditions are one-sided inequalities rather than a single first-order condition, and the steady state, where prices equal their references, sits exactly at the kink. I therefore solve for the exact nonlinear perfect-foresight path after the shock, in which the equilibrium determines whether firms price above, below, or at their references in each period. Scaling the shock in each model to generate a one-percentage-point peak increase in quarterly inflation, I find that the consumption-equivalent welfare loss is 4.3 times that in the standard New Keynesian model. A decomposition shows that the new first-order term accounts for around 80% of the welfare losses. This amplification is larger for smaller shocks because the new term is first order while the conventional costs are second order.

I then quantify these welfare costs during the 2021–2023 U.S. inflation surge using a heterogeneous-agent New Keynesian model. Two considerations motivate this extension. First, reference-dependent demand has been documented most extensively for frequently purchased goods, whose shares in household expenditure vary across income groups. Guided by this evidence, I define the reference-dependent sector to include food, energy, and other frequently purchased nondurables, with expenditure shares across income groups disciplined using data from the Consumer Expenditure Survey. Second, I incorporate sticky wages and heterogeneous nominal asset holdings to quantify the importance of reference-dependent demand relative to these other mechanisms emphasized in the recent literature. For the average household, the total cost of the episode is equivalent to 5.3% of annual steady-state consumption. The additional utility loss attributable to reference dependence is equivalent to 0.97%, or about 18% of the total cost of the episode. This additional cost is about 30% higher in the initial earnings group with the largest expenditure share on reference-dependent goods than in the group with the smallest share.

These results bear on the debate over how much weight monetary policy should place on food and energy inflation. Reference-dependent demand has been documented in both food and energy markets, including grocery products and gasoline. The conventional case for looking through temporary movements in these prices is that responding aggressively can increase volatility in core inflation and real activity. My results show that, in addition to disproportionately affecting lower-income households through their consumption baskets, food and energy inflation carries a first-order welfare cost through reference-dependent demand. These findings align with survey evidence on households' concerns during the inflation surge.[2]

[2]In a 2022 Pew survey, rising prices for food and consumer goods and for gasoline and energy ranked as the leading economic concerns, with three-quarters of U.S. adults reporting that they were very concerned about each (Pew Research Center, 2022). In the University of Michigan's Surveys of Consumers, respondents volunteered concerns about high food and gasoline prices during interviews about their finances and economic outlook. Over 2021–2023, respondents who mentioned these prices reported lower consumer sentiment than those who did not (Hsu, 2024).

This cost must be weighed against the costs of stabilizing these prices.

Related literature. This paper contributes to four strands of the literature. First, it builds on a long-standing literature that seeks to understand and quantify the welfare costs of inflation. Standard accounts emphasize the welfare costs of economizing on money holdings (Fischer, 1981; Lucas, 2000) and of inefficient relative-price dispersion (Woodford, 2003; Galí, 2015). More recent work examines the welfare costs of real-wage erosion and costly wage adjustment (Afrouzi et al., 2024; Guerreiro et al., 2024), as well as redistribution across households with different net nominal positions (Doepke and Schneider, 2006; Pallotti et al., 2024). I introduce reference-dependent demand, grounded in consumer psychology and marketing evidence, as a new source of inflation's welfare costs. I estimate the parameters governing this demand through a consumer survey and use them to calibrate the demand system in a New Keynesian model, allowing me to quantify its importance relative to other costs of inflation. This mechanism offers a possible explanation for the anger at rising prices documented by Shiller (1997) and Stantcheva (2024). Thaler's (1985) discussion of transaction disutility in terms of annoyance and feeling ripped off provides a psychological interpretation of this utility loss.

I also contribute to work that incorporates insights from behavioral economics into models of price setting and monetary transmission. Loss aversion has been used to explain regular prices and sales (Heidhues and Kőszegi, 2014), price stickiness (Angelis, 2025), and asymmetric monetary transmission (Santoro et al., 2014). Blinder et al. (1998) document firms' concerns about antagonizing customers through price increases, while Rotemberg (2005) and Eyster et al. (2021) embed these concerns in macroeconomic models to study price rigidity. Relative to these papers, I show how reference-dependent consumer demand generates endogenous price rigidity and estimate the parameters governing this mechanism using a new consumer survey. I solve the model in dynamic general equilibrium, preserving the demand kink and accounting for how firms' pricing decisions affect future reference prices and demand. I further contribute by integrating this behavioral mechanism into a rich heterogeneous-agent New Keynesian model to quantify its aggregate and distributional welfare effects.

This paper also relates to research on heterogeneous consumption baskets and the distributional effects of inflation. Empirical work documents higher inflation for lower-income households over longer horizons, reflecting differences in the goods they purchase (Jaravel, 2019; Argente and Lee, 2021). Olivi et al. (2026) study how heterogeneous consumption baskets shape monetary policy trade-offs, while Bobasu et al. (2025) examine how energy expenditure shares and household wealth shape the distributional effects of energy price shocks. Relative to this literature, I show that reference-dependent demand creates an additional channel through which consumption-basket heterogeneity affects welfare during inflationary episodes. I examine how losses attributable to reference dependence vary across income groups during the 2021–2023 U.S. inflation surge.

Finally, I contribute to the extensive empirical marketing literature on reference prices and loss aversion in consumer demand (Winer, 1986; Mayhew and Winer, 1992; Hardie et al., 1993; Kalyanaram and Little, 1994; Briesch et al., 1997; Bell and Lattin, 2000; Mazumdar et al., 2005). These papers typically focus on a few product categories and document reference-dependent demand. However, evidence is mixed on whether demand responds more strongly to price increases above the reference than to equal-sized decreases below it, as loss aversion would predict. Relative to these studies, I identify reference-price elasticities using hypothetical shopping scenarios that generate exogenous variation in reference prices while holding posted prices fixed. The survey also explicitly instructs respondents to exclude stockpiling and postponing purchases, and I find evidence of loss aversion in their stated consumption choices. I also estimate the same demand system using NielsenIQ scanner data for 22 grocery categories, finding a reference-price elasticity on the loss side close to the survey estimate but a substantially larger elasticity on the gain side. These contrasting findings suggest that stockpiling during sales can obscure loss aversion in purchase data, helping reconcile the survey evidence with the mixed findings in existing work that uses scanner data.

The rest of the paper proceeds as follows. Section 2 presents the model and its main theoretical results. Section 3 uses survey evidence to estimate the parameters of the reference-dependent demand system. Section 4 examines macroeconomic dynamics and welfare costs in the baseline New Keynesian model with reference dependence. Section 5 quantifies aggregate and distributional welfare losses during the 2021–2023 U.S. inflation surge using the HANK model. Section 6 concludes.

2 A New Keynesian Model with Reference-Dependent Demand

In this section, I show that reference-dependent demand generates a first-order welfare cost of inflation in an otherwise standard New Keynesian model. The gap between posted and reference prices enters the CES consumption aggregator as a taste shifter, with reference prices formed from past posted prices. Holding a variety's posted price fixed, a lower reference price makes the purchase a worse deal, reducing both demand and utility. Firms face Rotemberg adjustment costs and internalize how current prices affect future reference prices and demand. I show that a second-order approximation of household utility around the zero-inflation steady state contains a new term linear in the gap between posted and reference prices. Intuitively, prices above references reduce the consumption utility delivered by a given physical bundle, so maintaining consumption utility requires more output and labor. The welfare loss is greater when demand is more sensitive to reference prices and when reference prices update more slowly.

2.1 Reference-Dependent Demand

There is a unit mass of differentiated goods indexed by $i \in [0,1]$. Good i has a posted price $P_t(i)$ and a reference price $R_t(i)$, the benchmark the consumer uses to assess how good a deal the variety offers.

Let $C_t(i)$ denote physical consumption of variety i. Following Sibly (2002) and Ahrens et al. (2017), I define the consumption composite C_t^U using a reference-dependent CES (RD–CES) aggregator with variety-specific taste shifters $s_t(i)$ that depend on the gaps between posted and reference prices:

$$
\begin{aligned}
C_t^U &= \left[\int_0^1 s_t(i)^{1/\varepsilon} C_t(i)^{(\varepsilon-1)/\varepsilon}\,\mathrm{d}i\right]^{\varepsilon/(\varepsilon-1)}, \qquad \varepsilon > 1, \\
s_t(i) &= \begin{cases} \left[\dfrac{P_t(i)}{R_t(i)}\right]^{-\Gamma_L}, & P_t(i) \geq R_t(i), \\ \left[\dfrac{P_t(i)}{R_t(i)}\right]^{-\Gamma_G}, & P_t(i) < R_t(i). \end{cases}
\end{aligned}
\tag{2.1}
$$

The parameters Γ_L and Γ_G govern reference-dependent demand when posted prices are above and below reference prices, respectively. For $\Gamma_L > 0$, purchases at posted prices above their reference prices are perceived as worse deals. The aggregator captures this by assigning a lower consumption composite C_t^U, and hence less consumption utility, for a given physical consumption bundle $\{C_t(i)\}_i$. Appendix A.1 provides a transaction-utility microfoundation for the relative demands implied by this aggregator.[3]

Taking posted prices and reference prices as given, the household chooses quantities $\{C_t(i)\}_i$ to minimize the expenditure required to attain a given level of C_t^U. The resulting demand for each variety and the ideal price index are:

$$
\begin{aligned}
C_t(i) &= s_t(i)\left(\frac{P_t(i)}{P_t^{\mathrm{RD}}}\right)^{-\varepsilon} C_t^U, \\
P_t^{\mathrm{RD}} &= \left[\int_0^1 s_t(i) P_t(i)^{1-\varepsilon}\,\mathrm{d}i\right]^{1/(1-\varepsilon)}.
\end{aligned}
\tag{2.2}
$$

The ideal price index P_t^{RD} measures the expenditure required to obtain one unit of the consumption composite C_t^U.

The parameters Γ_L and Γ_G are the reference-price elasticities of demand, holding the variety's posted price fixed. When a variety's posted price exceeds its reference, a 1% reduction in the reference price makes the purchase a worse deal and lowers demand by approximately Γ_L%. When the posted price lies below its reference, a 1% increase in the reference price makes

[3] This construction uses the link between discrete-choice models and CES demand (Anderson et al., 1989), incorporating transaction utility as in Thaler (1985).

the purchase a better deal and raises demand by approximately $\Gamma_G\%$.

Reference dependence also changes how demand responds to the posted price. In the standard CES model, the own-price elasticity is ε. Here, a higher posted price also makes the purchase a worse deal relative to its reference price. Holding the reference price fixed, the absolute own-price elasticity is therefore $\varepsilon + \Gamma_L$ when the posted price exceeds its reference and $\varepsilon + \Gamma_G$ when it lies below. These elasticities are evaluated holding the aggregate price index P_t^{RD} and consumption composite C_t^U fixed.

Reference prices are formed from past posted prices:

$$R_{t+1}(i) = R_t(i)^{\rho} P_t(i)^{1-\rho} e^{\bar{\pi}}, \qquad \rho \in [0, 1). \tag{2.3}$$

Here $\bar{\pi}$ denotes trend inflation. The factor $e^{\bar{\pi}}$ makes posted and reference prices coincide in any steady state with constant inflation $\bar{\pi}$, so only departures from trend inflation open gaps between them. I set $\bar{\pi} = 0$ throughout. In logs, the reference price is therefore an exponentially weighted average of past posted prices. It equals last period's posted price when $\rho = 0$ and adjusts more slowly as ρ rises.

To understand the effect of reference-dependent demand on the ideal price index, let P_t denote the conventional CES price index. For the remainder of this section, I assume all varieties share a common posted price, $P_t(i) = P_t$, and reference price, $R_t(i) = R_t$.[4] With lowercase letters denoting natural logs, the common taste shifter when $P_t > R_t$ is

$$s_t = e^{-\Gamma_L(p_t - r_t)} = e^{-(\varepsilon-1)\chi_t}, \qquad \chi_t \equiv \frac{\Gamma_L}{\varepsilon - 1}(p_t - r_t). \tag{2.4}$$

This yields the following result.

Lemma 1 (The ideal RD–CES price index)**.** *Suppose all varieties share a common posted price P_t and a common reference price R_t, with $P_t > R_t$. Then the ideal price index satisfies*

$$P_t^{\mathrm{RD}} = P_t e^{\chi_t}, \qquad p_t^{\mathrm{RD}} = p_t + \chi_t. \tag{2.5}$$

The reference wedge χ_t is the log difference between the ideal price index under reference-dependent demand and the conventional CES price index. When $\Gamma_L > 0$, posted prices above their references make purchases worse deals, so a given physical bundle delivers a lower consumption composite C_t^U and hence lower utility. Attaining the same consumption composite consequently requires greater expenditure, so $P_t^{\mathrm{RD}} > P_t$. Without reference dependence, the two indices coincide. For $P_t < R_t$, the same price-index relationship holds with $\chi_t = \Gamma_G(p_t - r_t)/(\varepsilon - 1)$.[5]

[4] This corresponds to a symmetric equilibrium of the Rotemberg model introduced below, with identical firms and common initial posted and reference prices.

[5] When posted and reference prices differ across varieties, the relationship in Lemma 1 holds to first order

2.2 The Intertemporal Household Problem

The intratemporal problem implies that expenditure on the consumption composite C_t^U is $P_t^{\mathrm{RD}} C_t^U$. The household chooses consumption, labor supply, and saving in an otherwise standard intertemporal problem, taking the ideal price index as given.

Given initial bond holdings B_0, the representative household maximizes expected lifetime utility subject to its budget constraint and a no-Ponzi condition:

$$\begin{aligned} \max_{\{C_t^U, N_t, B_{t+1}\}_{t=0}^{\infty}} \quad & \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{(C_t^U)^{1-\sigma} - 1}{1-\sigma} - \frac{N_t^{1+\varphi}}{1+\varphi} \right] \\ \text{s.t.} \quad & P_t^{\mathrm{RD}} C_t^U + Q_t B_{t+1} \leq B_t + W_t N_t + D_t^F + T_t, \qquad t \geq 0, \\ & \liminf_{T \to \infty} \left(\prod_{s=0}^{T} Q_s \right) B_{T+1} \geq 0. \end{aligned}$$

Here $\beta \in (0,1)$, $\sigma \geq 1$, and $\varphi \geq 0$, with the usual logarithmic limit at $\sigma = 1$. The variable Q_t is the price of a one-period nominal bond, W_t is the nominal wage, D_t^F denotes distributed firm profits, and T_t denotes lump-sum transfers net of taxes. Bonds are in zero net supply.

Let $I_t \equiv Q_t^{-1}$ denote the gross nominal interest rate. Consider a deterministic zero-inflation steady state, where posted and reference prices coincide and $\bar{I} = 1/\beta$. I normalize the initial steady-state price level to one, $\bar{P} = \bar{R} = 1$. For the analysis that follows, every lowercase variable denotes the log deviation of its level counterpart from this initial steady state, so p_t and r_t are also the natural logs of posted and reference prices, and $i_t \equiv \log(I_t/\bar{I})$. To first order, the Euler equation is

$$c_t^U = \mathbb{E}_t c_{t+1}^U - \frac{1}{\sigma} \left(i_t - \mathbb{E}_t \pi_{t+1} \right) + \frac{1}{\sigma} \left(\mathbb{E}_t \chi_{t+1} - \chi_t \right), \tag{2.6}$$

where $\pi_{t+1} \equiv p_{t+1} - p_t$ is posted-price inflation.[6] Holding all else constant, an increase in the reference wedge χ_t, the scaled gap between posted and reference prices, lowers the consumption utility delivered by a given physical bundle today. The Euler equation then implies a lower current consumption composite C_t^U.

Around the same steady state, the labor-supply condition is

$$w_t - p_t = \sigma c_t^U + \varphi n_t + \chi_t. \tag{2.7}$$

around a symmetric allocation with posted prices equal to reference prices:

$$p_t^{\mathrm{RD}} - p_t \approx \int_0^1 \chi_t(i) \, \mathrm{d}i, \qquad \chi_t(i) \equiv -\frac{\log s_t(i)}{\varepsilon - 1}.$$

[6] By Lemma 1, inflation in the ideal price index satisfies $\pi_{t+1}^{\mathrm{RD}} = \pi_{t+1} + \chi_{t+1} - \chi_t$. The household's real return to saving therefore depends on inflation in the price of the consumption composite.

At a given posted real wage and fixed hours, a higher reference wedge reduces how much of the consumption composite wage income can buy.

2.3 Firms and Inflation Dynamics

Firms set prices facing reference-dependent demand and Rotemberg adjustment costs. When $\Gamma_L > \Gamma_G$, demand is kinked at the reference price, making the firm's pricing problem nonsmooth. To build intuition about how reference-dependent demand affects firms' pricing decisions, I first consider the smooth case, $\Gamma_L = \Gamma_G \equiv \Gamma$. Appendix B extends the results to the kinked case, $\Gamma_L > \Gamma_G$.

Firm i is owned by the household and produces physical output $Y_t(i)$ of variety i. Let Y_t^U aggregate these quantities using the RD–CES aggregator in (2.1). Taking aggregate variables and initial conditions $R_0(i)$ and $P_{-1}(i)$ as given, firm i chooses its price sequence to maximize the present discounted value of profits:[7]

$$\begin{aligned}
\max_{\{P_t(i)\}_{t=0}^{\infty}} \quad & \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \frac{\Lambda_t}{P_t^{\mathrm{RD}}} \left[P_t(i) Y_t(i) - (1-\tau) W_t N_t(i) - \frac{\psi_p}{2} \left(\frac{P_t(i)}{P_{t-1}(i)} - 1 \right)^2 P_t^{\mathrm{RD}} Y_t^U \right] \\
\text{s.t.} \quad & Y_t(i) = \left(\frac{P_t(i)}{R_t(i)} \right)^{-\Gamma} \left(\frac{P_t(i)}{P_t^{\mathrm{RD}}} \right)^{-\varepsilon} Y_t^U, \\
& Y_t(i) = A_t N_t(i)^{1-\alpha}; \qquad R_{t+1}(i) = R_t(i)^{\rho} P_t(i)^{1-\rho}.
\end{aligned}$$

Here $\Lambda_t \equiv (C_t^U)^{-\sigma}$ is marginal utility of the consumption composite, $\alpha \in [0, 1)$ governs returns to labor, τ is an employment subsidy, and $\psi_p \geq 0$ governs price-adjustment costs, which are incurred in units of the consumption composite.[8] At a symmetric equilibrium, define nominal marginal cost relative to the posted price:

$$mc_t \equiv \frac{(1-\tau) W_t}{P_t \mathrm{MPL}_t}, \tag{2.8}$$

where MPL_t is the marginal product of labor.

The reference price is an additional state variable, so optimality also requires a costate condition. Let Θ_t denote the shadow value of the reference price: the additional firm value from a marginal proportional increase in that price, normalized by $\Lambda_t Y_t^U$. It satisfies

$$\Theta_t = \Gamma(1 - mc_t) + \beta\rho\, \mathbb{E}_t \left[\mathcal{M}_{t+1} \Theta_{t+1} \right], \tag{2.9}$$

where $\mathcal{M}_{t+1} \equiv \Lambda_{t+1} Y_{t+1}^U / (\Lambda_t Y_t^U)$. Holding the posted price fixed, a 1% higher reference price raises sales by approximately Γ%, with a profit margin $1 - mc_t$ on those additional sales. A

[7] Posted prices satisfy $P_t(i)/P_t \in [1/K, K]$ for some finite $K > 1$. These bounds are slack under symmetry and, together with the bounds on aggregate paths in Assumption A.3, ensure that firm value is finite.

[8] Under symmetry, $P_t^{\mathrm{RD}} Y_t^U = P_t Y_t$, so these costs can equivalently be expressed in units of physical output Y_t.

fraction ρ of this increase carries into tomorrow's reference price; the second term captures its discounted value to the firm.[9]

Let $\Pi_t \equiv P_t/P_{t-1}$ denote gross posted-price inflation. At an interior optimum, the firm's exact price-setting condition is

$$\psi_p\Big[(\Pi_t-1)\Pi_t-\beta\mathbb{E}_t\{\mathcal{M}_{t+1}(\Pi_{t+1}-1)\Pi_{t+1}\}\Big]=(\varepsilon+\Gamma)mc_t-(\varepsilon+\Gamma-1)+\beta(1-\rho)\mathbb{E}_t[\mathcal{M}_{t+1}\Theta_{t+1}]. \tag{2.10}$$

Relative to the standard Rotemberg model, reference dependence changes the optimal pricing condition in two ways. First, with reference prices predetermined, firms face a higher static demand elasticity, $\varepsilon+\Gamma$ rather than ε. Second, a fraction $1-\rho$ of today's proportional price increase carries into tomorrow's reference price, raising future demand at given posted prices: a benefit valued by Θ_{t+1}. Appendix A.2 gives the derivation.

Steady state and subsidy. At the deterministic zero-inflation steady state, posted and reference prices coincide and price-adjustment costs are zero. Evaluating (2.9) and (2.10) at this steady state yields the effective demand elasticity and gross markup:

$$\varepsilon_{\text{eff}}=\varepsilon+\Gamma\frac{1-\beta}{1-\beta\rho},\qquad \bar{\mu}=\frac{\varepsilon_{\text{eff}}}{\varepsilon_{\text{eff}}-1}. \tag{2.11}$$

A permanent 1% increase in a firm's price reduces its discounted total demand by approximately ε_{eff}%, holding aggregate conditions at steady state. The demand loss initially reflects the elasticity $\varepsilon+\Gamma$, then diminishes as the reference price catches up.[10] I offset the steady-state monopoly distortion with the employment subsidy $1-\tau=1/\bar{\mu}$.

In a symmetric equilibrium, all firms produce the same quantity, so aggregate physical output is $Y_t=Y_t(i)$ for all i. To derive the Phillips curve below, I specialize to log utility, $\sigma=1$, and define $\widetilde{y}_t\equiv y_t-a_t$ as the log deviation of physical output from its technology benchmark.[11] Without reference dependence, $\widetilde{y}_t$ coincides with both the efficient output gap and the natural output gap under the employment subsidy. With one-period reference prices, $\rho=0$, the pricing conditions yield the following Phillips curve.

Proposition 1 (The RD–Rotemberg Phillips curve)**.** *Suppose $\Gamma_L=\Gamma_G\equiv\Gamma$, $\sigma=1$, $\rho=0$, and $\psi_p>0$, with the subsidy $1-\tau=1/\bar{\mu}$. Around the zero-inflation steady state, inflation*

[9] The regularity conditions in Appendix A.2 rule out non-fundamental solutions to the costate recursion and ensure that the firm's transversality conditions hold.

[10] The demand elasticity j periods after the permanent price increase is $\varepsilon+\Gamma\rho^j$, so

$$\varepsilon_{\text{eff}}=(1-\beta)\sum_{j=0}^{\infty}\beta^j(\varepsilon+\Gamma\rho^j)=\varepsilon+\Gamma\frac{1-\beta}{1-\beta\rho}.$$

[11] With log utility, the log deviation of marginal cost is proportional to $\widetilde{y}_t$ to first order; Appendix A.2 derives this relationship.

satisfies, to first order,

$$\pi_t = \beta \mathbb{E}_t \pi_{t+1} + \kappa_{\text{RD}} \left(\widetilde{y}_t - \beta \gamma \, \mathbb{E}_t \widetilde{y}_{t+1} \right), \tag{2.12}$$

where

$$\kappa_{\text{RD}} \equiv \frac{(\varepsilon + \Gamma)(1 + \varphi)}{\psi_p \bar{\mu}(1 - \alpha)}, \qquad \gamma \equiv \frac{\Gamma}{\varepsilon + \Gamma}. \tag{2.13}$$

The higher static demand elasticity makes inflation more responsive to current marginal cost. A persistent cost increase also compresses future profit margins, reducing the value of a higher reference price tomorrow and weakening the incentive to raise today's price, as captured by the negative expected future output-gap term in equation (2.12). Solving the Phillips curve forward for an AR(1) marginal-cost process shows that reference dependence increases pass-through to inflation relative to the standard Rotemberg model, with a smaller percentage increase for more persistent shocks.[12] When $\Gamma = 0$, the standard Rotemberg Phillips curve is recovered.

With $\Gamma_L > \Gamma_G$, one-sided conditions replace the smooth pricing condition (2.10) at the reference price. Under the conditions described in Appendix B.2, the kink generates an inaction band near the zero-inflation steady state: the firm optimally sets $P_t = R_t$ over a range of marginal costs.[13] Within this band, a price increase loses too much demand, while a price cut attracts too few additional sales to offset the lower margin. A sufficiently large increase in marginal costs narrows profit margins, making it profitable to raise the price above the reference despite the larger demand elasticity. The optimal price therefore satisfies the nonlinear pricing condition (2.10), with Γ_L replacing Γ in the current-demand terms. Conversely, a sufficiently large fall in marginal costs makes additional sales more profitable, inducing the firm to cut its price below the reference despite the weaker demand response. The corresponding pricing condition uses Γ_G in the current-demand terms. Appendix B.3 provides the formal pricing conditions and their implications for inflation dynamics.

2.4 Monetary Policy and Equilibrium

Under symmetry, aggregate production and goods-market clearing imply

$$Y_t \equiv \int_0^1 Y_t(i) \, \mathrm{d}i = A_t N_t^{1-\alpha} = e^{\chi_t} Y_t^U, \tag{2.14}$$

$$Y_t^U = C_t^U + \frac{\psi_p}{2} (\Pi_t - 1)^2 Y_t^U. \tag{2.15}$$

[12] With $\widehat{mc}_t$ following an AR(1) process with persistence ρ_m, solving (A.13) forward gives

$$\pi_t = \frac{\varepsilon + \Gamma(1 - \beta\rho_m)}{\psi_p \bar{\mu}(1 - \beta\rho_m)} \widehat{mc}_t.$$

For the same ψ_p, the proportional increase over the standard model, approximately $\Gamma(1 - \beta\rho_m)/\varepsilon$, falls as ρ_m rises.

[13] For a related mechanism of price inaction, see Angelis (2025).

Monetary policy. The central bank responds to posted-price inflation and to the log deviation of physical output from its deterministic steady state:

$$i_t = \phi_\pi \pi_t + \phi_y \log\left(\frac{Y_t}{\bar{Y}}\right) + \nu_t, \qquad \phi_\pi > 0, \quad \phi_y \geq 0. \tag{2.16}$$

Here ν_t is an exogenous monetary-policy shock.

Equilibrium. Given exogenous sequences $\{A_t, \nu_t\}_{t=0}^{\infty}$ and initial conditions $B_0 = 0$, R_0, and P_{-1}, a symmetric equilibrium is a path along which the household's choices solve its intratemporal and intertemporal problems in Sections 2.1 and 2.2, each firm's price sequence maximizes the present discounted value of its profits, reference prices follow (2.3), the nominal interest rate follows (2.16), the government finances the employment subsidy with lump-sum taxes, $T_t = -\tau W_t N_t$, and the bond, labor, and composite-good markets clear, the last through the resource constraint (2.15). With $\Gamma_L = \Gamma_G$, firm optimality implies (2.9) and (2.10). With $\Gamma_L > \Gamma_G$, these conditions hold with the active branch's elasticity away from the reference price, and one-sided conditions replace the pricing equation at the reference price (Appendix B). Appendix A.4 states the definition formally, including the price-aggregation and symmetry conditions.

2.5 Welfare Costs of Inflation under Reference-Dependent Demand

The economy is initially at its deterministic zero-inflation steady state. At time 0, an unanticipated aggregate shock occurs. Its subsequent path is known, and no further shocks arrive, so the economy follows a perfect-foresight transition. I use a standard second-order approximation of household utility around the initial zero-inflation steady state to evaluate the welfare consequences of this transition (Galí, 2015; Woodford, 2003). I measure the discounted lifetime utility loss relative to the no-shock continuation of the initial steady state.

Proposition 2 (Welfare following an unanticipated shock)**.** *Suppose* $\Gamma_L = \Gamma_G \equiv \Gamma$*,* $\sigma = 1$*, and* $\rho = 0$*, with the employment subsidy* $1 - \tau = 1/\bar{\mu}$*. Following an unanticipated shock at time* 0*, the representative household's discounted lifetime utility loss has the second-order expansion*

$$\mathcal{L}_0 = \frac{1}{2}\sum_{t=0}^{\infty} \beta^t \left[\frac{1+\varphi}{1-\alpha}\tilde{y}_t^2 + \frac{2\Gamma}{\varepsilon - 1}\pi_t + \psi_p \pi_t^2\right] + \text{t.i.p.} + O(3). \tag{2.17}$$

Appendix A.3 provides the derivation. As in the standard model, the quadratic output-gap term reflects the consumption–labor trade-off, while the quadratic inflation term captures resources consumed by Rotemberg adjustment costs. Reference-dependent demand adds a term linear in the reference wedge $\chi_t = \Gamma(p_t - r_t)/(\varepsilon - 1)$, which is proportional to the gap between posted and reference prices. With one-period references, this gap equals current inflation.

The aggregation identity (2.14), $Y_t^U = e^{-\chi_t} Y_t$, shows how this wedge enters welfare. When posted prices exceed references, purchases are perceived as worse deals, and a given quantity of physical output delivers fewer units of composite output. Together with goods-market clearing (2.15), this implies a lower consumption composite C_t^U, and hence lower utility, for given physical output and inflation. For a given positive log gap between posted and reference prices, a higher reference-price elasticity Γ implies a larger reduction in the consumption composite and hence a larger first-order welfare loss. Compensating for this loss would require more output and labor. This is the general-equilibrium welfare counterpart of the price-index wedge in Lemma 1. This first-order welfare effect arises even when the employment subsidy eliminates the steady-state monopoly distortion.[14]

With gradual reference-price updating ($\rho > 0$), the utility loss from a price increase can persist even after inflation has subsided. Starting from the zero-inflation steady state, the discounted first-order welfare loss from reference dependence is

$$\sum_{t=0}^{\infty} \beta^t \chi_t = \frac{\Gamma}{(\varepsilon - 1)(1 - \beta\rho)} \sum_{t=0}^{\infty} \beta^t \pi_t. \tag{2.18}$$

Slower updating keeps reference prices below posted prices for longer following a price increase, prolonging the associated utility loss. Holding the inflation path fixed, this amplifies the first-order welfare loss by $1/(1 - \beta\rho)$ relative to one-period references.

Unequal reference-price elasticities preserve this first-order channel: Γ_L governs losses above references, while Γ_G governs gains below them. When $\Gamma_L > \Gamma_G$, equal and opposite log price–reference gaps generate larger losses than gains at first order. The approximation exploits the smoothness of household utility in composite consumption and labor, with the reference wedge entering through the aggregation identity linking physical and composite output. This identity holds on both sides of the kink, so the welfare evaluation along the nonlinear perfect-foresight transition retains the kink. Appendix B.4 extends the approximation to unequal elasticities and general CRRA utility.

3 Survey Design: Estimating Reference-Price Elasticities and Persistence

In this section, I estimate reference-price elasticities and the speed at which reference prices update using hypothetical shopping scenarios in a Prolific survey. Observational purchase data do not record reference prices, and constructing them from past prices can confound their

[14] This differs from Benigno and Woodford (2005), where linear terms in the initial utility expansion arise from steady-state distortions.

effects with shifts in purchases across time.[15] In contrast, the survey directly elicits respondents' reference prices and intended purchases. I then present scenarios in which the posted price equals the respondent's initial reference price but is framed as a temporary deviation from what the product usually costs. Holding the rest of the choice environment fixed, changes in elicited reference prices and purchases relative to baseline identify the reference-price elasticities.

To infer how quickly reference prices update, I use a separate scenario in which I re-elicit respondents' reference prices after they encounter a hypothetical price increase on a single shopping trip.

3.1 Survey Design, Sample, and Reference-Price Descriptives

The survey was administered on Prolific in late April 2026, recruiting 1,501 U.S. respondents.[16] I exclude 69 respondents who fail attention checks or report implausible prices or quantities (see Appendix D.2), leaving 1,432 respondents for the descriptive analysis.

Table 1 compares the sample with the U.S. population aged 18–65 in the American Community Survey (ACS). The sample broadly resembles this population in age, sex, and full- and part-time employment shares. It is slightly younger, with a slightly higher share of women and a somewhat lower share of full-time workers. To address these differences, I also report estimates using weights calibrated to ACS age, sex, and employment benchmarks (see Appendix D.6).

Table 1: Sample Composition and ACS Benchmarks

	Full sample	ACS 2024
Age (years), mean (sd)	38.7 (12.3)	41.0 (13.8)
Sex		
Female	784 (52.5%)	50.3%
Male	698 (46.7%)	49.7%
Prefer not to say	12 (0.8%)	–
Employment status		
Full-time	774 (56.0%)	61.6%
Part-time	191 (13.8%)	13.8%
Student	214 (15.3%)	11.5%

Notes: The sample column covers all respondents in the Prolific sample (N = 1,501). For categorical variables, cells report counts and their shares of responses to the item; for numeric variables, the mean with the standard deviation in parentheses. The ACS column reports the same statistic for U.S. residents aged 18–65 in the 2024 one-year ACS. Dashes indicate rows that do not have an ACS counterpart. Appendix D.6 describes the reweighting to ACS benchmarks.

Respondents begin the survey by naming a product they buy frequently, the package size and the store where they usually buy their chosen product, anchoring the scenarios to a familiar shopping environment. They report the price they typically expect to pay for the product

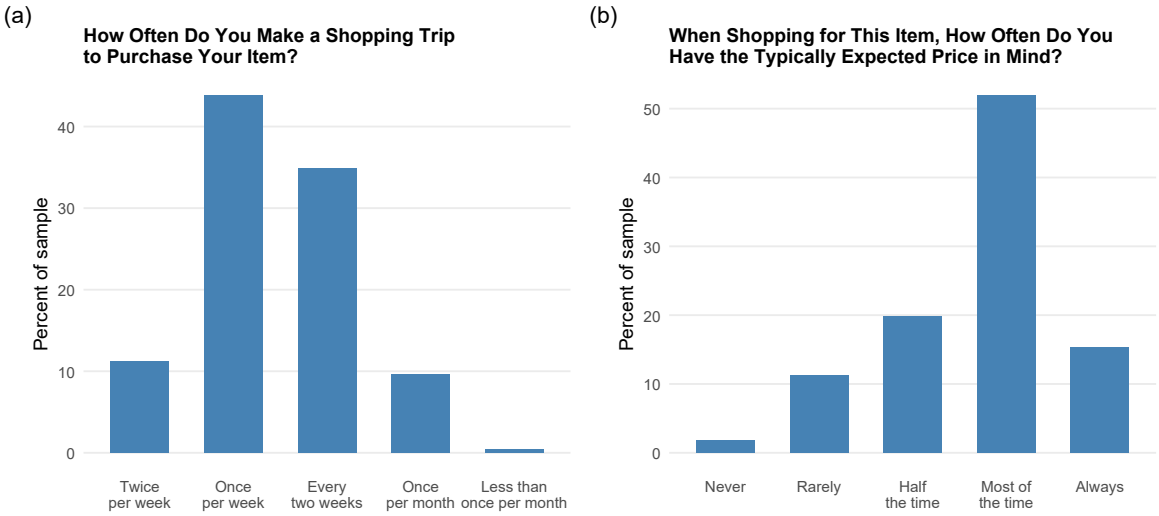
[15] For example, consumers may stock up during a sale and buy less afterward (Hendel and Nevo, 2006). Once the sale ends, the posted price exceeds a reference price constructed by averaging past prices, including the discount, so lower purchases due to earlier stockpiling may be misattributed to reference dependence.

[16] Every question screen is reproduced in Appendix C.

at that store, which I take as their initial reference price (median \$3.99). They also report how much they would buy over the next month at that price (median three units; Appendix Figure D.1 shows both distributions). Appendix Figures C.1–C.3 reproduce these screens.

Ninety percent of respondents shop for their chosen product at least once every two weeks, suggesting that they have a clear sense of the price they typically expect to pay (Figure 1, panel a). Reference prices are also salient when shopping: 67% report having their typically expected price in mind most of the time or always when shopping for the item (panel b). 83% of respondents judge a posted price equal to their reported expected price to be "about right," supporting its interpretation as the benchmark consumers use to evaluate deals (Appendix Table D.4).[17] Eighty-one percent of respondents cite their own past shopping experiences as a factor that influences the price they typically expect to pay (Figure 2). This supports modeling reference prices as backward-looking, as in Section 2.[18]

Figure 1: Purchase Frequency and Reference-Price Salience



Notes: Panel (a): how often respondents make a shopping trip for their chosen item. Panel (b): how often respondents report having the typically expected price in mind when shopping for the item. Sample: $N = 1{,}432$ after baseline exclusions.

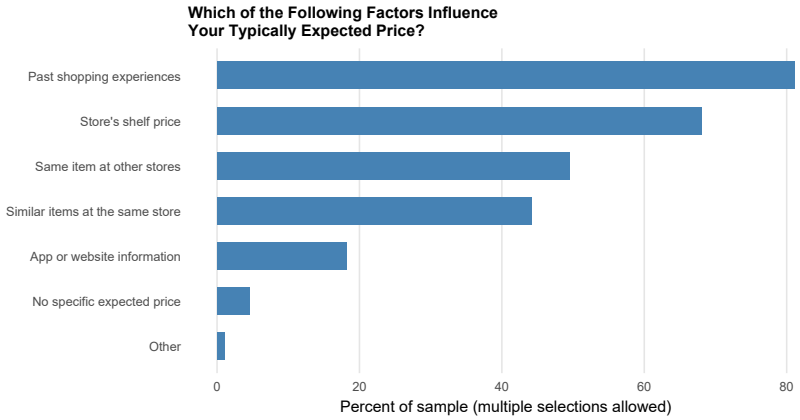
3.2 Identifying the Reference-Price Elasticities

Choice environment and identification. For each respondent i, let f denote the product identified in the survey. This product may differ across respondents but remains fixed across scenarios for a given respondent. Prices and quantities indexed by i refer to this selected

[17] Price expectations need not coincide with the internal reference prices consumers use to evaluate deals (Thomas and Menon, 2007).

[18] An extensive marketing literature constructs internal reference prices from past prices and estimates their effects on demand. For reviews, see Kalyanaram and Winer (1995); Mazumdar et al. (2005).

Figure 2: How Consumers Form Their Reference Prices



Notes: Share of respondents selecting each factor as an influence on the price they typically expect to pay; multiple selections allowed. Sample: $N = 1{,}432$ after baseline exclusions.

product. On each of the M_i monthly purchase occasions, the respondent chooses between this product and the available alternatives. I assume that this choice set is a finite approximation to the continuum of varieties in Section 2. Appendix A.1 shows that, under additional assumptions, this environment delivers the aggregate relative demands implied by equation (2.2). Respondent i's utility from each option on occasion m is:

$$u_{ifm} = \delta_{if} - \varepsilon \log P_i + \Gamma_b \log\left(\frac{R_i}{P_i}\right) + \xi_{ifm}, \qquad u_{ijm} = \delta_{ij} + \xi_{ijm}, \quad j \neq f,$$
$$\Gamma_b = \begin{cases} \Gamma_L, & P_i \geq R_i, \\ \Gamma_G, & P_i < R_i. \end{cases} \tag{3.1}$$

Here, P_i is the posted price respondent i faces for product f next month and R_i is their reference price for that product. The terms δ_{if} and δ_{ij} capture respondent-specific components of mean utility. The term $\Gamma_b \log(R_i/P_i)$ captures transaction utility (Thaler, 1985), reflecting the respondent's evaluation of the deal relative to their reference price. When P_i exceeds R_i, the purchase is perceived as a loss and carries a utility cost. The taste shocks ξ_{ijm} are i.i.d. standard Type I extreme-value draws across alternatives and purchase occasions, yielding logit choice probabilities. Expected monthly purchases of f equal M_i times its choice probability.

Let R_{i0} denote respondent i's baseline reference price. At baseline, $P_i = R_{i0}$, so transaction utility is zero. Increasing P_i while holding $R_i = R_{i0}$ combines the conventional price effect, governed by ε, with the transaction-utility effect, governed by Γ_L. By contrast, a scenario with a lower reference price, $R_i < R_{i0}$, holding $P_i = R_{i0}$ and the rest of the choice environment fixed, affects choice *only* through the perceived deal. The following proposition formalizes this argument.

Proposition 3 (Identification of reference-price elasticities)**.** *Under the choice model above, suppose the posted price is fixed at the baseline reference price, $P_i = R_{i0}$, and the mean-utility components $\{\delta_{ij}\}_j$ and number of purchase occasions M_i remain unchanged.*

Let q_{i0} and q_{ib} denote purchases of f at reference prices R_{i0} and R_{ib}, respectively, where $b \in \{L, G\}$ and $R_{iL} < R_{i0} < R_{iG}$. Let ω_i denote the baseline choice probability of f. For each b,

$$\lim_{\omega_i \to 0} \frac{\mathbb{E}[q_{ib}]}{\mathbb{E}[q_{i0}]} = \left(\frac{R_{ib}}{R_{i0}}\right)^{\Gamma_b}. \tag{3.2}$$

Appendix D.1 provides the derivation. With the posted price and the rest of the choice environment fixed, quantity responses to exogenous reference-price shifts below R_{i0} identify Γ_L, while responses to shifts above R_{i0} identify Γ_G.[19]

Hypothetical shopping scenarios. To implement this design, I present each respondent with two hypothetical shopping scenarios involving the product, package size, and store they have already identified. Both scenarios keep next month's posted price equal to the respondent's baseline reference price. Respondents are instructed to hold their income and the prices of other goods fixed. The scenarios differ in what the product usually costs, framing the same posted price as a temporary increase in the loss scenario and a temporary discount in the gain scenario.

Consider the following loss-scenario question for a respondent whose baseline reference price is \$5:

> Reminder: Item = Clover Organic Whole Milk, Unit size = Half-Gallon, Usual store = Target.
>
> Assume that at your usual store (Target), the price of this item is **usually \$4 per unit.**
>
> **Next month only**, the price will temporarily increase to **\$5** per unit.
>
> **After next month, the price will return to \$4 per unit.** Assume your income and the prices of other goods stay the same. Please answer based only on how much you would want to buy for next month's use at that price. Ignore any possibility of buying extra to use later or delaying purchases to a later month.
>
> Recall that one unit is: Half-Gallon.
>
> How many units would you buy next month at **\$5 per unit at your usual store?** (Enter a number up to one decimal place; 0 is allowed.)

The scenario is designed so that respondents view the \$5 purchase as a worse deal when it is framed as a temporary price increase. The next screen restates this price path and asks: "What price per unit would you typically expect to pay for this item after next month?" I use

[19] The small-ω_i approximation treats the choice set as a counterpart to the continuum of varieties in Section 2. For $\omega_i > 0$, the approximation in Proposition 3 yields a lower bound on Γ_b.

this response as the respondent's reference price in the loss scenario. Figure 3 illustrates the scenario.

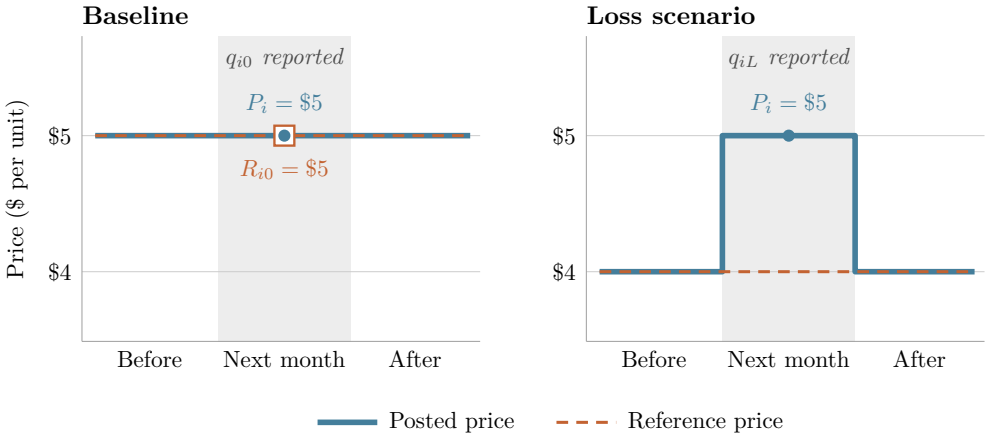
In the gain scenario, the same respondent is told that the product usually costs \$6, will be on sale for \$5 next month, and will return to \$6 afterward. They then report how many units they would buy next month at \$5, followed by the price they would typically expect to pay after next month.

Across respondents, the percentage gap between the baseline reference price and the scenario's usual price is randomly assigned to be 12%, 20%, or 28%. Randomizing the gap while holding the posted price and the rest of the choice environment fixed generates exogenous variation in elicited reference prices, which I use to estimate the reference-price elasticities. In the example above, a usual price of \$4.40 rather than \$4 would make next month's \$5 price a smaller increase, so the purchase may seem less unfavorable and induce a smaller reduction in intended purchases. Conversely, a usual price of \$3.60 frames \$5 as a larger increase, potentially inducing a larger drop in intended purchases as respondents perceive a worse deal. Consistent with this prediction, larger assigned gaps in the loss scenario, on average, induce larger reductions in intended purchases (Appendix Table D.3, Panel A).

Respondents are also instructed to report purchases for next month's use only. These instructions are intended to align reported purchases with next month's consumption, consistent with the model.

For each respondent, the same assigned percentage places the usual price below baseline in the loss scenario and above baseline in the gain scenario. The order of the loss and gain scenarios is randomized. The question screens are reproduced in Appendix Figures C.4–C.7.

Figure 3: Illustration of the Loss Scenario

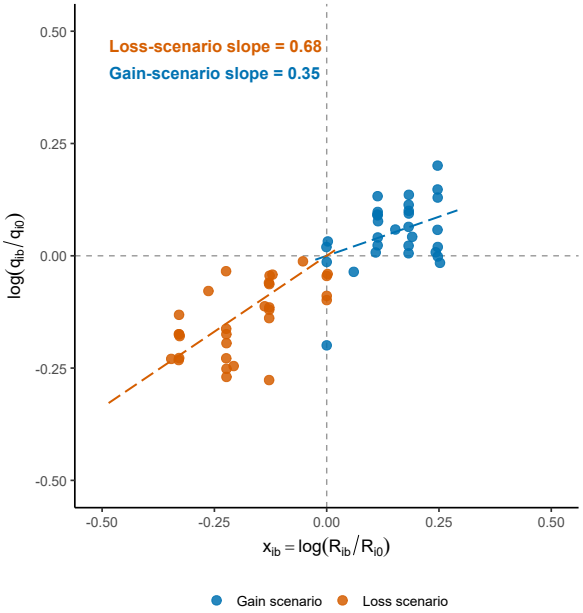


Notes: The dashed line illustrates a respondent whose reported reference price equals the usual price.

Figure 4 plots purchases against reference prices in both scenarios, with each variable expressed as a log change from the respondent's baseline. With the posted price held fixed,

a lower reference price discourages purchases more strongly than a higher reference price encourages them.

Figure 4: Demand Responses to Reference-Price Shifts



Notes: Binned means (30 equal-frequency bins per scenario) of the log quantity response $\log(q_{ib}/q_{i0})$ against the elicited reference-price gap $x_{ib} = \log(R_{ib}/R_{i0})$, where R_{ib} is the reference price elicited in scenario b and R_{i0} the baseline reference price, which equals the posted price. The dashed lines represent least-squares fits to the individual responses in each scenario, with the intercepts fixed at zero. The sample applies the baseline exclusions and reference-price filter and excludes observations with zero reported purchases (loss $N = 1{,}182$; gain $N = 1{,}212$).

Estimation. Let $x_{ib} = \log(R_{ib}/R_{i0})$ denote the change in respondent i's elicited reference price relative to baseline in scenario b. Under the small-share approximation in Proposition 3, expected purchases satisfy:

$$\mathbb{E}[q_{ib} \mid q_{i0}, x_{ib}] = q_{i0} \exp(\Gamma_b x_{ib}) \,. \tag{3.3}$$

I estimate this restriction by Poisson pseudo-maximum likelihood, separately for the loss and gain scenarios. This estimator is a natural choice for quantity responses recorded as counts.[20] The restriction further imposes that when the respondent's reference price is unchanged, expected purchases should not differ from baseline.

Imperfect understanding of the hypothetical scenarios or lapses in attention may introduce measurement error into elicited reference prices, which could bias the estimated elasticities. This measurement error may also depend on presentation order. Completing the first scenario

[20]The Poisson estimator is consistent when the conditional mean is correctly specified; quantities need not follow a Poisson distribution (Gourieroux et al., 1984; Santos Silva and Tenreyro, 2006).

may help respondents understand the second, while fatigue may reduce their attention. I therefore instrument x_{ib} with the randomly assigned log ratio of the scenario's usual price to the baseline reference price, denoted by z_{ib}. The exclusion restriction holds if z_{ib} affects purchases only through the respondent's reference price.

I implement this instrumental-variable strategy with a control function (Wooldridge, 2015). Let $O_{ib} = 1$ indicate that scenario b is presented first. The first stage is:

$$x_{ib} = \pi_0 + \pi_1 z_{ib} + \pi_O O_{ib} + \pi_{zO} O_{ib} z_{ib} + v_{ib}. \tag{3.4}$$

This specification allows the first-stage intercept and slope to vary by presentation order. Let $\hat{v}_{ib}$ denote the first-stage residual, capturing variation in x_{ib} not explained by the assigned gap z_{ib} or presentation order.

In the second stage, I include $\hat{v}_{ib}$ and its interaction with presentation order in the Poisson regression:

$$\mathbb{E}[q_{ib} \mid q_{i0}, x_{ib}, \hat{v}_{ib}, O_{ib}] = q_{i0} \exp(\Gamma_b x_{ib} + \delta \hat{v}_{ib} + \delta_O O_{ib} \hat{v}_{ib}) \,. \tag{3.5}$$

Under the control-function assumptions, controlling for $\hat{v}_{ib}$ allows Γ_b to be identified from variation in x_{ib} induced by the randomly assigned price gap z_{ib}.

I apply an additional filter that restricts elicited scenario reference prices to the ranges described in Appendix D.2.[21] The filter leaves 1,238 loss-scenario and 1,223 gain-scenario observations. I compute standard errors for the control-function estimates using a respondent-level bootstrap with 1,000 replications (Appendix D.3).

Main estimates. Panels A and B of Table 2 report estimates of Γ_L and Γ_G, respectively. Column (1) reports Poisson pseudo-maximum-likelihood estimates without the control function. Column (2) presents control-function estimates without correcting for the order in which the scenarios are presented. Column (3), the preferred specification, allows the first-stage intercept and slope and the second-stage residual coefficient to vary by presentation order. Column (4) re-estimates this specification using weights calibrated to match ACS demographic benchmarks.

The preferred specification in column (3) yields $\hat{\Gamma}_L = 0.875$ and $\hat{\Gamma}_G = 0.326$. At baseline, the posted price equals the reference price. Holding the posted price fixed, the estimates imply that a 1% reduction in the reference price lowers expected purchases by approximately 0.9%, while a 1% increase raises them by approximately 0.3%. Reweighting the sample to match ACS demographics has little effect on the estimated loss-side elasticity. In a joint specification on the balanced sample, the difference between Γ_L and Γ_G is statistically significant at the 1% level (Appendix Table D.5). The estimated loss-side elasticity is approximately 2.7 times the gain-side elasticity. This asymmetry is broadly consistent with experimental evidence on loss

[21] In the loss scenario, for example, reference prices substantially above the baseline reference price suggest a misunderstanding of the stated return to a lower usual price after next month.

aversion (Tversky and Kahneman, 1992).

Table 2: One-Sided Reference-Price Elasticities

	PPML (1)	CF (2)	CF + Order (3)	CF + Order (ACS wt.) (4)
		Panel A. Loss side (Γ_L)		
$\hat{\Gamma}_L$	0.788***	0.873***	0.875***	0.933***
	(0.084)	(0.095)	(0.097)	(0.131)
Respondents	1,238	1,238	1,238	1,187
First-stage F		751.7	375.6	338.1
		Panel B. Gain side (Γ_G)		
$\hat{\Gamma}_G$	0.347***	0.324***	0.326***	0.310**
	(0.105)	(0.108)	(0.109)	(0.141)
Respondents	1,223	1,223	1,223	1,174
First-stage F		523.6	262.0	264.3

Notes: Poisson pseudo-maximum likelihood of equation (3.3), with $\log q_{i0}$ as offset and no intercept, after the baseline exclusions and the reference-price screen described in Appendix D.2. Column (1) treats the elicited gap as exogenous and reports respondent-clustered standard errors. Columns (2)–(4) add the control function of equation (3.5), with the randomized gap as instrument; column (2) omits the presentation-order terms, and column (4) re-estimates column (3) with weights calibrated to the 2024 ACS population ages 18–65 (Appendix D.6), on the respondents inside the calibration universe. Columns (2)–(4) report respondent-level bootstrap standard errors (1,000 replications). $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.10$.

Robustness. Appendix Tables D.6 and D.7 report elasticity estimates across several specifications and sample restrictions. Estimates of Γ_L, which governs the first-order welfare loss from reference dependence during inflationary episodes (as discussed in Section 2), remain broadly stable, ranging from 0.69 to 1.03 across the checks in column (3). I restrict the sample to respondents whose baseline price feels "about right," since this assessment is consistent with zero transaction utility at baseline, as assumed in the identification argument. This restriction leaves the loss-side estimate almost unchanged ($\hat{\Gamma}_L = 0.864$). Allowing for an intercept and order-specific level controls relaxes the restriction that purchases equal baseline purchases when the reference price is unchanged, yielding $\hat{\Gamma}_L = 0.789$. Restricting the sample to perishable products, for which stockpiling is less feasible, yields $\hat{\Gamma}_L = 0.766$.[22] Log-linear 2SLS, which changes the functional form and excludes zero purchases, yields $\hat{\Gamma}_L = 0.732$. Allowing the elasticities to vary by presentation order checks for sensitivity to learning or fatigue; neither difference is statistically significant at the 5% level in the control-function specifications. Estimates of Γ_G remain positive in most specifications, although their magnitude and statistical significance are more sensitive to the specification and sample restrictions.

Appendix E describes an alternative empirical design that estimates reference-price elasticities using observational data from NielsenIQ Retail Measurement Services (RMS). The

[22] Products are classified as perishable based on respondents' own assessments.

analysis covers 22 product categories selected to align with respondents' product choices in the survey. While the scanner specification includes post-sale indicators, subsequent declines in purchases might vary with the depth of the discount and unobserved household-level inventories. With these caveats in mind, the average estimate of Γ_L across categories is 0.900, while the expenditure-weighted average is 0.761 (Appendix Tables E.1 and E.2). Both are similar in magnitude to the survey estimate of 0.875. The expenditure-weighted estimate of Γ_G is 1.117 (Appendix Table E.2), substantially above the survey estimate of 0.326. This difference is consistent with stockpiling during temporary discounts: scanner purchases can reflect inventory accumulation, whereas the survey asks about purchases for next month's use.

3.3 Reference-Price Updating

To estimate the speed at which reference prices update, respondents consider a scenario in which the price of their product has been equal to their baseline reference price on recent shopping trips and rises by 20% on the next trip. A randomly selected half report the price they would typically expect to pay on subsequent shopping trips (Appendix Figure C.10), while the other half report the price that would feel normal, defined as neither too high nor too low (Appendix Figure C.11).

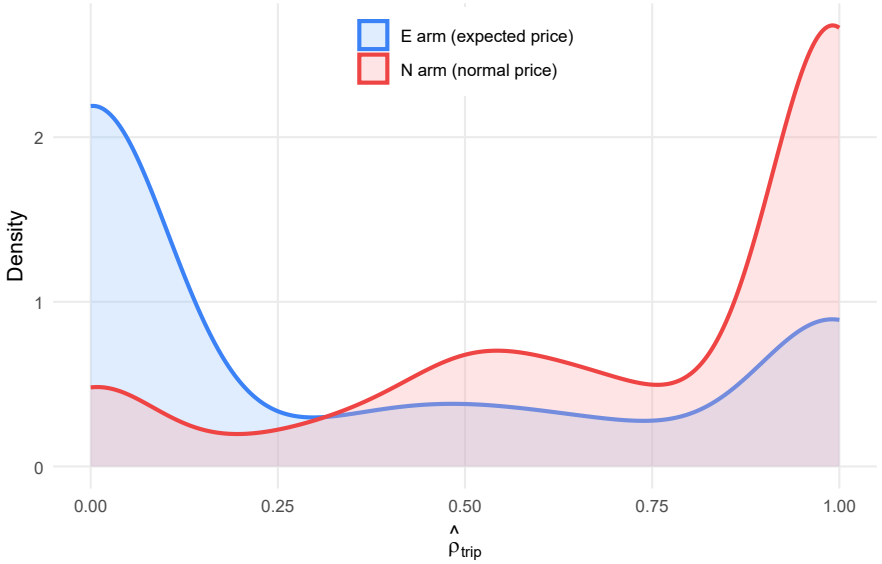
Inverting the reference-price law of motion in equation (2.3) yields a trip-level estimate of the updating parameter ρ for each respondent, with higher values indicating slower updating. Figure 5 shows the distribution of these estimates separately for the two questions. Among respondents who report expected prices, many have estimates near zero, indicating nearly full adjustment after one shopping trip. Among those who report normal prices, estimates are more concentrated near one, indicating little adjustment. Mean trip-level estimates are 0.33 for expected prices and 0.74 for normal prices.

A follow-up question asks respondents who reported price expectations how the higher price would feel after a month. Among respondents who judged their baseline price to be "about right" and whose price expectations had adjusted to the new price after one shopping trip, 76% say that the higher price would still feel too high after a month (Appendix Table D.4, Panel B). These responses suggest that consumers can expect to pay the higher price while still viewing the purchase as a bad deal. The normal-price estimate therefore serves as the baseline for the quantitative analysis.

I convert these estimates to the quarterly level using each respondent's reported shopping frequency (Figure 1, panel a) and then average across respondents. The resulting quarterly estimates are 0.53 for the normal-price question and 0.22 for the expected-price question. The normal-price estimate implies that approximately 47% of the log price gap closes within one quarter. Table 3 reports the quarterly estimates by shopping frequency, together with the ACS-weighted estimates.

Taken together, the survey estimates indicate that, holding the posted price fixed, a decrease

Figure 5: Distribution of the Trip-Level Reference-Price Updating Parameter



Notes: Kernel densities of respondent-level trip persistence by randomized question, restricted to $\hat{\rho}_{\text{trip},i} \in [0, 1]$. A value of 0 means the reference moves fully to the new posted price after one trip; 1 means it does not move. The expected-price question (E arm) has $N = 651$; the normal-price question (N arm) has $N = 629$.

Table 3: Quarterly Reference-Price Updating

	Expected-price question		Normal-price question	
Shopping frequency	N	Mean $\hat{\rho}_{\text{qtr}}$	N	Mean $\hat{\rho}_{\text{qtr}}$
Twice per week	73	0.192	63	0.608
Once per week	281	0.215	289	0.509
Every two weeks	235	0.222	208	0.534
Once per month	57	0.237	68	0.540
Overall	646	0.217	628	0.531
Overall (ACS-weighted)	617	0.211	607	0.544

Notes: Quarterly persistence is calculated using each respondent's reported shopping frequency and then averaged across respondents. Sample restrictions and frequency mappings appear in Appendix D.5; ACS weighting is described in Appendix D.6.

in the reference price reduces purchases more than an equal-sized increase raises them. Reference prices also adjust gradually following a price increase. The preferred estimates are $\Gamma_L = 0.87$, $\Gamma_G = 0.33$, and a quarterly updating parameter of $\rho = 0.53$. In the model of Section 2, the loss-side elasticity governs the strength of the first-order welfare effect, while the speed of updating determines how long reference prices lag behind posted prices. The next section uses these estimates to quantify the welfare costs of inflationary episodes and compare them with those implied by the standard model.

4 Quantitative analysis

I use the survey estimates to calibrate the model with reference dependence and compare welfare losses with those in the standard New Keynesian model. In each model, I scale cost-push shocks to generate a 1% peak in quarterly inflation. Under the baseline calibration, the consumption-equivalent loss is 4.3 times as large, with the first-order cost accounting for approximately 79% of the total loss. Reference dependence accounts for a bigger share of welfare losses for smaller shocks. For larger inflationary episodes, the second-order terms in the welfare expansion grow relative to the first-order loss from reference dependence.

4.1 Environment

The model is the same as in Section 2, with the parameters governing reference dependence taken from the survey estimates in Section 3 (hereafter RD-RANK). I compare the welfare costs of inflation in this economy with those in the standard representative-agent New Keynesian model (RANK), obtained by setting both reference-price elasticities to zero. I also allow for interest-rate smoothing in the monetary-policy rule. Appendix F contains all the equilibrium conditions.

Starting at the deterministic zero-inflation steady state, I consider an unanticipated proportional increase in firms' marginal costs. Firms face real marginal cost $z_t \equiv \upsilon_t mc_t$, where mc_t is defined in Section 2 and the cost-push factor υ_t follows

$$\log \upsilon_t = \rho_u \log \upsilon_{t-1} + \varepsilon_t^u, \qquad \rho_u = 0.90, \tag{4.1}$$

with $\upsilon_t = 1$ in steady state. The innovation occurs once, and its subsequent effects are fully anticipated.

The survey estimates identify a larger reference-price elasticity for losses than for gains, $\Gamma_L > \Gamma_G$, creating a kink in demand at the firm's reference price. As discussed in Section 2, this kink can make it optimal for the firm to set its posted price equal to the reference price over a range of marginal costs. To characterize the firm's optimal pricing decisions in this setting, let $\mathcal{D}_t^+$ and $\mathcal{D}_t^-$ denote the right and left derivatives of its dynamic pricing objective with respect to its current log posted price.[23] The pricing conditions in symmetric equilibrium are:

$$\begin{aligned} P_t > R_t: &\quad \mathcal{D}_t^+ = 0, \\ P_t < R_t: &\quad \mathcal{D}_t^- = 0, \\ P_t = R_t: &\quad \mathcal{D}_t^+ \leq 0 \leq \mathcal{D}_t^-. \end{aligned} \tag{4.2}$$

When $P_t \neq R_t$, the pricing and costate conditions take the form of equations (2.9)–(2.10),

[23] The derivatives are normalized by $\Lambda_t Y_t^U$; their expressions at $P_t = R_t$ are given in Appendix B.2.

Table 4: Baseline quarterly calibration

Parameter	Symbol	Value	Source or target
Discount factor	β	0.99	Standard quarterly value
CRRA coefficient	σ	2	Conventional curvature
Decreasing-returns parameter	α	1/3	Standard value
Inverse Frisch elasticity	φ	1	Standard value
CES demand elasticity	ε	4	Steady-state markup of one third
Loss-side reference elasticity	Γ_L	0.87	Survey estimate, Section 3
Gain-side reference elasticity	Γ_G	0.33	Survey estimate, Section 3
Reference persistence	ρ	0.53	Normal-price survey arm
Cost-push persistence	ρ_u	0.90	Persistent inflation episode
Interest-rate smoothing	ρ_i	0.80	Baseline policy rule
Inflation-rule coefficient	ϕ_π	1.50	Baseline policy rule
Output-rule coefficient	ϕ_y	0.125	Baseline policy rule
Calvo non-reset probability	θ	2/3	Three-quarter price duration
Rotemberg adjustment coefficient	ψ_p	52.94	Duration-preserving mapping
Perfect-foresight horizon	T	200	Numerical convergence
Target peak quarterly inflation	Peak π_t	1.00%	Matched-experiment normalization

Notes: In each model, the cost-push innovation is chosen to deliver a 1% peak quarterly inflation rate. Panel A of Table 5 also reports welfare losses for $\rho = 0.22$, the mean of the expected-price arm, and $\rho = 0.88$, the median of the normal-price arm.

with Γ replaced by Γ_L when $P_t > R_t$ and by Γ_G when $P_t < R_t$.[24] When marginal cost exceeds an upper threshold $\overline{z}_t$, the firm has an incentive to raise its price from the reference; when it falls below a lower threshold $\underline{z}_t$, the firm has an incentive to cut it. Appendix B.2 derives these thresholds conditional on inherited states and continuation values.

When $P_t = R_t$, the one-sided inequalities hold for marginal costs $z_t \in [\underline{z}_t, \overline{z}_t]$. This inaction region generates endogenous nominal rigidity at a reference price that evolves with the firm's past pricing decisions. The reference-price costate in this regime measures the marginal value of a higher reference price when the posted price tracks it. Appendix F gives the corresponding recursion.

I solve the nonlinear model under perfect foresight over 200 quarters, using the zero-inflation steady state as the terminal condition. The algorithm solves the nonlinear equilibrium conditions conditional on a conjectured sequence of pricing regimes. It then updates this sequence until the equilibrium path satisfies the conditions associated with each regime. Appendix F describes the solution algorithm in detail.

4.2 Calibration and macroeconomic dynamics

I scale the initial cost-push innovation ε_0^u separately in each model to produce a 1% peak in quarterly inflation. Table 4 reports the calibrated parameters. The survey estimates imply $\Gamma_L = 0.87$ and $\Gamma_G = 0.33$. I set reference-price persistence to $\rho = 0.53$, the mean quarterly

[24] In both conditions, mc_t is replaced by z_t.

persistence in the normal-price arm of the survey (Section 3.3). Household utility has curvature $\sigma = 2$, and the CES demand elasticity is $\varepsilon = 4$. I set the Rotemberg coefficient to $\psi_p = 52.94$ so that the model without reference dependence matches the Phillips-curve slope of a Calvo model with an average price duration of three quarters. I use the same coefficient in both models. In RD-RANK, I set the employment subsidy to the midpoint of the interval supporting the zero-inflation steady state derived in Proposition B.1.

Columns 4 and 5 of Panel A in Table 5 show that RD-RANK requires a smaller cost-push innovation to generate the same inflation peak, consistent with the higher pass-through discussed in Section 2. Figure 6 shows the impulse responses for $\rho_u = 0.70$. Appendix Figure F.1 shows the baseline case, $\rho_u = 0.90$. The smaller innovation reduces cost pressure, while forward-looking firms anticipate eventually setting $P_t = R_t$ as the shock dissipates. Rotemberg adjustment costs encourage firms to spread this return over several periods. These forces contribute to faster disinflation in RD-RANK and, through the monetary-policy rule, a faster subsequent decline in the nominal interest rate. Inflation in RD-RANK becomes negative in quarter 5 and reaches a trough of approximately -0.060% in quarter 6.[25] Prices equal their references in quarter 7, and inflation is zero from quarter 8 onward.

Physical output and employment contract less in RD-RANK, while composite output initially falls more. A positive reference wedge χ_t reduces the consumption utility delivered by a given physical bundle.[26] With $\sigma > 1$, the intertemporal elasticity of substitution is below one, making households reluctant to accept a temporary decline in consumption utility. They therefore have an incentive to purchase more physical goods to partly offset this loss. This response limits the contraction in physical output and employment but does not fully restore consumption utility. At the quarter-2 trough, physical output falls by 0.57% and composite output by 0.85%. In RANK, where the two output measures coincide, both fall by 0.73%. The reference wedge disappears when prices equal their references in quarter 7. The associated reduction in consumption utility is central to the welfare losses examined in the next subsection.

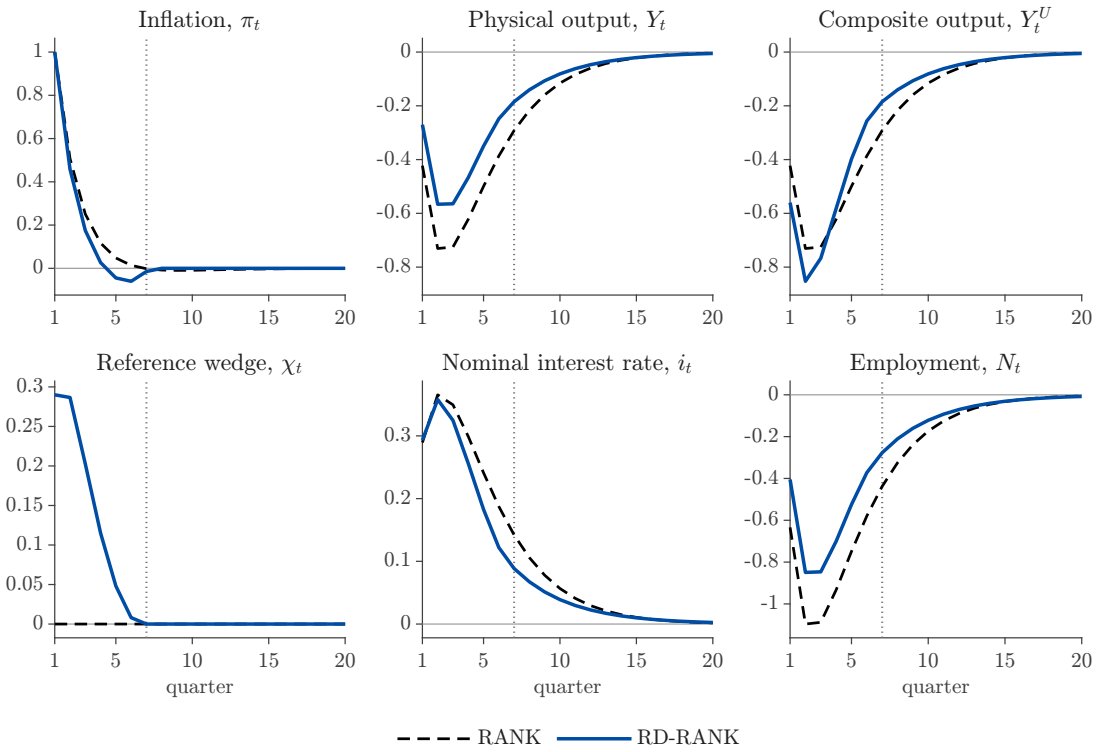
4.3 Welfare losses

I measure welfare losses from the episode relative to the initial steady state. To this end, I calculate discounted household utility from composite consumption C_t^U and labor N_t along each nonlinear transition. Holding labor at its steady-state level, I define the consumption-equivalent loss λ as the permanent proportional reduction in steady-state consumption that generates the

[25] The small inflation undershoot in RANK reflects interest-rate smoothing.

[26] By the aggregation identity (2.14), $\chi_t = \log(Y_t/Y_t^U)$. When $P_t > R_t$, it equals $\Gamma_L \log(P_t/R_t)/(\varepsilon - 1)$, linking the gap between physical and composite output to the gap between posted and reference prices.

Figure 6: Matched-peak cost-push shock with lower persistence: $\rho_u = 0.70$



Notes: Responses to a cost-push shock with persistence $\rho_u = 0.70$, scaled separately in each model to produce a 1% peak in quarterly inflation. Reference-price persistence is $\rho = 0.53$; all other parameters are those of Table 4. Quarter 1 is the quarter of the shock, $t = 0$. Physical output Y_t, composite output Y_t^U, employment N_t, and the gross nominal interest rate are expressed as log deviations from steady state multiplied by 100; inflation is $100\,\pi_t$ and the reference wedge is $100\,\chi_t$. The vertical dotted line marks quarter 7, when the RD-RANK model returns to $P_t = R_t$; inflation is exactly zero from quarter 8 onward.

same lifetime utility loss (see Lucas, 2003):

$$\sum_{t=0}^{\infty} \beta^t \left[\frac{(\bar{C}^U)^{1-\sigma}}{1-\sigma} - \frac{\left[(1-\lambda)\bar{C}^U\right]^{1-\sigma}}{1-\sigma} \right] = \Delta W. \tag{4.3}$$

Here, $\Delta W \equiv \sum_{t=0}^{T-1} \beta^t(\bar{u} - u_t)$ is the discounted utility loss along the transition, where u_t denotes period household utility and $\bar{u}$ its steady-state value. I report consumption-equivalent losses in percentage terms as 100λ.[27]

Panel A of Table 5 reports welfare losses for a cost-push shock with persistence $\rho_u = 0.90$, scaled separately in each model to generate a 1% peak in quarterly inflation. The consumption-equivalent loss is 0.0087% in RANK, compared with 0.0266% in RD-RANK when $\rho = 0.22$, the expected-price arm, and 0.0376% when $\rho = 0.53$. Reference dependence therefore raises the

[27] A permanent loss of λ has the same present value as a one-time loss of $\lambda/(1-\beta)$ quarters of steady-state consumption, or 25λ years at $\beta = 0.99$. The baseline RD-RANK loss of 0.0376% thus corresponds to about 0.94% of one year's consumption, the unit used in Section 5.

Table 5: Welfare losses from a matched cost-push shock and their decomposition

Panel A. Exact consumption-equivalent losses

Peak (% per quarter)	ρ_u	ρ	Innovation ε_0^u (log points)		Loss, $100 \times \lambda$ (% of $\bar{C}$, permanent)		Difference (pp)	Ratio (RD/RANK)
			RANK	RD-RANK	RANK	RD-RANK		
1.0	0.90	0.22	8.36	7.95	0.0087	0.0266	0.0179	3.052
1.0	0.90	0.53	8.36	7.89	0.0087	0.0376	0.0289	4.310
1.0	0.90	0.88	8.36	8.15	0.0087	0.1018	0.0931	11.673
1.0	0.70	0.53	10.83	10.30	0.0040	0.0130	0.0090	3.244
0.5	0.90	0.53	4.23	3.98	0.0022	0.0158	0.0136	7.100

Panel B. Component shares of the second-order loss

Model	Peak (%)	ρ_u	Share of second-order loss (%)				Approximate	Exact
			$\frac{\sigma-1}{2}(y_t^U)^2$	$\frac{1+\varphi}{2(1-\alpha)}\widetilde{y}_t^2$	$\boldsymbol{\chi}_t$	$\frac{\psi_p}{2}\pi_t^2$	$100 \times \lambda^{(2)}$	$100 \times \lambda$
RANK	1.0	0.90	6.2	18.6	**0.0**	75.2	0.0086	0.0087
RD-RANK, $\rho = 0.22$	1.0	0.90	2.2	5.0	**69.4**	23.3	0.0265	0.0266
RD-RANK, $\rho = 0.53$	1.0	0.90	1.8	3.3	**78.5**	16.5	0.0375	0.0376
RD-RANK, $\rho = 0.88$	1.0	0.90	1.0	0.9	**92.1**	6.0	0.1017	0.1018
RANK	1.0	0.70	2.7	8.2	**0.0**	89.1	0.0040	0.0040
RD-RANK, $\rho = 0.53$	1.0	0.70	0.9	1.3	**72.4**	25.4	0.0130	0.0130
RANK	0.5	0.90	6.4	19.2	**0.0**	74.3	0.0022	0.0022
RD-RANK, $\rho = 0.53$	0.5	0.90	1.0	1.9	**87.3**	9.8	0.0158	0.0158

Panel C. Deflationary episode: contributions to the second-order loss

Model	Trough (%)	ρ_u	Contribution to second-order loss				Approximate	Exact
			$\frac{\sigma-1}{2}(y_t^U)^2$	$\frac{1+\varphi}{2(1-\alpha)}\widetilde{y}_t^2$	$\boldsymbol{\chi}_t$	$\frac{\psi_p}{2}\pi_t^2$	$100 \times \lambda^{(2)}$	$100 \times \lambda$
RANK	-1.0	0.90	0.0007	0.0021	**0.0000**	0.0069	0.0097	0.0096
RD-RANK, $\rho = 0.53$	-1.0	0.90	0.0007	0.0019	**−0.0121**	0.0068	−0.0027	−0.0028

Notes: RANK and RD-RANK denote the models without and with reference dependence. Panel A reports exact consumption-equivalent losses, 100λ, at $\sigma = 2$: the permanent percentage reduction in steady-state consumption defined in equation (4.3). Cost-push innovations are in log points and are scaled separately in each model to match the reported inflation peak or trough. Differences are RD-RANK minus RANK in percentage points; ratios are RD-RANK/RANK. Panel B reports component shares of the second-order loss in equation (4.4), evaluated along each nonlinear path. Panel C reports component contributions in consumption-equivalent percentage units; negative values denote welfare gains. The last two columns in Panels B and C compare approximate and exact losses. Appendix F details the welfare calculations.

welfare cost by factors of 3.05 and 4.31, respectively. Using the median of the normal-price arm instead, $\rho = 0.88$, raises the RD-RANK loss to 0.1018%, 11.7 times the RANK loss, with the reference wedge accounting for 92.1% of the second-order loss. Slower reference-price updating makes the utility loss from a given price increase more persistent (Appendix Figure F.2).

To interpret these losses, I use the extension of Section 2's welfare approximation to the case $\Gamma_L > \Gamma_G$ and general CRRA utility derived in Appendix B.4. For the cost-push experiment, the normalized second-order loss is[28]

$$\mathcal{L}^{(2)} = \sum_{t=0}^{T-1} \beta^t \left[\frac{\sigma - 1}{2} (y_t^U)^2 + \frac{1 + \varphi}{2(1 - \alpha)} \widetilde{y}_t^2 + \chi_t + \frac{\psi_p}{2} \pi_t^2 \right], \tag{4.4}$$

where $\widetilde{y}_t = y_t - a_t$ (lowercase quantities denote log deviations from steady state). Relative to the log-utility case in Section 2, general CRRA utility introduces the additional term $\frac{\sigma-1}{2}(y_t^U)^2$. When $\sigma > 1$, greater utility curvature makes a given decline in composite consumption more costly than under log utility. The last two columns of Panel B in Table 5 show that the approximation closely reproduces the exact consumption-equivalent losses, with relative errors below 0.5% in RD-RANK and 1.4% in RANK. Column 6 of Panel B in Table 5 shows that the reference wedge χ_t accounts for 69.4% and 78.5% of the approximated RD-RANK loss at $\rho = 0.22$ and $\rho = 0.53$, respectively. The increase in welfare losses is therefore primarily accounted for by the first-order contribution of the reference wedge, χ_t.

Panel A of Table 5 shows how welfare losses vary with cost-push persistence. For a 1% peak in quarterly inflation, reducing cost-push persistence from $\rho_u = 0.90$ to 0.70 lowers the RD-RANK loss to 0.0130%, or 3.24 times the RANK loss, compared with 4.31 in the baseline. More persistent shocks keep posted prices above their references for longer, increasing the cumulative welfare loss. With $\rho_u = 0.90$, halving the inflation peak to 0.5% lowers losses to 0.0022% in RANK and 0.0158% in RD-RANK, raising their ratio to 7.10. As shocks become larger and peak inflation rises, the quadratic terms in the welfare decomposition become more important relative to χ_t.[29]

Panel C of Table 5 shows that the deflationary episode yields a relatively small consumption-equivalent *gain* of 0.0028% in RD-RANK, as the first-order gain outweighs the quadratic costs, compared with a loss of 0.0096% in RANK. Since welfare gains from prices below their references are governed by Γ_G, a given price–reference gap generates smaller first-order gains in response to a negative cost-push shock. Reference dependence can therefore help explain why recent surveys find that a substantial share of households prefer negative inflation rates (Georgarakos et al., 2025; Pfajfar and Winkler, 2025; Afrouzi et al., 2025).

[28] Utility losses are normalized by steady-state marginal utility times consumption, $(\bar{C}^U)^{1-\sigma}$.

[29] Under the baseline parameters, a 4% peak in quarterly inflation gives the first-order reference contribution a share of approximately 51% of the second-order RD-RANK loss, roughly matching the three quadratic components combined.

5 Welfare costs during the 2021–2023 inflation episode

Section 4 examines the welfare implications of reference dependence following a cost-push shock in a representative-agent economy. To quantify its importance during the 2021–2023 U.S. inflation surge, I extend the framework to a two-sector heterogeneous-agent New Keynesian model. Two considerations motivate this extension. First, reference-dependent demand has been extensively documented for frequently purchased goods, and exposure to this sector varies across the income distribution. Second, recent work emphasizes sticky wages and heterogeneity in net nominal positions as important determinants of welfare during the episode, motivating their inclusion in the model.[30] I fit the model to U.S. data to assess whether reference dependence is a quantitatively important driver of welfare losses during this episode.

5.1 Model

Time is discrete and quarterly. The economy is populated by a unit continuum of households $i \in [0, 1]$ that face idiosyncratic earnings risk and differ in wealth and discount factors. Households save in a one-period nominal bond subject to a borrowing constraint. They consume goods from two sectors, combined using a CES aggregator. Expenditure shares across the two sectors vary with household earnings. Sector R features reference-dependent demand as developed in Section 2; sector S has standard CES demand. In both sectors, monopolistically competitive firms produce using labor and face Rotemberg price adjustment costs. Nominal wages are sticky and set by unions, which allocate hours uniformly across households. The government issues nominal debt and levies labor-income taxes to finance spending on goods and services, transfers, and subsidies. Monetary policy follows a Taylor rule.

At each date, I solve a nonlinear transition under perfect foresight over aggregate variables, setting future aggregate innovations to zero while retaining household idiosyncratic risk (Auclert et al., 2021). Expectations below are evaluated under this information structure.

5.1.1 Households

Household i enters quarter t with state $(\beta_{it}, z_{it}, b_{i,t-1})$, where $b_{i,t-1}$ denotes inherited bond holdings, z_{it} its earnings state, and β_{it} its discount factor. The earnings state z_{it} follows a finite-state Markov chain with transition matrix Π_z and determines labor efficiency $e_{z_{it}}$, normalized to have a stationary mean of one. Independently of the earnings process, $\beta_{i,t+1} = \beta_{it}$ with probability $1 - p_\beta$. With probability p_β, the household draws a new discount factor, equal to β_H with probability $\pi_\beta(\beta_H)$ and $\beta_L < \beta_H$ otherwise (Auclert et al., 2025). All households supply N_t hours, determined by union labor demand. Appendix G.1 gives further details of the household problem.

[30] See Afrouzi et al. (2024) on real-wage erosion and costly wage adjustment, and Pallotti et al. (2024) on redistribution across households with different net nominal positions.

Preferences and consumption baskets. Household i's period utility is

$$u(c_{it}) - v(N_t) = \frac{c_{it}^{1-\sigma}}{1-\sigma} - \varphi_N \frac{N_t^{1+\varphi}}{1+\varphi},$$

where σ is relative risk aversion, φ is the inverse Frisch elasticity, and φ_N scales labor disutility. Composite consumption is

$$c_{it} = \left[\omega_R(z_{it})^{1/\nu}(c_{it}^R)^{(\nu-1)/\nu} + (1-\omega_R(z_{it}))^{1/\nu}(c_{it}^S)^{(\nu-1)/\nu}\right]^{\nu/(\nu-1)}. \tag{5.1}$$

Here ν is the elasticity of substitution across sectors and $\omega_R(z_{it})$ is household i's weight on sector R. The quantities c_{it}^R and c_{it}^S are consumption in utility units. In sector S, these coincide with physical quantities. In sector R, the reference-dependent aggregator of Section 2 implies that $e^{\chi_{R,t}}$ physical units are required to deliver one unit of c_{it}^R, where $\chi_{R,t}$ is the reference wedge for sector-R goods.

Let $P_{R,t}$ and $P_{S,t}$ denote posted sectoral prices, $\tilde{q}_t = P_{R,t}/P_{S,t}$ their relative price, and $\Pi_{j,t} = P_{j,t}/P_{j,t-1}$ gross inflation in sector j. The effective relative price of sector-R consumption is $q_t = e^{\chi_{R,t}}\tilde{q}_t$. Expressing expenditure in units of the sector-S good, cost minimization gives household i's consumption price index

$$P_{z_{it}}^C(q_t) = \left[\omega_R(z_{it})q_t^{1-\nu} + 1 - \omega_R(z_{it})\right]^{1/(1-\nu)}. \tag{5.2}$$

Thus $P_{z_{it}}^C(q_t)c_{it}$ is the expenditure required to attain composite consumption c_{it}. At the normalized steady state, $q_{\text{ss}} = 1$, the weight $\omega_R(z_{it})$ equals the household's sector-R expenditure share and satisfies $\partial \log P_{z_{it}}^C(q)/\partial \log q\Big|_{q=1} = \omega_R(z_{it})$. Away from steady state, expenditure shares also respond to relative prices.

Intertemporal household problem. Taking aggregate paths as given, household i chooses consumption c_{it} and end-of-quarter bond holdings b_{it} to maximize utility subject to its budget constraint. In the recursive problem, I suppress household subscripts and write $(\beta, z, b) = (\beta_{it}, z_{it}, b_{i,t-1})$, $c = c_{it}$, and $b' = b_{it}$. Primes on the exogenous states denote their next-quarter values. The common value function satisfies

$$V_t(\beta, z, b) = \max_{c, b' \geq 0}\left\{u(c) - v(N_t) + \frac{\beta}{\zeta_t}\mathbb{E}\left[V_{t+1}(\beta', z', b') \mid \beta, z\right]\right\}, \tag{5.3}$$

subject to household i's budget and borrowing constraints, expressed in units of the sector-S good,

$$P_{z_{it}}^C(q_t)c_{it} + b_{it} = R_t^b b_{i,t-1} + (1-\tau_L)\mathcal{T}^w w_t e_{z_{it}} N_t + \xi_{z_{it}}\mathcal{D}_t + Tr_t^{\text{hh}}, \qquad b_{it} \geq 0, \tag{5.4}$$

where $w_t = W_t/P_{S,t}$ is the real wage, τ_L the labor-income tax rate, $\mathcal{T}^w$ the gross wage subsidy, $\mathcal{D}_t$ aggregate dividends, $\xi_{z_{it}}$ household i's dividend incidence weight, and Tr_t^{hh} the lump-sum transfer common to all households. The realized return on nominal bonds is

$$R_t^b = \frac{1 + i_{t-1}}{\Pi_{S,t}}, \tag{5.5}$$

where i_{t-1} is the nominal interest rate fixed in the preceding quarter. The variables $b_{i,t-1}$ and b_{it} denote inherited and new real bond holdings in units of the sector-S good. Aggregate demand shocks enter through the discount-factor shifter ζ_t, so household i's effective discount factor is β_{it}/ζ_t (Auclert et al., 2021).

Sector-R inflation affects the cost of consumption through the effective relative price q_t, which incorporates both relative prices and the reference wedge. Sector-S inflation also affects q_t and enters the realized real return on nominal bonds. For a given nominal interest rate, higher sector-S inflation reduces the real bond payoff in units of the sector-S good.

5.1.2 Firms and unions

Firms and price setting. In each sector $j \in \{R, S\}$, a continuum of monopolistically competitive firms produces differentiated goods using labor with constant returns and productivity $Z_t Z_{j,t}$, where Z_t is aggregate productivity and $Z_{j,t}$ is sectoral productivity. The within-sector CES elasticity is ϵ_j. Firms choose prices to maximize the present value of profits, subject to demand and quadratic price-adjustment costs with coefficient ψ_j. Constant production subsidies offset markup distortions in steady state.

In sector S, optimal pricing in a symmetric equilibrium gives the Rotemberg Phillips curve

$$(\Pi_{S,t} - 1)\Pi_{S,t} = \frac{\epsilon_S}{\psi_S}\left(\upsilon_{S,t} mc_{S,t} - \frac{\epsilon_S - 1}{\epsilon_S}\right) + \delta_t \mathbb{E}_t\left[\frac{Y_{S,t+1}}{Y_{S,t}}(\Pi_{S,t+1} - 1)\Pi_{S,t+1}^2\right], \tag{5.6}$$

where $Y_{S,t}$ is sectoral output, $mc_{S,t}$ is real marginal cost inclusive of the production subsidy, and $\upsilon_{S,t}$ is a cost-push shock. Firms discount nominal profits at $\delta_t = (1 + i_t)^{-1}$ (Auclert et al., 2021).

Sector-R demand and reference updating follow (2.2) and (2.3) in Section 2. Price setting satisfies the smooth branch conditions away from the reference price and the one-sided optimality conditions at the kink, derived in Appendix B. Appendix G.2 collects the equations governing firms' production, pricing, and dividends.

Unions and wage setting. A continuum of unions sets nominal wages for differentiated labor services. Each union represents all households and chooses its wage to maximize their average utility, taking household consumption-saving decisions as given (Auclert et al., 2021). Hours are allocated uniformly across households. Wage adjustment costs are quadratic in log

wage changes and are borne in utility units. In a symmetric equilibrium, gross wage inflation $\Pi_{w,t} = W_t/W_{t-1}$ satisfies

$$\log \Pi_{w,t} = \kappa_w \left[\varphi_N N_t^{1+\varphi} - \frac{(1-\tau_L)\mathcal{T}^w}{\mu_w \upsilon_{w,t}} w_t N_t \int_0^1 e_{z_{it}} \frac{c_{it}^{-\sigma}}{P_{z_{it}}^C(q_t)} \, \mathrm{d}i \right] + \beta_w \mathbb{E}_t[\log \Pi_{w,t+1}], \tag{5.7}$$

where κ_w is the Phillips-curve slope, μ_w is the wage markup, $\upsilon_{w,t}$ a wage markup shock, and β_w the union discount factor, the stationary population mean of the households' discount factors (Appendix G.3). The factor $1/P_{z_{it}}^C(q_t)$ captures how much composite consumption an additional unit of income (measured in sector-S goods) can purchase. The wage subsidy offsets the steady-state union markup. Appendix G.3 provides further details on wage setting.

5.1.3 Policy and equilibrium

The central bank follows a Taylor rule with interest-rate smoothing,

$$1 + i_t = (1 + i_{t-1})^{\rho_i} \left[(1 + i_{\mathrm{ss}}) \prod_{j \in \{R,S\}} \Pi_{j,t}^{\phi_\pi \vartheta_j^\Pi} \left(\frac{Y_{j,t}^{\mathrm{phys}}}{\bar{Y}_j} \right)^{\phi_y \vartheta_j^Y} \right]^{1-\rho_i} e^{m_t}, \qquad m_t = \rho_m m_{t-1} + \varepsilon_t^i. \tag{5.8}$$

The coefficients $\phi_\pi \vartheta_j^\Pi$ and $\phi_y \vartheta_j^Y$ govern the responses to sectoral inflation and deviations of physical sectoral output from steady state, respectively. The parameter ρ_i governs interest-rate smoothing, and m_t is a monetary policy shock with persistence ρ_m and innovation ε_t^i.

Fiscal policy. The government issues one-period nominal bonds, purchases sector-S goods, and finances transfers to households and subsidies to firms and unions. Its budget constraint, expressed in units of the sector-S good, is

$$B_t = R_t^b B_{t-1} + G_t + Subs_t + Tr_t^{\mathrm{hh}} - \tau_L \mathcal{T}^w w_t N_t, \tag{5.9}$$

where B_t denotes real government debt, G_t government purchases, and $Subs_t$ the subsidy bill. The labor-income tax rate τ_L is fixed. Net household transfers Tr_t^{hh} comprise exogenous transfers less a lump-sum tax that responds to deviations of debt from steady state after a delay. This fiscal adjustment is inactive during 2021–2023: debt absorbs budget imbalances, and inflation-induced debt-revaluation gains are not automatically rebated to households during the episode. Appendix G.3 specifies the subsidy bill and fiscal adjustment rule.

Market clearing. Goods and labor markets clear, and aggregate household bond holdings equal government debt. Appendix G.4 defines equilibrium and collects the equilibrium conditions.

5.2 Calibration and estimation

The curvature of consumption utility (σ), reference-dependence parameters ($\Gamma_G, \Gamma_L, \rho_R$), sector-$R$ demand elasticity (ϵ_R), and Taylor-rule parameters (ρ_i, ϕ_π, ϕ_y) follow the calibration in Table 4. In the monetary-policy rule, sectoral inflation weights (ϑ_j^Π) equal fixed CPI expenditure shares, while output weights (ϑ_j^Y) equal steady-state GDP shares.

I calibrate steady-state sectoral expenditure weights $\omega_R(z)$ using the 2020 Consumer Expenditure Survey. The baseline reference-dependent basket contains food, energy, and frequently purchased nondurables; a broader definition adds rent and recurring services. Sector S contains the remaining consumption categories. Appendix I.1 describes both constructions, and Table I.3 reports the weights across earnings groups. I set the elasticity of substitution between the two sectors to $\nu = 0.40$ (Bobasu et al., 2025).

I calibrate the dividend-incidence rule to the distribution of dividend income across earnings groups in the 2019 Survey of Consumer Finances. Figure I.1 in Appendix I.2 compares the fitted rule with the data.

I use the monthly regular-price change frequencies reported by Nakamura and Steinsson (2008) to construct expenditure-weighted medians of 10.6% in sector R and 8.8% in sector S. Matching the corresponding Calvo Phillips-curve slopes gives $\psi_R = 34.6$ and $\psi_S = 89.7$. Wage-adjustment costs imply a wage Phillips-curve slope of $\kappa_w \simeq 0.085$, corresponding through a Calvo slope comparison to wage adjustment approximately once a year.

I set the quarterly persistence and unconditional standard deviation of idiosyncratic log earnings to 0.966 and 0.50, respectively (Auclert et al., 2021). I calibrate the household discount-factor distribution to match an aggregate quarterly marginal propensity to consume of 0.25 and government debt equal to 1.40 times annual GDP. I estimate seven shock-persistence parameters jointly using survey expectations of headline and core CPI inflation, short-term interest rates, real GDP growth, and firms' unit costs. Appendix H.3 describes the mapping between survey measures and model forecasts and the estimation procedure. Table I.1 in Appendix I reports all parameter values and their sources or calibration targets.

Estimation. I recover eight aggregate innovations in each quarter of 2021Q1–2023Q4 to match two sectoral CPI inflation rates,[31] nominal wage inflation measured by the BLS Employment Cost Index, the effective federal funds rate, real GDP, nonfarm business hours, and federal social benefits and the federal primary deficit, both as shares of GDP. Output and hours are detrended against their 2015–2019 log-linear trends, with an additional level adjustment for hours. The policy rate and fiscal ratios are measured relative to their 2015–2019 means; price inflation is measured relative to 2% annually and wage inflation relative to this benchmark plus

[31] To align the price measures with the CEX basket definitions, I map consumption categories to CPI item-level price indices and aggregate them using fixed December 2020 CPI weights. Sectoral inflation is computed from the resulting indices.

average real wage growth over 2015–2019. I recover the innovations separately for economies with and without reference dependence, matching the same eight observed series in each case. Appendix Table H.1 links these observables to the innovations they jointly identify. Appendix Figures H.2 and H.3 report the observed and fitted series and the recovered shock innovations, respectively. Appendix H.3 details the data transformations and estimation.

At each date t, agents observe a vector of unanticipated aggregate innovations. They know the persistence of these shocks and anticipate no further innovations. Taking the vector of inherited state variables and the cross-sectional distribution of household states as initial conditions, I compute the nonlinear equilibrium transition. I solve the kinked pricing problem in sector R using a complementarity formulation of the one-sided optimality conditions used in Section 4; Appendix H.4 describes the numerical implementation. Only the date-t allocation is realized. The resulting aggregate state and household distribution carry forward to date $t+1$, when new unanticipated innovations arrive and the transition is recomputed. Appendix H.2 details the sequential solution.

5.3 Welfare

I measure the welfare cost of the 2021–2023 episode by comparing households' allocations with those in an economy that remains in steady state. The calculation includes utility during the episode and the continuation value of households' positions at its end. In the steady-state economy, all aggregate inputs, including the discount-factor shifter $\zeta = 1$, remain at their steady-state values.

Let $t = 0$ denote 2021Q1 and $T = 12$ denote 2024Q1. For household i, lifetime welfare in scenario $x \in \{\text{ss}, tr\}$ is

$$V_i^x = \mathbb{E}_{i0}^x \left[\sum_{t=0}^{T-1} D_{it} \left\{ u(c_{it}^x) - v(N_t^x) - \frac{\psi_w}{2} \left(\log \Pi_{w,t}^x \right)^2 \right\} + D_{iT} \mathcal{V}_T^x(s_{iT}^x) \right],$$

where $s_{iT}^x = (\beta_{iT}, z_{iT}, b_{i,T-1}^x)$ is the household's state entering 2024, $D_{i0} = 1$, and $D_{it} = \prod_{s=0}^{t-1} \beta_{is}$. Expectations integrate over households' idiosyncratic earnings and discount-factor transitions, taking the aggregate path in each scenario as given. The continuation value $\mathcal{V}_T^x$ includes all subsequent consumption utility, labor disutility, and wage adjustment costs.

During the episode, households' allocations reflect decisions made under each quarter's information. Their continuation value follows the equilibrium path anticipated at the end of 2023, assuming no further aggregate innovations. Future prices, wages, bond returns, and fiscal policy determine consumption and saving along this path, including the consequences of eventual debt repayment. In the steady-state economy, continuation utility is evaluated using the steady-state value function. Both scenarios are evaluated with the aggregate discount shifter fixed at $\zeta = 1$, while retaining households' idiosyncratic discount-factor process. This measures

how much consumption households would be willing to surrender to avoid the episode when its consequences are valued using steady-state preferences. Holding the preference specification fixed provides a common basis for comparing the two allocations.

I express the welfare difference as a fraction of annual steady-state consumption. Household i's consumption-equivalent loss, CE_i, is the proportional reduction in its steady-state consumption during the four quarters of 2021 that makes it indifferent to the episode. The compensating allocation scales steady-state consumption uniformly across idiosyncratic states for $t = 0, \ldots, 3$, holding consumption from $t = 4$ onward and the entire paths of hours and wage adjustment costs at their steady-state allocations. With CRRA utility,

$$V_i^{\mathrm{ss}} + \left[(1 - \mathrm{CE}_i)^{1-\sigma} - 1\right] \underline{V}_i^{c,\mathrm{ss}} = V_i^{tr}, \qquad \underline{V}_i^{c,\mathrm{ss}} = \mathbb{E}_{i0}^{\mathrm{ss}} \sum_{t=0}^{3} D_{it} u(c_{it}^{\mathrm{ss}}). \tag{5.10}$$

Thus, the consumption adjustment is confined to one year, while the welfare difference includes the episode and its full continuation. I report the population mean,

$$100 \int_0^1 \mathrm{CE}_i \, \mathrm{d}i,$$

with initial household states distributed according to Ψ_{ss}. I measure the cost of reference dependence as the consumption equivalent of the incremental utility loss from reference dependence. I compare households with the same initial asset holdings, earnings state, and discount-factor type, $(b_{i,-1}, z_{i0}, \beta_{i0})$. For each household, I measure the episode's utility loss in the RD economy relative to the RD steady state, and the corresponding loss in the no-RD economy relative to the no-RD steady state. Denoting these losses by $\Delta V_i^x = V_i^{\mathrm{ss},x} - V_i^{tr,x}$, for $x \in \{\mathrm{RD}, \mathrm{no\,RD}\}$, I convert their difference into a reduction in 2021 steady-state consumption using the same rule as (5.10):

$$\left[(1 - \mathrm{CE}_i^{\mathrm{RD}})^{1-\sigma} - 1\right] \underline{V}_i^{c,\mathrm{ss}} = -\left(\Delta V_i^{\mathrm{RD}} - \Delta V_i^{\mathrm{no\,RD}}\right). \tag{5.11}$$

Because this conversion is nonlinear, the cost of reference dependence is not the difference between the two economies' consumption equivalents. I report the three population means and express the cost of reference dependence as a share of the cost of the episode, calculated as the ratio of the corresponding population means. Appendix H.6 provides the computational details.

5.3.1 Welfare costs and the cost of reference dependence

The average household loses the equivalent of 5.32% of its 2021 steady-state consumption in the baseline economy, compared with 4.43% without reference dependence (Table 6). The cost of reference dependence is equivalent to 0.97% of 2021 steady-state consumption, or 18% of the cost of the episode. Under the broader basket definition, which includes rent and recurring services, the corresponding episode costs are 5.71% and 4.39%. The cost of reference dependence

is 1.44% of 2021 steady-state consumption, or 25% of the cost of the episode.

Table 6: The welfare cost of the episode and the cost of reference dependence

	Baseline basket	Broad basket
Cost of the episode	5.32	5.71
Cost without reference dependence	4.43	4.39
Cost of reference dependence	0.97	1.44
Share of the cost of the episode	18%	25%

Notes: Welfare costs are population means of household consumption equivalents, expressed as percentages of annual steady-state consumption in 2021. The economy without reference dependence re-estimates all shock innovations against the same eight observables under the same sequential information. The third row converts each household's additional utility loss from reference dependence into a consumption equivalent and reports the average across households (equation 5.11). It is not the difference between the first two rows. The fourth row divides the third by the first. Calculations include the fitted history through 2023Q4 and the model's continuation from 2024Q1 (Appendix H.6).

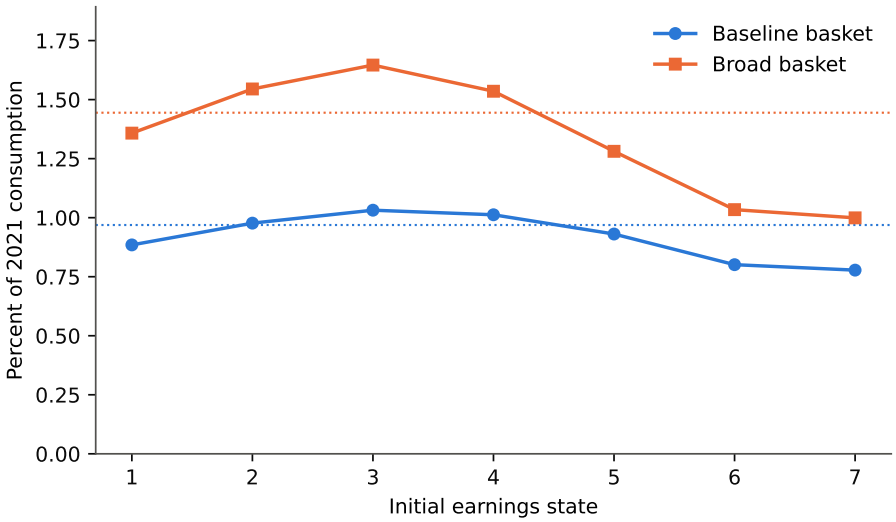
Reference dependence raises welfare costs because a given physical consumption bundle delivers less utility when posted prices exceed reference prices. Under the baseline basket, this cost is largest in initial earnings states 3 and 4, which also experience the largest total episode losses. It is lower at the bottom of the earnings distribution and smallest in the highest earnings state (Figure 7).

Differences in consumption baskets help explain this pattern. The cost of reference dependence is 1.03% of 2021 steady-state consumption in state 3, which has the largest expenditure share on reference-dependent goods, compared with 0.80% in state 6, which has the smallest share. The cost is therefore about 30% higher in the most exposed group. Under the broader basket, the corresponding costs are 1.65% and 1.03%, a difference of about 60%. These groups describe households' initial earnings states; households can transition between earnings states over time.

Reference dependence raises welfare losses under every continuation convention, although the magnitude of the total loss depends on how post-2023 outcomes are valued. Restricting the welfare calculation to 2021–2023, with no continuation value, yields losses of 4.29% and 4.35% of 2021 steady-state consumption under the baseline and broader baskets. The costs of reference dependence are 0.65% and 0.82%, equivalent to 15% and 19% of the episode costs, compared with 18% and 25% under full continuation. Valuing households' positions at the end of 2023 using steady-state value functions, net of future debt repayment, gives episode costs of 3.74% and 3.92%. The costs of reference dependence are 0.65% and 0.81%. Full continuation produces larger losses because the estimated persistence carries the episode's cost-push, wage-markup and monetary disturbances into the continuation (Appendix H.6).

I also assess sensitivity to the treatment of preference shocks in welfare evaluation. First, I evaluate both scenarios using the realized aggregate discount shifters rather than their pre-episode value, retaining steady-state consumption and saving rules in the benchmark. Second, I allow households in the steady-state benchmark to re-optimize consumption and saving in

Figure 7: The welfare cost of reference dependence by earnings group



Notes: Consumption equivalent of the incremental utility loss from reference dependence, equation (5.11), by initial earnings state (1 is the lowest), in percent of 2021 steady-state consumption. Losses follow the fitted history through 2023Q4 and the model's continuation from 2024Q1. Dotted lines denote population means, which equal the cost of reference dependence in Table 6.

response to aggregate discount-factor shocks, holding all other aggregate inputs at steady state. This allows the benchmark allocation to adjust to the preferences used to evaluate it. Including the post-2023 equilibrium adjustment anticipated at the end of 2023, both exercises leave overall welfare losses and the cost of reference dependence close to the baseline estimates. Appendix Tables H.5 and H.6 report these results and further robustness checks.

6 Conclusion

Reference dependence in consumer demand creates a first-order welfare cost of inflation: when posted prices exceed slowly adjusting reference prices, a given physical bundle delivers less consumption utility. Using survey estimates to discipline the model, I find that this mechanism substantially increases inflation's welfare costs in both a representative-agent economy and a richer heterogeneous-agent economy with sticky wages and differences in households' wealth and consumption baskets.

The findings of this paper suggest several directions for future research. First, optimal monetary policy could be studied in an economy where sectors differ both in price rigidity and in the presence of reference-dependent demand. This would establish whether reference dependence warrants greater stabilization of inflation in relatively flexible-price sectors, given the consequences for inflation elsewhere and real activity.

In this paper, I assume that reference prices are formed solely from past posted prices. A

second extension would allow reference prices to incorporate expected future prices, so that they can respond before posted prices change. This would allow us to quantify differences in the welfare costs of anticipated and unanticipated inflation. Finally, solving the kinked model under aggregate uncertainty would clarify how the asymmetry between gains and losses affects the welfare costs of business-cycle fluctuations and the potential gains from stabilization.

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A Proofs and Derivations

A.1 Transaction Utility and RD–CES Relative Demand

This subsection derives the relative demand system in Section 2.1 from a discrete-choice model with transaction utility.

Consider consumer h on purchase occasion m. The utility from choosing inside variety $j \in \{1, \ldots, J\}$ is

$$u_{hjm} = \bar{v}_j - \varepsilon \log P_j - (\varepsilon - 1)\chi_{hj} + \xi_{hjm}, \tag{A.1}$$

where

$$\chi_{hj} = \begin{cases} \dfrac{\Gamma_L}{\varepsilon - 1} \log(P_j / R_j^h), & P_j \geq R_j^h, \\ \dfrac{\Gamma_G}{\varepsilon - 1} \log(P_j / R_j^h), & P_j < R_j^h. \end{cases} \tag{A.2}$$

The outside option delivers $u_{h0m} = v_0^h + \xi_{h0m}$. The term $-(\varepsilon - 1)\chi_{hj}$ is transaction utility: prices above the reference reduce choice utility, while prices below the reference increase it.

Assumption A.1 (Taste shocks)**.** *The shocks ξ_{hjm}, including the outside option $j = 0$, are independent and identically distributed standard Type I extreme-value random variables across consumers, alternatives, and purchase occasions.*

Under Assumption A.1, the inside-good choice probability is

$$\Pr_h(j) = \frac{e^{\bar{v}_j} e^{-(\varepsilon-1)\chi_{hj}} P_j^{-\varepsilon}}{e^{v_0^h} + \sum_{k=1}^{J} e^{\bar{v}_k} e^{-(\varepsilon-1)\chi_{hk}} P_k^{-\varepsilon}}. \tag{A.3}$$

Assumption A.2 (Aggregation)**.** *Reference prices R_j and reference-price elasticities (Γ_L, Γ_G) are common across households. The systematic non-price component of utility is the same across varieties, $\bar{v}_j = \bar{v}$.*

Define

$$s_j \equiv e^{-(\varepsilon-1)\chi_j}, \qquad \Delta \equiv \sum_{k=1}^{J} s_k P_k^{-\varepsilon}. \tag{A.4}$$

If each inside purchase delivers one unit and consumer h has M_h purchase occasions, expected aggregate purchases satisfy

$$C_j = s_j P_j^{-\varepsilon} \Omega(\Delta), \qquad \Omega(\Delta) \equiv e^{\bar{v}} \int \frac{M_h}{e^{v_0^h} + e^{\bar{v}} \Delta} \, \mathrm{d}h. \tag{A.5}$$

Heterogeneity in shopping intensity and outside-option values enters only through the common market-size term $\Omega(\Delta)$.

Proposition A.1 (Relative demand under transaction utility)**.** *Under Assumptions A.1 and A.2, relative demand for any two inside varieties j and k satisfies*

$$\frac{C_j}{C_k} = \frac{s_j P_j^{-\varepsilon}}{s_k P_k^{-\varepsilon}}. \tag{A.6}$$

Proof. Demand for variety j in equation (A.5) is the product of the variety-specific term $s_j P_j^{-\varepsilon}$ and the common term $\Omega(\Delta)$. Taking the ratio of demand for varieties j and k cancels the common term and gives (A.6). □

The relative-demand equations in Proposition A.1 coincide with those generated by the RD–CES aggregate over J varieties

$$C^U = \left[\frac{1}{J}\sum_{j=1}^{J} s_j^{1/\varepsilon} C_j^{(\varepsilon-1)/\varepsilon}\right]^{\varepsilon/(\varepsilon-1)}, \tag{A.7}$$

when expenditure is measured as $J^{-1}\sum_j P_j C_j$. Under Riemann-sum regularity, the limit as $J \to \infty$ yields (2.1) and the ideal price index in (2.2). Expenditure minimization under (A.7), using the same mass weights in expenditure and the aggregate, gives (A.6). The sum $J^{-1}\sum_j s_j P_j^{1-\varepsilon}$ converges to $\int_0^1 s_t(i) P_t(i)^{1-\varepsilon}\,\mathrm{d}i$.

Remark A.1 (Scope of the microfoundation). The proposition establishes relative demand across varieties; the intertemporal household problem is specified separately.

A.2 The Smooth Phillips Curve

Maintain $\Gamma_L = \Gamma_G \equiv \Gamma$ and the firm's problem in Section 2.3. This appendix derives its nonlinear optimality conditions and obtains Proposition 1 by linearizing around the symmetric zero-inflation steady state. The following assumption also applies to the kinked model in Appendix B.

Assumption A.3 (Admissible prices and aggregate paths)**.** *Posted prices lie in the corridor $P_t(i)/P_t \in [1/K, K]$ of the firm's problem in Section 2.3. Aggregate log inflation is uniformly bounded in absolute value and initial relative prices are finite and positive, so inherited posted and reference prices, expressed relative to the aggregate price, remain in a compact set. The consumption composite C_t^U, composite output Y_t^U, productivity A_t, the posted real wage W_t/P_t, and the ratio P_t^{RD}/P_t are uniformly bounded and bounded away from zero across dates and aggregate states.*

Optimality conditions. Consider an optimal price plan. Let G_t^R and G_t^P denote the marginal effects of the inherited log reference and lagged posted prices on expected discounted profits along this plan, with each period's profits $D_t^F(i)$ weighted by the household's marginal utility

of income, $\Lambda_t/P_t^{\mathrm{RD}}$. The price plan and aggregate conditions are held fixed when computing these effects. Under symmetry, the shadow value of the reference price in Section 2.3 is

$$\Theta_t \equiv \frac{G_t^R}{\Lambda_t Y_t^U}.$$

Let $MC_t(i) \equiv (1-\tau)W_t/\mathrm{MPL}_t(i)$ denote nominal marginal cost. Demand has elasticities $-(\varepsilon+\Gamma)$ and Γ with respect to the posted and reference prices. The reference law maps their logs into tomorrow's log reference with weights $1-\rho$ and ρ. The reference-price costate satisfies

$$G_t^R = \frac{\Lambda_t}{P_t^{\mathrm{RD}}}\,\Gamma\big[P_t(i) - MC_t(i)\big]Y_t(i) + \beta\rho\,\mathbb{E}_t G_{t+1}^R. \tag{A.8}$$

The lagged posted price affects only the current adjustment cost, so its costate is

$$G_t^P = \Lambda_t \psi_p(\Pi_t(i)-1)\Pi_t(i)Y_t^U,$$

where $\Pi_t(i) \equiv P_t(i)/P_{t-1}(i)$. Differentiating the sequential objective with respect to the current log price gives, at an interior optimum,

$$\begin{aligned} 0 = \frac{\Lambda_t}{P_t^{\mathrm{RD}}}\Big\{P_t(i)Y_t(i) - (\varepsilon+\Gamma)\big[P_t(i)-MC_t(i)\big]Y_t(i) - \psi_p(\Pi_t(i)-1)\Pi_t(i)P_t^{\mathrm{RD}}Y_t^U\Big\} \\ + \beta\mathbb{E}_t\Big[(1-\rho)G_{t+1}^R + \Lambda_{t+1}\psi_p(\Pi_{t+1}(i)-1)\Pi_{t+1}(i)Y_{t+1}^U\Big]. \end{aligned} \tag{A.9}$$

The last term is the lagged-price costate one period ahead. Under symmetry, $Y_t(i) = e^{\chi_t}Y_t^U$, $P_t^{\mathrm{RD}} = P_t e^{\chi_t}$, and $MC_t(i)/P_t = mc_t$. Normalizing (A.8) and (A.9) by $\Lambda_t Y_t^U$ and using the definitions of Θ_t and $\mathcal{M}_{t+1}$ in Section 2.3 gives (2.9) and (2.10).

Assumption A.3 bounds relative prices, firm demand and employment, and Λ_t. The derivative of weighted period profits with respect to the log reference price, given by the first term in (A.8), is therefore uniformly bounded across dates, admissible plans, and states. A log-reference perturbation shrinks by a factor ρ each period along a fixed price plan, so its discounted marginal payoff is summable and G_t^R is bounded. Under symmetry, its definition gives the present-value representation

$$\Theta_t = \mathbb{E}_t \sum_{j=0}^{\infty} (\beta\rho)^j \frac{\Lambda_{t+j}Y_{t+j}^U}{\Lambda_t Y_t^U}\,\Gamma(1-mc_{t+j}).$$

The discounted continuation term therefore vanishes:

$$\lim_{J\to\infty} (\beta\rho)^J \mathbb{E}_t[\Lambda_{t+J}Y_{t+J}^U\Theta_{t+J}] = 0.$$

We next verify the firm's transversality conditions separately for the reference price and the

previous period's posted price. The reference-price costate is bounded by the argument above. Under Assumption A.3, $\Lambda_t Y_t^U$ and $\Pi_t(i)$ are uniformly bounded, so the lagged-price costate is also bounded. Holding aggregates fixed, let $\delta \log R_{t+J}(i)$ and $\delta \log P_{t+J-1}(i)$ denote uniformly bounded admissible variations in the inherited log prices. The reference-price transversality condition is

$$\lim_{J\to\infty} \beta^J \mathbb{E}_t \left[G_{t+J}^R \, \delta \log R_{t+J}(i) \right] = 0.$$

The lagged-price transversality condition is

$$\lim_{J\to\infty} \beta^J \mathbb{E}_t \left[G_{t+J}^P \, \delta \log P_{t+J-1}(i) \right] = 0.$$

Each limit follows because the costate and the admissible variation are uniformly bounded, so the absolute value of each discounted contribution is bounded by a constant times β^J.

Steady-state markup. At the deterministic zero-inflation steady state, $\bar{\Pi} = \bar{\mathcal{M}} = 1$, $\bar{\chi} = 0$, and $\bar{\Theta} = \Gamma(1 - \bar{mc})/(1 - \beta\rho)$. Substitution into the pricing condition gives

$$\bar{mc} = \frac{\varepsilon_{\text{eff}} - 1}{\varepsilon_{\text{eff}}} = \frac{1}{\bar{\mu}}, \qquad \varepsilon_{\text{eff}} = \varepsilon + \Gamma \frac{1-\beta}{1-\beta\rho}. \tag{A.10}$$

The future-reference benefit offsets part of the instantaneous demand elasticity. The subsidy $1 - \tau = 1/\bar{\mu}$ removes the steady-state monopoly distortion.

Under Assumption A.3 and the restriction $\alpha \geq 1/\varepsilon_{\text{eff}}$, any interior and feasible firm plan that satisfies the nonlinear first-order, costate, and transversality conditions above is strictly optimal within a sufficiently small neighborhood of that plan, provided inherited firm states are initially close to steady state and aggregate and firm-level variables remain uniformly close to their steady-state values (Casas and Tröltzsch, 2012, Theorem 1.3).

First-order pricing equation. Let $\widehat{mc}_t$ denote the log deviation of subsidized real marginal cost in posted-price units from its steady-state value, and let $\theta_t \equiv \Theta_t - \bar{\Theta}$. Under log utility, $\sigma = 1$, $c_t^U = y_t^U$ to first order, so $\mathcal{M}_{t+1}$ has no first-order variation. Linearizing (2.10) and (2.9) gives

$$\psi_p(\pi_t - \beta \mathbb{E}_t \pi_{t+1}) = \frac{\varepsilon + \Gamma}{\bar{\mu}} \widehat{mc}_t + \beta(1-\rho)\mathbb{E}_t \theta_{t+1}, \tag{A.11}$$

$$\theta_t = -\frac{\Gamma}{\bar{\mu}} \widehat{mc}_t + \beta\rho \mathbb{E}_t \theta_{t+1}. \tag{A.12}$$

With $\rho = 0$, the costate equation is static. Substituting its one-period-ahead version into (A.11) gives

$$\psi_p(\pi_t - \beta \mathbb{E}_t \pi_{t+1}) = \frac{\varepsilon + \Gamma}{\bar{\mu}} \left(\widehat{mc}_t - \beta\gamma \mathbb{E}_t \widehat{mc}_{t+1} \right), \qquad \gamma = \frac{\Gamma}{\varepsilon + \Gamma}. \tag{A.13}$$

To express marginal cost in terms of physical output relative to its technology benchmark, use the log deviations defined in Section 2.2. Under log utility, labor supply (2.7) and marginal cost (2.8) imply $\widehat{mc}_t = c_t^U + \chi_t - a_t + (\varphi + \alpha)n_t$. Since $c_t^U = y_t^U$ to first order and (2.14) gives $\widetilde{y}_t = y_t - a_t = y_t^U + \chi_t - a_t = (1-\alpha)n_t$, it follows that

$$\widehat{mc}_t = (1+\varphi)n_t = \frac{1+\varphi}{1-\alpha}\widetilde{y}_t. \tag{A.14}$$

Thus, to first order, marginal cost is at its steady-state value when employment is at $\bar{N}$, or equivalently when physical output equals the technology benchmark $A_t\bar{N}^{1-\alpha}$. Substituting (A.14) into (A.13) and dividing by $\psi_p > 0$ proves Proposition 1.

A.3 The Welfare Approximation

Under log utility, period utility is

$$U_t = \log C_t^U - \frac{N_t^{1+\varphi}}{1+\varphi}. \tag{A.15}$$

Expand around the zero-inflation steady state. Because the subsidy removes the steady-state labor wedge,

$$\bar{N}^{1+\varphi} = 1 - \alpha. \tag{A.16}$$

The second-order expansion of period utility is

$$U_t - \bar{U} = c_t^U - (1-\alpha)n_t - \frac{(1+\varphi)(1-\alpha)}{2}n_t^2 + O(3). \tag{A.17}$$

The resource constraint gives

$$c_t^U = y_t^U - \frac{\psi_p}{2}\pi_t^2 + O(3), \tag{A.18}$$

while the exact log production identity gives

$$n_t = \frac{y_t^U + \chi_t - a_t}{1-\alpha}. \tag{A.19}$$

Substituting these two relations into (A.17) yields

$$U_t - \bar{U} = -\chi_t - \frac{\psi_p}{2}\pi_t^2 - \frac{1+\varphi}{2(1-\alpha)}(y_t^U - a_t + \chi_t)^2 + a_t + O(3). \tag{A.20}$$

The term a_t depends only on the exogenous productivity path and is independent of policy to the relevant order. Using $\widetilde{y}_t = y_t - a_t = y_t^U + \chi_t - a_t$, changing signs, discounting, and

collecting terms gives

$$\mathcal{L}_{t_0} = \frac{1}{2}\mathbb{E}_{t_0}\sum_{t=t_0}^{\infty}\beta^{t-t_0}\left[\frac{1+\varphi}{1-\alpha}\widetilde{y}_t^2 + 2\chi_t + \psi_p\pi_t^2\right] + \text{t.i.p.} + O(3). \tag{A.21}$$

For the experiment in Section 2.5, set $t_0 = 0$ and omit the expectation operator along the perfect-foresight transition. Under symmetric pricing and $\rho = 0$, the reference law implies $2\chi_t = 2\Gamma\pi_t/(\varepsilon - 1)$, giving Proposition 2.

A.4 Symmetric Equilibrium

Maintain the smooth specification $\Gamma_L = \Gamma_G = \Gamma$. Given the exogenous processes $\{A_t, \nu_t\}_{t=0}^{\infty}$ and symmetric initial conditions $B_0 = 0$, $R_0(i) = R_0 > 0$, and $P_{-1}(i) = P_{-1} > 0$, a symmetric equilibrium is a state-contingent sequence of prices and allocations

$$\left\{\begin{array}{c} C_t^U, N_t, B_{t+1}, Y_t, Y_t^U, W_t, Q_t, I_t, P_t, P_t^{\mathrm{RD}}, D_t^F, T_t, \\ \{C_t(i), Y_t(i), N_t(i), P_t(i), R_t(i), D_t^F(i)\}_{i\in[0,1]} \end{array}\right\}_{t=0}^{\infty}$$

satisfying the following conditions at every date and almost surely:

1) *Household optimality.* Given prices, wages, profits, and transfers, variety demands solve the intratemporal expenditure-minimization problem, and $\{C_t^U, N_t, B_{t+1}\}_{t=0}^{\infty}$ solves the household's intertemporal problem in Section 2.

2) *Firm optimality.* Given aggregate prices and quantities, each firm solves the expected discounted profit-maximization problem in Section 2.

3) *Aggregation, reference updating, and symmetry.* Price indices and variety demands satisfy the aggregation relations in Section 2, and reference prices follow the specified updating law. For every i,

$$P_t(i) = P_t, \qquad R_t(i) = R_t, \qquad N_t(i) = N_t,$$
$$C_t(i) = e^{\chi_t}C_t^U, \qquad Y_t(i) = Y_t = e^{\chi_t}Y_t^U.$$

   Aggregate production satisfies $Y_t = A_t N_t^{1-\alpha}$.

4) *Monetary policy.* The nominal interest rate satisfies the posted-price-inflation Taylor rule in Section 2, with $I_t = Q_t^{-1}$.

5) *Fiscal policy.* Lump-sum taxes finance the employment subsidy, so household transfers satisfy $T_t = -\tau W_t N_t$.

6) *Market clearing.* Bonds are in zero net supply, $B_{t+1} = 0$. Labor and distributed profits

satisfy

$$N_t = \int_0^1 N_t(i)\,\mathrm{d}i, \qquad D_t^F = \int_0^1 D_t^F(i)\,\mathrm{d}i.$$

Goods-market clearing requires

$$Y_t^U = C_t^U + \frac{\psi_p}{2}(\Pi_t - 1)^2 Y_t^U, \qquad \Pi_t = \frac{P_t}{P_{t-1}}.$$

Choices depend only on available information, and expectations are consistent with the exogenous processes and equilibrium outcomes.

With the other parameters fixed at conventional values, numerical checks confirm that the smooth specification $\Gamma_L = \Gamma_G = \Gamma$ satisfies the Blanchard–Kahn conditions for $\Gamma \in [0, 1]$. Throughout this range, the system linearized around the zero-inflation steady state admits a unique stable rational-expectations solution (Blanchard and Kahn, 1980).

B The Hard-Kink RD–CES Model

Section 2 derives closed-form pricing and welfare results under the smooth restriction $\Gamma_L = \Gamma_G$. This appendix restores the hard kink but maintains the RD–CES demand system and reference law. Throughout, I focus on the loss-aversion ordering $\Gamma_L > \Gamma_G \geq 0$. At the normalized steady state, posted and reference prices coincide and the reference wedge is zero, but the kink changes the firm's marginal incentive to move its price in either direction.

The pricing thresholds, transition dynamics, and welfare analysis in Appendices B.2–B.4 are derived under perfect foresight, consistent with the main text and quantitative analysis.

The extension has four economic consequences. First, the differentiable steady-state pricing condition becomes a pair of one-sided conditions, so an interval of employment subsidies can support $P = R$. Second, under the conditions stated below, the kink can generate an endogenous inaction region even without Rotemberg adjustment costs. Third, outside that region, firms satisfy branch-specific nonlinear pricing conditions whose first-order approximations differ across the loss and gain branches. Finally, inflationary and deflationary excursions can have asymmetric welfare effects. The results below provide the analytical counterpart to the rule-conditioned nonlinear transitions used in the quantitative analysis.

Customer-side behavioral models provide a natural precedent for this mechanism. Perceived unfairness and customer anger can restrain price increases and change the frequency of price adjustment (Rotemberg, 2005, 2011), while Rotemberg (2008) discusses the broader behavioral evidence and its monetary-policy implications. The RD–CES model gives these responses a specific demand-system representation based on posted prices relative to reference prices.

B.1 Steady-State Pricing at the Kink

At $P = R$, the firm's payoff is continuous but generally not differentiable. The usual equality first-order condition must therefore be replaced by a right derivative for a price increase and a left derivative for a price cut. This result does not require log utility or a one-period reference: take $\sigma \geq 1$ and $\rho \in [0, 1)$. Define $d_t(i) \equiv p_t(i) - r_t(i) = \log[P_t(i)/R_t(i)]$. The hard-kink demand schedule is

$$Y_t(i) = \begin{cases} \left[\dfrac{P_t(i)}{R_t(i)}\right]^{-\Gamma_L} \left[\dfrac{P_t(i)}{P_t^{\mathrm{RD}}}\right]^{-\varepsilon} Y_t^U, & d_t(i) \geq 0, \\ \left[\dfrac{P_t(i)}{R_t(i)}\right]^{-\Gamma_G} \left[\dfrac{P_t(i)}{P_t^{\mathrm{RD}}}\right]^{-\varepsilon} Y_t^U, & d_t(i) < 0, \end{cases} \qquad \Gamma_L > \Gamma_G \geq 0. \tag{B.1}$$

Here Γ_L and Γ_G are the reference-price elasticities above and below the reference price. With $R_{t+1}(i) = R_t(i)^\rho P_t(i)^{1-\rho}$, the firm's flow profit and Bellman equation are

$$\begin{aligned} D_t^F(i) &= P_t(i)Y_t(i) - (1-\tau)W_t N_t(i) - \frac{\psi_p}{2}\left[\frac{P_t(i)}{P_{t-1}(i)} - 1\right]^2 P_t^{\mathrm{RD}} Y_t^U, \\ Y_t(i) &= A_t N_t(i)^{1-\alpha}, \\ \mathcal{V}_t(R_t(i), P_{t-1}(i)) &= \max_{P_t(i)} \left\{ \Lambda_t \frac{D_t^F(i)}{P_t^{\mathrm{RD}}} + \beta \mathbb{E}_t \mathcal{V}_{t+1}(R_{t+1}(i), P_t(i)) \right\}. \end{aligned} \tag{B.2}$$

The firm chooses its posted price; (B.1) determines sales, and the technology in (B.2) determines the employment required to meet them.

Throughout, inherited states and the aggregate path are held fixed in firm-level comparisons, and the Bellman return includes optimized continuation choices. Maintain Assumption A.3. Global optimality results additionally require the following assumption.

Assumption B.1 (Branchwise single-peakedness)**.** *On the admissible domain, the maximand of* (B.2)*, viewed as a function of* $d_t(i) = \log[P_t(i)/R_t(i)]$ *holding states and aggregates fixed, is strictly quasiconcave on each branch* $\{d_t(i) \geq 0\}$ *and* $\{d_t(i) \leq 0\}$*.*

Consider a unilateral deviation at date t from the deterministic zero-inflation allocation $\bar{P} = \bar{R} = \bar{P}_{-1}$, evaluated against the firm's own continuation policy. Suppose that after a sufficiently small price deviation the firm tracks its updated reference price in each subsequent period, $P_{t+k}(i) = R_{t+k}(i)$ for $k \geq 1$; Proposition B.1 maintains this tracking condition. A date-t log-price change h then raises all subsequent references and posted prices permanently: $\log R_{t+k}(i) = \log P_{t+k}(i) = \log \bar{P} + (1-\rho)h$ for every $k \geq 1$. Holding the aggregate path fixed, the deviation changes the posted price relative to its reference only at date t. In subsequent periods, posted and reference prices move together, so only the relative-price effect governed by ε remains.

The coefficient $\Phi(\rho)$ summarizes the discounted future effect of today's price change on the firm's relative price. Averaging the one-period branch penalty over the $1 + \Phi(\rho)$ discounted periods of exposure yields the directional effective elasticities

$$\Phi(\rho) \equiv \sum_{k=1}^{\infty} \beta^k (1-\rho) = \frac{\beta(1-\rho)}{1-\beta}, \qquad \varepsilon^{\uparrow} \equiv \varepsilon + \Gamma_L \frac{1-\beta}{1-\beta\rho}, \qquad \varepsilon^{\downarrow} \equiv \varepsilon + \Gamma_G \frac{1-\beta}{1-\beta\rho}, \tag{B.3}$$

using $1 + \Phi(\rho) = (1-\beta\rho)/(1-\beta)$. These expressions follow from equation (2.11) by setting $\Gamma = \Gamma_L$ for upward deviations and $\Gamma = \Gamma_G$ for downward deviations. An upward deviation pays the loss-branch penalty Γ_L during its single transition period and the ordinary elasticity ε thereafter, and symmetrically for a downward deviation with Γ_G.

At the MRS–MPL allocation, $\mathrm{MRS}_{N,C^U} \equiv -U_N/U_{C^U} = (C^U)^\sigma N^\varphi = \mathrm{MPL}$. At this allocation, household labor supply implies that unsubsidized real marginal cost in posted-

price units is $W/(\bar{P}\,\mathrm{MPL}) = 1$. The firm's subsidized real marginal cost is therefore $\bar{mc} = (1-\tau)W/(\bar{P}\,\mathrm{MPL}) = 1-\tau$.

Let $\mathscr{B}_t(h)$ denote the firm's Bellman return when $P_t(i) = \bar{P}e^h$, holding inherited states and the aggregate path fixed and optimizing continuation choices. Where tracking is locally optimal, the continuation term follows the policy above. Define

$$\mathcal{D}^+ \equiv \frac{1}{\bar{\Lambda}\bar{Y}^U}\lim_{h\downarrow 0}\frac{\mathscr{B}_t(h)-\mathscr{B}_t(0)}{h}, \quad \mathcal{D}^- \equiv \frac{1}{\bar{\Lambda}\bar{Y}^U}\lim_{h\downarrow 0}\frac{\mathscr{B}_t(-h)-\mathscr{B}_t(0)}{-h}.$$

The normalization $\bar{\Lambda}\bar{Y}^U$ is steady-state output in composite units valued at the marginal utility of consumption, which under symmetric pricing equals the utility value of revenue, so the derivatives are measured in current-revenue-equivalent units. They are derivatives with respect to the current log price, not derivatives with respect to a state variable. Direct computation of the deviation value gives

$$\mathcal{D}^+ = (1+\Phi(\rho))\big[1-\varepsilon^{\uparrow}(1-\bar{mc})\big], \qquad \mathcal{D}^- = (1+\Phi(\rho))\big[1-\varepsilon^{\downarrow}(1-\bar{mc})\big]. \tag{B.4}$$

No profitable price increase requires $\mathcal{D}^+ \le 0$, while no profitable price cut requires $\mathcal{D}^- \ge 0$.

Proposition B.1 (Subsidies supporting the reference price)**.** *Suppose the Bellman return is continuous at $P = R$, tracking is optimal following sufficiently small deviations, and $\varepsilon^{\uparrow}, \varepsilon^{\downarrow} > 1$. Then the one-sided first-order no-deviation conditions at $P = R = \bar{P}$ hold if and only if*

$$\frac{1}{\varepsilon^{\uparrow}} \le \tau \le \frac{1}{\varepsilon^{\downarrow}}. \tag{B.5}$$

Strictly inside this interval,

$$\mathcal{D}^+ < 0 < \mathcal{D}^-,$$

so the reference price is a strict local maximizer of the Bellman return. Under Assumption B.1, it is also the unique global maximizer on the admissible price domain.

The interval is nonempty because $\Gamma_L > \Gamma_G$. When the two elasticities coincide, it collapses to the smooth-model subsidy $\tau = 1/\varepsilon_{\mathrm{eff}}$.

B.2 The Inaction Region

Under the conditions below, the hard kink can make the reference price optimal over an interval of pricing pressure. Inaction here means setting the posted price equal to the current reference price. With persistent references, this need not imply an unchanged posted price upon entry into the region. Define

$$z_t \equiv mc_t = \frac{(1-\tau)W_t}{P_t\mathrm{MPL}_t}. \tag{B.6}$$

Section 4 adds a cost-push factor υ_t, so that $z_t = \upsilon_t mc_t$ there. Higher marginal cost relative to the posted price, z_t, increases the incentive to raise that price. Upward and downward deviations affect future references differently, shifting the two thresholds separately.

Related inaction mechanisms arise from asymmetric consumer search (Dupraz, 2017) and managers' reference-dependent mental accounting (Angelis, 2025). Here the asymmetry enters household demand, and the thresholds depend on the firm's continuation values.

Consider a date on a deterministic perfect-foresight path at which $P_t(i) = R_t(i)$. At the states and aggregate paths considered below, assume that optimized continuation value admits left- and right-hand partial derivatives with respect to its inherited reference price, holding its inherited posted-price state fixed. Let $\Pi_t = P_t/P_{t-1}$ and define the intertemporal scaling term and directional reference costates as

$$\mathcal{M}_{t+1} \equiv \left(\frac{C^U_{t+1}}{C^U_t}\right)^{-\sigma} \frac{Y^U_{t+1}}{Y^U_t}, \qquad \Theta^{R,\pm}_{t+1} \equiv \frac{R_{t+1}}{\Lambda_{t+1} Y^U_{t+1}} D^{\pm}_R \mathcal{V}_{t+1}. \tag{B.7}$$

Here $D^{\pm}_R \mathcal{V}_{t+1}$ is the one-sided partial derivative of optimized firm value with respect to its reference state, holding its inherited posted-price state fixed. The signs correspond to the reference change induced by a current price increase $(+)$ or cut $(-)$. Future pricing choices remain optimized. The adjustment-cost and continuation terms are

$$\begin{aligned} \mathcal{A}_t &\equiv -\psi_p(\Pi_t - 1)\Pi_t + \beta\psi_p \mathcal{M}_{t+1}(\Pi_{t+1} - 1)\Pi_{t+1}, \\ \mathcal{R}^{\pm}_t &\equiv \beta(1-\rho)\mathcal{M}_{t+1}\Theta^{R,\pm}_{t+1}. \end{aligned} \tag{B.8}$$

As in Appendix B.1, let $\mathcal{D}^+_t$ and $\mathcal{D}^-_t$ denote the right and left derivatives of the Bellman return with respect to the current log posted price, normalized by $\Lambda_t Y^U_t$. Holding inherited states and the aggregate path fixed, and evaluating continuation value under optimal future pricing, their values at the kink are

$$\begin{aligned} \mathcal{D}^+_t &= 1 - (\varepsilon + \Gamma_L)(1 - z_t) + \mathcal{A}_t + \mathcal{R}^+_t, \\ \mathcal{D}^-_t &= 1 - (\varepsilon + \Gamma_G)(1 - z_t) + \mathcal{A}_t + \mathcal{R}^-_t. \end{aligned} \tag{B.9}$$

Holding $\mathcal{A}_t$ and $\mathcal{R}^{\pm}_t$ fixed, the roots of these derivatives define the lower and upper thresholds:

$$\begin{aligned} \underline{z}_t &\equiv 1 - \frac{1 + \mathcal{A}_t + \mathcal{R}^-_t}{\varepsilon + \Gamma_G}, \qquad & \mathcal{D}^-_t(\underline{z}_t) = 0, \\ \overline{z}_t &\equiv 1 - \frac{1 + \mathcal{A}_t + \mathcal{R}^+_t}{\varepsilon + \Gamma_L}, \qquad & \mathcal{D}^+_t(\overline{z}_t) = 0. \end{aligned} \tag{B.10}$$

Because $\mathcal{R}^+_t$ and $\mathcal{R}^-_t$ depend on future regimes, both thresholds are state-contingent equilibrium objects.

Proposition B.2 (Inaction thresholds and optimality)**.** *Suppose the Bellman return is continuous on the compact admissible price domain, the reference price lies in its interior, and the*

one-sided derivatives defined above exist. Holding $\mathcal{A}_t$ *and* $\mathcal{R}_t^{\pm}$ *fixed in the threshold calculation, suppose* $0 < \underline{z}_t \leq \overline{z}_t$*. Then*

$$\underline{z}_t \leq z_t \leq \overline{z}_t \quad \Longleftrightarrow \quad \mathcal{D}_t^+ \leq 0 \leq \mathcal{D}_t^-. \tag{B.11}$$

Strictly inside this interval,

$$\mathcal{D}_t^+ < 0 < \mathcal{D}_t^-,$$

so $P_t(i) = R_t(i)$ *is a strict local maximizer. Under Assumption B.1, a unique global maximizer exists in each strict case and satisfies*

$$\begin{cases} P_t^\star(i) < R_t(i), & z_t < \underline{z}_t, \\ P_t^\star(i) = R_t(i), & \underline{z}_t < z_t < \overline{z}_t, \\ P_t^\star(i) > R_t(i), & z_t > \overline{z}_t, \end{cases} \tag{B.12}$$

Remark B.1 (Local and global optimality). Strict one-sided inequalities make sufficiently small deviations in either direction unprofitable. Branchwise single-peakedness additionally excludes profitable larger deviations. At the endpoints of either the subsidy or inaction interval, one derivative is zero, and the first-order conditions alone do not establish local or global optimality. Appendix F.2 provides numerical support for branchwise single-peakedness and approximate firm optimality along the tested baseline cost-push paths, with continuation choices re-optimized after each deviation.

The threshold ordering required by Proposition B.2 is equivalent to

$$\frac{1 + \mathcal{A}_t + \mathcal{R}_t^-}{\varepsilon + \Gamma_G} \geq \frac{1 + \mathcal{A}_t + \mathcal{R}_t^+}{\varepsilon + \Gamma_L}. \tag{B.13}$$

A sufficient condition is $1 + \mathcal{A}_t + \mathcal{R}_t^+ > 0$ and $\mathcal{R}_t^- \geq \mathcal{R}_t^+$. When the continuation value at date $t+1$ is differentiable in its reference state, $\Theta_{t+1}^{R,+} = \Theta_{t+1}^{R,-}$, so $\mathcal{R}_t^+ = \mathcal{R}_t^- = \mathcal{R}_t$. Weak threshold ordering then requires $1 + \mathcal{A}_t + \mathcal{R}_t \geq 0$; strict ordering requires a strict inequality, as at the policy-consistent zero-inflation continuation in Appendix B.1. Away from that continuation, the nonlinear equilibrium determines the thresholds and their ordering jointly with the active regime.

Corollary (Inaction without Rotemberg costs)**.** *Maintain the continuity and directional differentiability conditions of Proposition B.2 and Assumption A.3. Set* $\psi_p = 0$ *and evaluate the policy-consistent zero-inflation continuation used in Appendix B.1. Then*

$$\frac{\varepsilon^\downarrow - 1}{\varepsilon^\downarrow} \leq z_t \leq \frac{\varepsilon^\uparrow - 1}{\varepsilon^\uparrow} \tag{B.14}$$

is an interval on whose strict interior the reference price is a strict local maximizer, even

though changing prices carries no quadratic cost. Under Assumption B.1, it is the unique global maximizer on the admissible domain. The interval's width is

$$\frac{\Gamma_L - \Gamma_G}{\varepsilon^{\uparrow}\varepsilon^{\downarrow}} \frac{1-\beta}{1-\beta\rho} > 0. \tag{B.15}$$

Inaction here comes from the different marginal returns to raising and cutting prices at the reference. It survives even when price changes consume no resources.

With log utility and no Rotemberg adjustment costs, let $\lambda_y \equiv (1+\varphi)/(1-\alpha)$ and recall from Section 2.3 that $\widetilde{y}_t \equiv y_t - a_t$ is the log deviation of physical output from its technology benchmark. The household and production conditions imply

$$z_t = (1-\tau)\exp\{\lambda_y \widetilde{y}_t\}. \tag{B.16}$$

These thresholds translate into an interval for $\widetilde{y}_t$, the physical-output deviation from its technology benchmark, with the same local and conditional global optimality conclusions on its strict interior.

Proposition B.2 is conditional on inherited states and continuation values. It supplies the complementarity conditions used by the nonlinear equilibrium solution; it does not by itself establish aggregate existence, uniqueness, or regime selection.

Assumption A.3 also bounds the shadow values of the firm's state variables. Holding the price plan fixed, a change in the log reference price shrinks by a factor ρ each period, while the lagged posted price affects only the current adjustment cost. Discounting yields a Lipschitz bound that is uniform across dates and admissible plans. Maximizing over these plans preserves the bound (Milgrom and Segal, 2002, Theorem 2). The assumed one-sided derivatives are therefore bounded, and their normalized costates satisfy

$$\lim_{J\to\infty} \beta^J \left|\Lambda_{t+J} Y_{t+J}^U \Theta_{t+J}^{R,\pm}\right| = 0.$$

Before normalization by $\Lambda_t Y_t^U$, the continuation multipliers are $\beta\rho$ on smooth branches and β under tracking. Together with the uniform bound on shadow values, this makes the discounted remainder converge to zero under either regime. This rules out non-fundamental solutions without requiring the costate itself to converge to zero.

B.3 Inflation Dynamics Away from the Kink

Outside the inaction region, pricing depends on the active branch's demand elasticity and the continuation value of a higher reference price. Maintain $\sigma = 1$, $\rho = 0$, symmetric firms, and deterministic perfect foresight. Then $d_t = \log(P_t/R_t) = \pi_t$: positive inflation selects the loss branch $b_t = L$, and negative inflation the gain branch $b_t = G$.

On a smooth branch, let $\Theta_t \equiv [R_t/(\Lambda_t Y_t^U)]\partial\mathcal{V}_t/\partial R_t$ denote the ordinary reference-state

costate. For an interior optimum, where the price corridor does not bind, the exact pricing system is

$$\begin{aligned}\mathcal{P}_t &\equiv \psi_p[(\Pi_t - 1)\Pi_t - \beta\mathcal{M}_{t+1}(\Pi_{t+1} - 1)\Pi_{t+1}]\,,\\ \Theta_t &= \Gamma_{b_t}(1 - z_t),\\ \mathcal{P}_t &= (\varepsilon + \Gamma_{b_t})z_t - (\varepsilon + \Gamma_{b_t} - 1) + \beta\mathcal{M}_{t+1}\Theta_{t+1}.\end{aligned} \tag{B.17}$$

Here $\Pi_t = P_t/P_{t-1}$ is gross inflation, $\mathcal{P}_t$ is the Rotemberg residual, and z_t and $\mathcal{M}_{t+1}$ are defined in Appendix B.2. If the economy switches branch tomorrow, Θ_{t+1} uses tomorrow's elasticity; if it reaches the kink, the appropriate directional costate $\Theta^{R,+}_{t+1}$ or $\Theta^{R,-}_{t+1}$ replaces the ordinary costate.

Let $\bar{mc} = 1 - \tau$ and recall $\widetilde{y}_t = y_t - a_t = y^U_t + \chi_t - a_t$ and $\lambda_y = (1 + \varphi)/(1 - \alpha)$.

Proposition B.3 (Off-kink branchwise Phillips curves)**.** *Conditional on interior pricing on the same branch $b \in \{L, G\}$ at dates t and $t + 1$, the directional first-order pricing equation is*

$$\psi_p(\pi_t - \beta\pi_{t+1}) = \Delta_b + \bar{mc}\lambda_y\left[(\varepsilon + \Gamma_b)\widetilde{y}_t - \beta\Gamma_b\widetilde{y}_{t+1}\right], \qquad \Delta_b \equiv 1 - [\varepsilon + (1 - \beta)\Gamma_b]\,(1 - \bar{mc}). \tag{B.18}$$

Use $b = L$ when $\pi_t, \pi_{t+1} > 0$ and $b = G$ when $\pi_t, \pi_{t+1} < 0$.

Under log utility, $c^U_t = y^U_t$ to first order, so $\mathcal{M}_{t+1}$ has no first-order variation. Substituting $z_t = \bar{mc}(1 + \lambda_y\widetilde{y}_t) + O(2)$ into (B.17) and retaining first-order terms gives (B.18), as in Appendix A.2.

The branch elasticity enters both current demand and the continuation value of a higher reference price. The intercept also differs: setting $\Delta_b = 0$ requires $1 - \bar{mc} = 1/[\varepsilon + (1 - \beta)\Gamma_b]$. One employment subsidy cannot set both intercepts to zero when $\Gamma_L \neq \Gamma_G$, even though it can support the kink allocation of Proposition B.1. Equal-sized inflationary and deflationary shocks therefore need not generate mirror-image responses.

Under Proposition B.2 and Assumptions A.3 and B.1, a shock that raises z_t above $\overline{z}_t$ selects the loss branch; one that lowers it below $\underline{z}_t$ selects the gain branch. Equation (B.17) governs interior pricing away from the kink. On reentry at $d_t = 0$, the one-sided condition $\mathcal{D}^+_t \leq 0 \leq \mathcal{D}^-_t$ of (B.11) replaces the pricing equality.

Equation (B.18) is a fixed-branch directional approximation. If $\Delta_b \neq 0$, that branch cannot approach $(\pi_t, \widetilde{y}_t) = (0, 0)$ as an ordinary smooth perturbation. The nonlinear solution determines exit, persistence on a branch, and reentry into the inaction region.

B.4 Welfare with Kinked Reference Dependence and CRRA Utility

This subsection extends the welfare approximation in Appendix A.3 to unequal reference-price elasticities and CRRA curvature $\sigma \geq 1$, with log utility at $\sigma = 1$. Maintain symmetric pricing and perfect foresight, allowing any reference persistence $\rho \in [0, 1)$. The benchmark is the

zero-inflation MRS–MPL allocation, with $\bar{P} = \bar{R}$, $\bar{\chi} = 0$, and $\bar{C}^U = \bar{Y}^U = \bar{Y}$. Interpreting this benchmark as a steady-state equilibrium requires firm optimality; the global conclusion of Proposition B.1 provides sufficient conditions.

Lowercase real quantities denote log deviations from this benchmark. Recall $\widetilde{y}_t = y_t - a_t = y_t^U + \chi_t - a_t$ and $\lambda_y = (1+\varphi)/(1-\alpha)$. Let $\bar{\Lambda} = (\bar{C}^U)^{-\sigma}$ denote steady-state marginal utility. Normalize period utility losses by $\bar{\Lambda}\bar{C}^U = (\bar{C}^U)^{1-\sigma}$:

$$\ell_t \equiv \frac{\bar{u} - u_t}{(\bar{C}^U)^{1-\sigma}}. \tag{B.19}$$

Here u_t is period utility and $\bar{u}$ is its benchmark value.

Proposition B.4 (Welfare with kinked reference dependence and CRRA utility)**.** *Under the assumptions above, the normalized period utility loss has the second-order expansion*

$$\ell_t = \frac{\sigma - 1}{2}(y_t^U)^2 + \frac{\lambda_y}{2}\widetilde{y}_t^2 + \chi_t + \frac{\psi_p}{2}\pi_t^2 + \text{t.i.p.} + O(3), \tag{B.20}$$

where the policy-independent term is $-a_t$. Summing this approximation over time with discount factor β defines the normalized lifetime loss $\mathcal{L}_{t_0}^{(2)}$. At $\sigma = 1$, the consumption-curvature term vanishes, yielding the log-utility welfare kernel underlying (A.21), with the kinked reference wedge.

Proof. The benchmark condition implies $\bar{N}^{1+\varphi} = (1-\alpha)\bar{\Lambda}\bar{C}^U$. After normalization, the expansion of period utility losses has the same linear and labor terms as the log-utility loss in Appendix A.3, plus $(\sigma-1)(c_t^U)^2/2$. Substituting $c_t^U = y_t^U - \psi_p\pi_t^2/2 + O(3)$ from (A.18) and $n_t = \widetilde{y}_t/(1-\alpha)$ from (2.14) gives (B.20). These aggregation identities hold on both sides of the kink and at the reference price. □

The curvature term is quadratic in composite output y_t^U, while the activity term is quadratic in $\widetilde{y}_t$. The reference term is signed and first order in the realized price–reference gap $d_t = \log(P_t/R_t)$: $\chi_t = \Gamma_L d_t/(\varepsilon-1)$ above the reference and $\chi_t = \Gamma_G d_t/(\varepsilon-1)$ below it. Thus equal and opposite gaps generate larger first-order losses than gains when $\Gamma_L > \Gamma_G$. At the kink, $\chi_t = 0$, but $\widetilde{y}_t$ need not vanish. This remains possible without Rotemberg costs under the conditions in Appendix B.2.

When $\rho = 0$, $d_t = \pi_t$, so the reference term can be written directly in terms of current inflation. With persistent references, the sign of d_t selects the branch. The expansion is directional at the kink. Absolute losses relative to steady state must retain the productivity term $-a_t$; it vanishes in the cost-push exercises of Section 4, where $a_t = 0$.

Consumption-equivalent losses. The permanent consumption-equivalent loss λ reduces steady-state consumption to $(1-\lambda)\bar{C}^U$, holding labor at $\bar{N}$. For an exact discounted utility

loss ΔW, define $x = (1-\beta)\Delta W/(\bar{\Lambda}\bar{C}^U)$. The exact conversion is $\lambda = 1 - \big(1-(1-\sigma)x\big)^{1/(1-\sigma)}$ for $\sigma > 1$, with log-utility limit $\lambda = 1 - e^{-x}$. Its second-order expansion is

$$\lambda = x - \frac{\sigma}{2}\,x^2 + O(x^3). \tag{B.21}$$

Using $x = (1-\beta)\mathcal{L}_0^{(2)}$ produces an approximation even when the exact conversion formula is applied. An order-consistent second-order conversion retains the square of only the full first-order part of x, including the productivity term when it is present.

C Survey Instrument

This appendix provides further details on the structure of the survey. Appendix C.1 describes the order in which questions are presented, how scenarios are randomized, and how respondents' earlier answers enter later questions. Appendix C.2 reproduces the screens for the questions used in the analysis, with the product, package size, store, and prices filled in for an example respondent.

C.1 Structure, Randomization, and Logic

Entry. Respondents recruited on Prolific are first asked to provide their Prolific ID (automatically filled in), complete a bot-verification check, and indicate whether they consent to participate. The consent form states the study's purpose and expected duration of about ten minutes. It also states that the survey contains two attention checks and that compensation requires passing both. It asks respondents not to use AI tools to answer the questions. The survey ends if a respondent does not consent to participate. A short introduction then informs respondents that they will identify a product, report the price they typically expect to pay for it, and answer questions about their purchase decisions in hypothetical shopping scenarios. Page timers record time spent on the entry screens, and Qualtrics records total completion time.

Product setup. The respondent selects a product category (a grocery staple, or a self-described alternative) and then enters three free-text fields: the specific product, the package or unit size they typically buy, and the store where they usually buy it (Figure C.1). Many subsequent questions remind respondents of their product, package size, and usual store. All prices are quoted for the package or unit size identified by the respondent. A first attention check follows (a six-point agreement scale with the instruction to select "Disagree").

Baseline elicitation and constructed prices. Each respondent i reports the price they typically expect to pay for one unit of their product at their usual store, denoted R_{i0}, as a numeric entry with up to two decimal places (Figure C.2). They then report the number of units they would purchase in a typical month (denoted q_{i0}) at their baseline reference price (Figure C.3). The survey uses the reported reference price to calculate every subsequent price shown to the respondent in the hypothetical scenarios.

Demand scenarios and their randomization. Having identified their product and reported their baseline reference price and monthly purchases at that price, respondents then answer questions about two hypothetical shopping scenarios used to identify the reference-price elasticities. As discussed in Section 3, both scenarios keep next month's posted price equal to

the respondent's baseline reference price, R_{i0}, but frame it as a temporary deviation from what the product usually costs.

In the loss scenario, the usual price is below R_{i0}, so next month's price is presented as a temporary increase (Figures C.4 and C.5). In the gain scenario, the usual price is above R_{i0}, so next month's price is presented as a temporary decrease (Figures C.6 and C.7). In both scenarios, the price returns to its usual level after next month.

The gap between the usual and baseline prices is randomly assigned to be 12%, 20%, or 28% of the baseline reference price, with the same percentage applying to both scenarios for a given respondent. The order in which respondents encounter the loss and gain scenarios is randomized. In each scenario, respondents first report how many units they would purchase next month and then the price they would typically expect to pay after next month.

In each of the above scenarios, respondents are asked to hold income and the prices of other goods fixed and to state their intended purchases for next month's use only. A second attention check follows these questions, and the survey terminates early for respondents who have failed both checks.

Descriptive questions. Three questions follow: whether the product is perishable, how often the respondent shops for it at their usual store (Figure C.8), and how a posted price equal to R_{i0} would feel (too low, about right, or too high; Figure C.9).

Reference-price updating. To estimate how quickly reference prices update in response to new price information, respondents consider a scenario in which they paid R_{i0} on previous shopping trips and encounter a price of $1.2R_{i0}$, a 20% increase, on their next trip. Respondents are randomly assigned to one of two arms. The expected-price (E) arm asks what price they would typically expect to pay going forward (Figure C.10). The normal-price (N) arm asks what price would feel like the normal price going forward, defined as "a price you've gotten used to paying that feels neither too high nor too low" (Figure C.11).

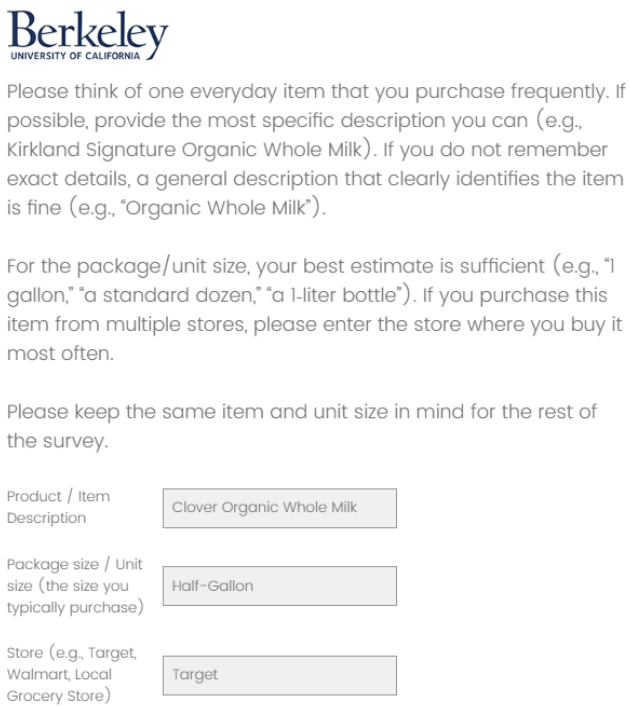
E-arm respondents receive one follow-up: after the higher price has persisted for a full month, does it feel too low, about right, or too high (Figure C.12). All respondents then answer a trend-inflation question: after five years in which all prices and the respondent's income rise steadily by 2% per year, so that the product's price reaches $1.02^5 R_{i0} \approx 1.104 R_{i0}$, does that price feel too low, about right, or too high. This question is not used in the analysis in this paper.

The survey then asks respondents how often they have their typically expected price in mind when shopping for the product (Figure C.14). They then report which factors influence the price they typically expect to pay (Figure C.13). Finally, respondents answer a question about their emotional response to encountering a price 20% above their baseline reference price, R_{i0}, followed by the corresponding question about a price 20% below it (Figures C.15 and C.16).

C.2 Question Screens

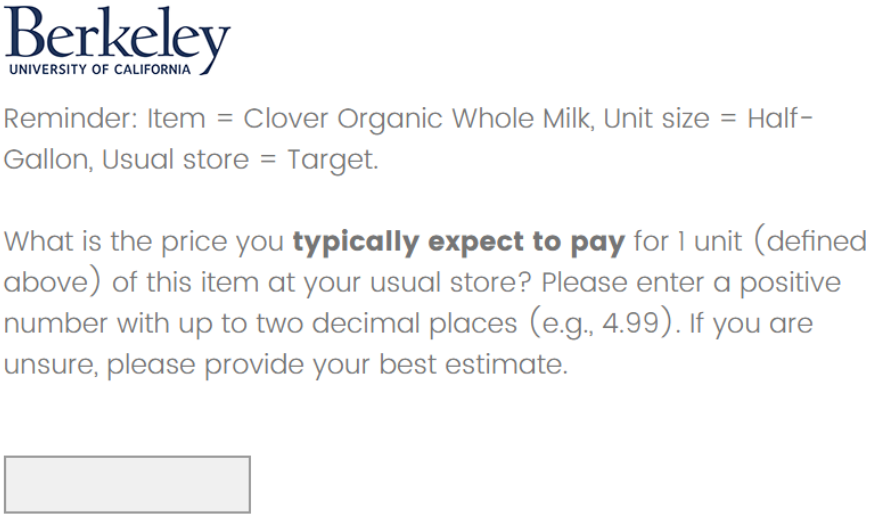
The screens below reproduce the questions used in the analysis. The example follows a respondent who buys Clover Organic Whole Milk in half-gallon packages at Target and reports a baseline reference price of $R_{i0} = \$4.99$.

Figure C.1: Setup: Product, Package Size, and Usual Store



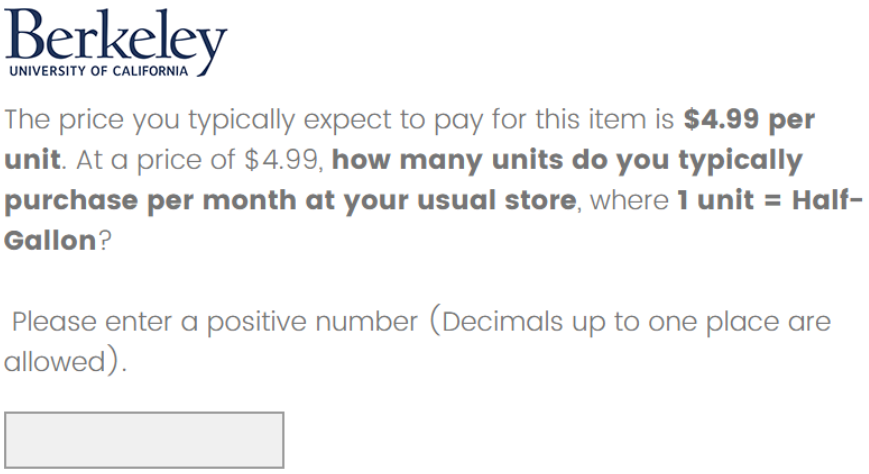
Notes: All later questions pipe the selected product, package/unit size, and store into the question text.

Figure C.2: Baseline Reference-Price Elicitation (R_{i0})



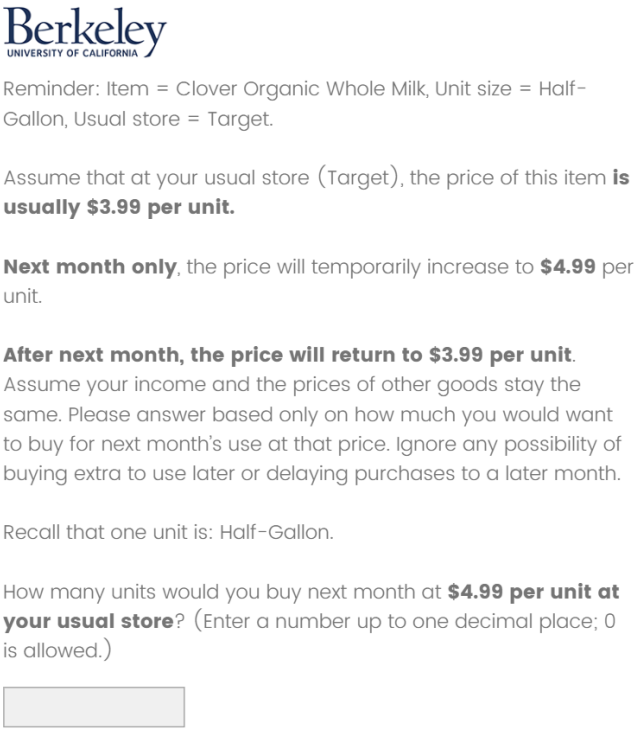
Notes: The per-unit price the respondent typically expects to pay for the item at the usual store.

Figure C.3: Baseline Quantity (q_{i0})



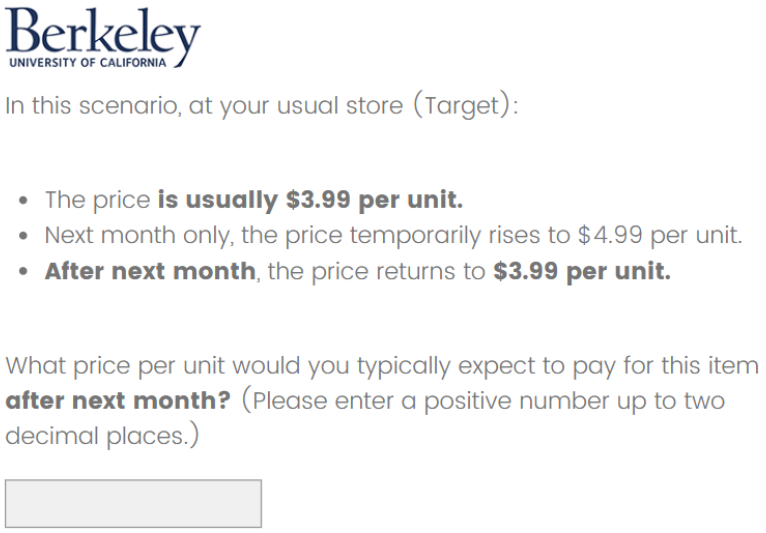
Notes: Units purchased per month at the baseline reference price R_{i0}; q_{i0} is the offset in the estimating equations.

Figure C.4: Loss Scenario: Quantity (q_{iL})



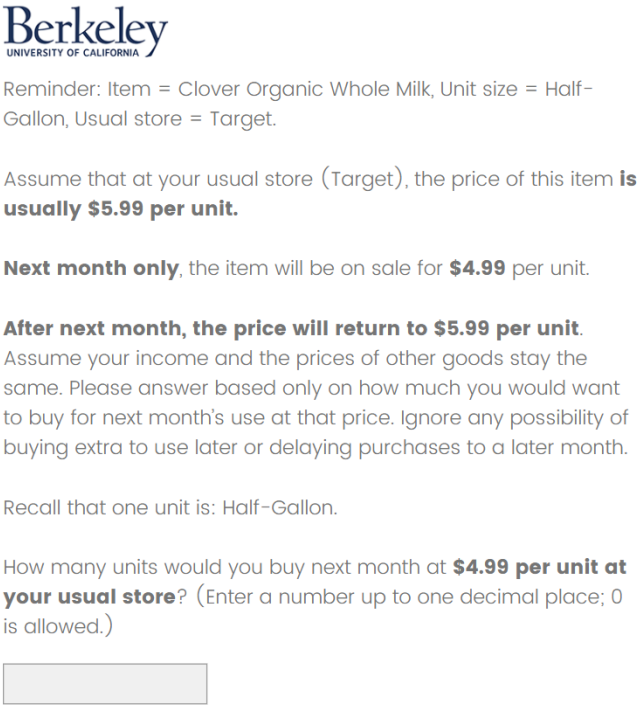
Notes: A usual price of $(1 - g_i)R_{i0}$, a temporary one-month increase to the posted price $P_i = R_{i0}$, and the units the respondent would buy that month.

Figure C.5: Loss Scenario: Elicited Reference (R_{iL})



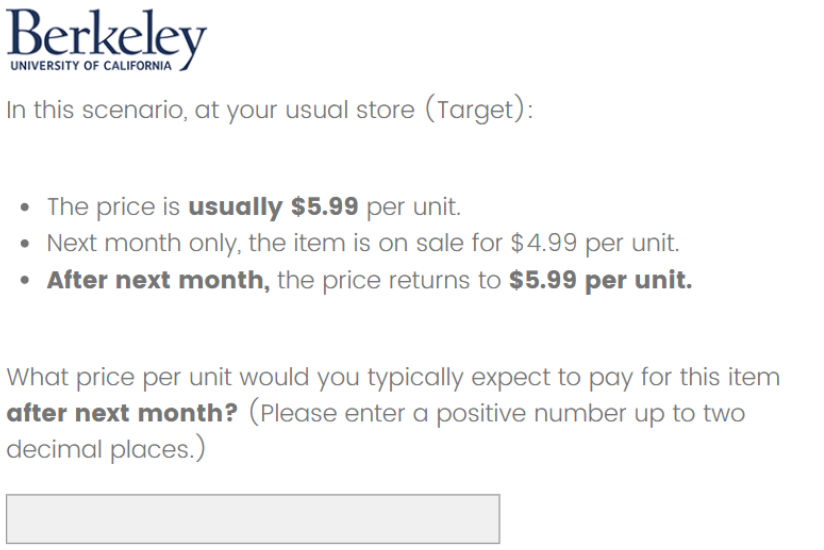
Notes: The per-unit price the respondent would expect to pay going forward.

Figure C.6: Gain Scenario: Quantity (q_{iG})



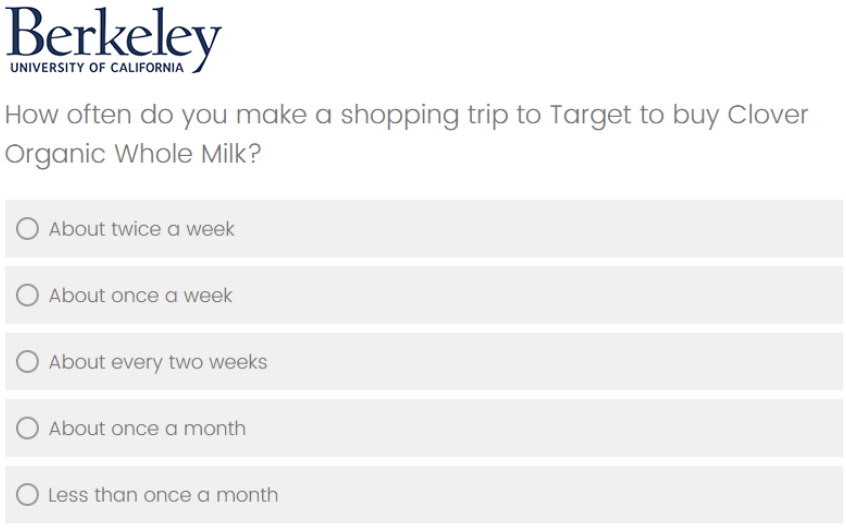
Notes: A usual price of $(1 + g_i)R_{i0}$, a temporary one-month sale at the posted price $P_i = R_{i0}$, and the units the respondent would buy that month.

Figure C.7: Gain Scenario: Elicited Reference (R_{iG})



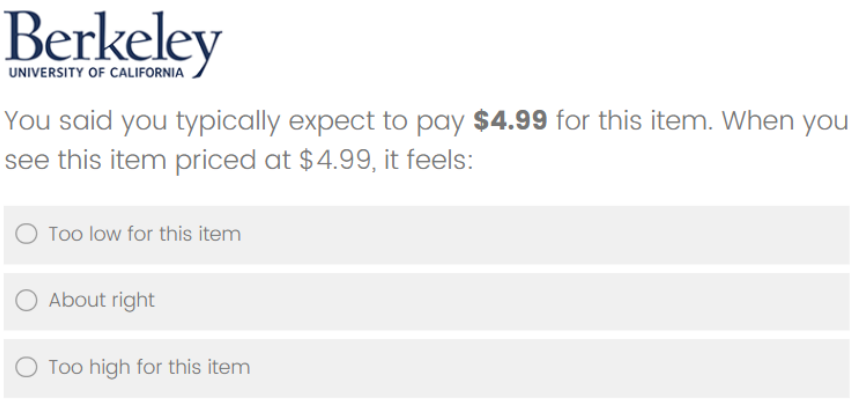
Notes: The per-unit price the respondent would expect to pay going forward.

Figure C.8: Shopping Frequency



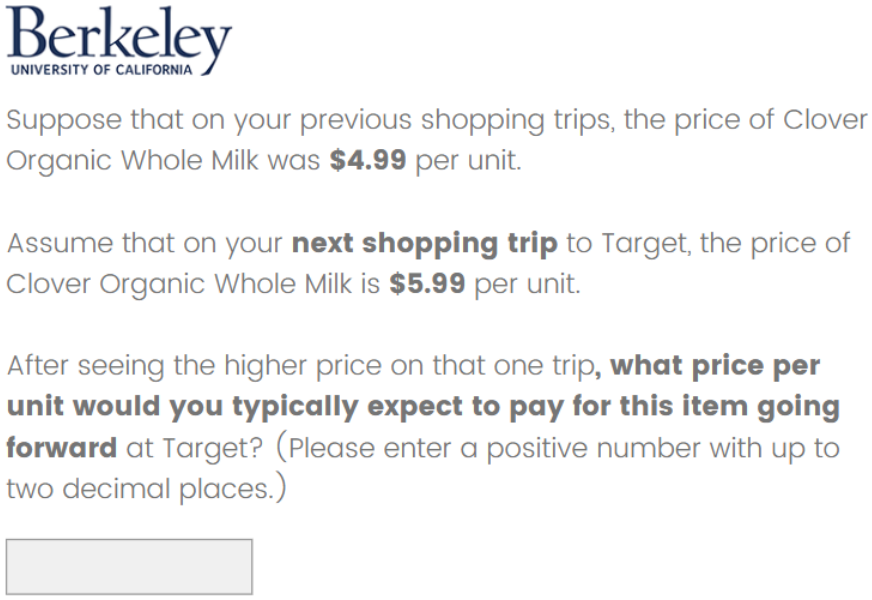
Notes: How often the respondent makes a trip to the usual store to buy the item. This response supplies the trips-per-quarter exponent n_i used to convert $\hat{\rho}_{\text{trip},i}$ to $\hat{\rho}_{\text{qtr},i}$.

Figure C.9: Baseline Reference-Price Feeling



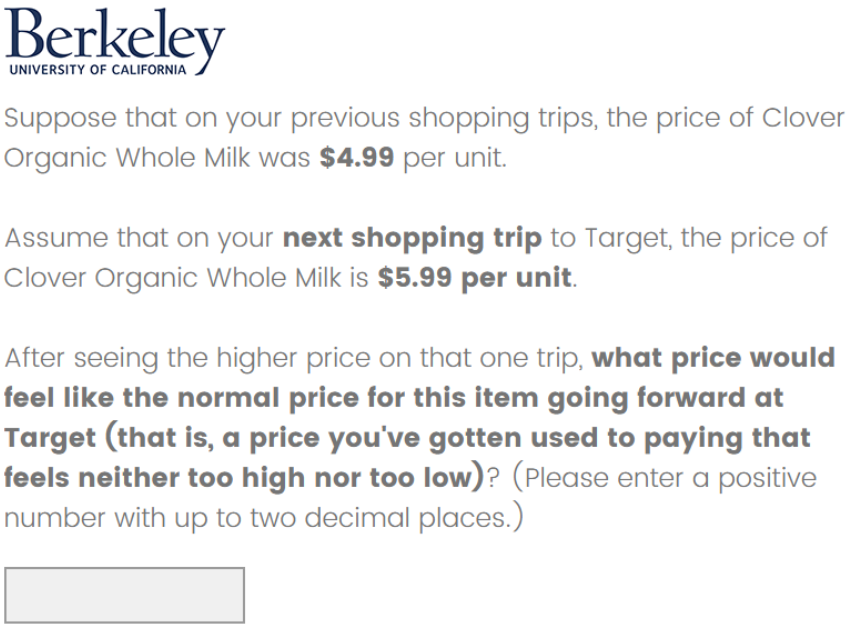
Notes: Whether a posted price equal to R_{i0} feels too low, about right, or too high for the item.

Figure C.10: Reference-Price Persistence Elicitation, E Arm



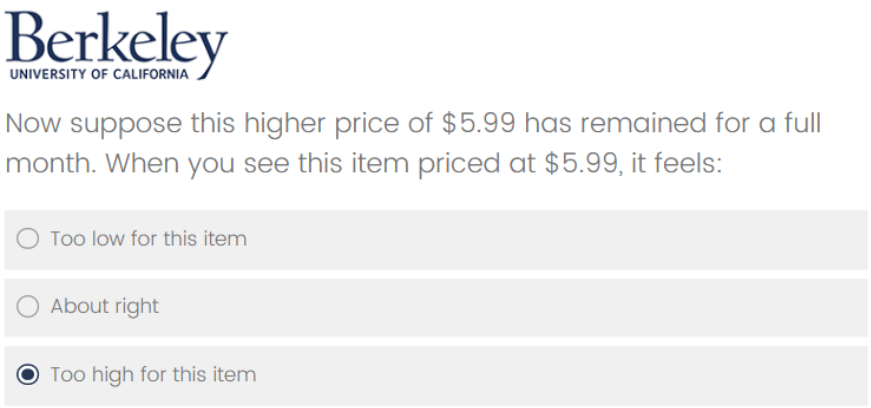
Notes: The price the respondent would *typically expect to pay* going forward after one trip at a price 20% above R_{i0}.

Figure C.11: Reference-Price Persistence Elicitation, N Arm



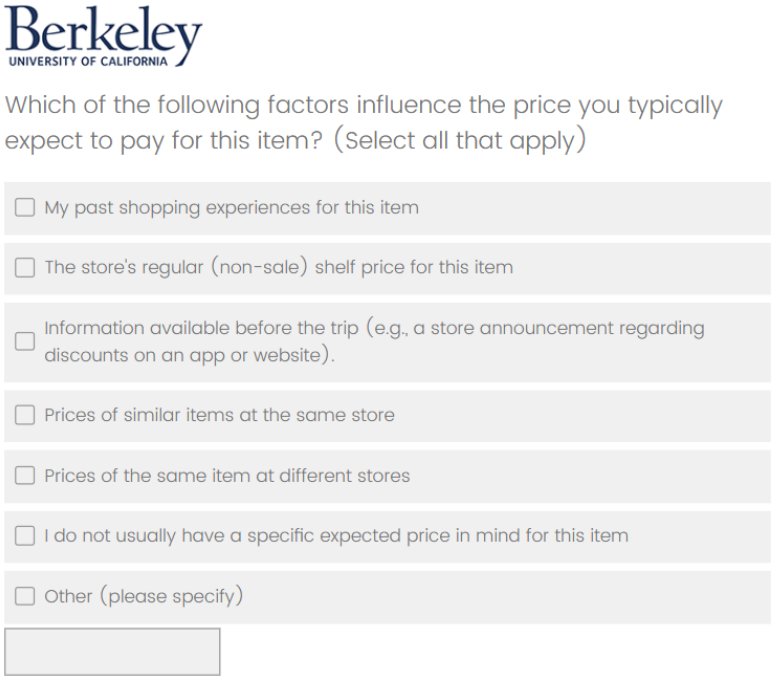
Notes: The price that would *feel like the normal price* going forward after one trip at a price 20% above R_{i0}.

Figure C.12: Post-Shock Feeling Follow-Up (E Arm)



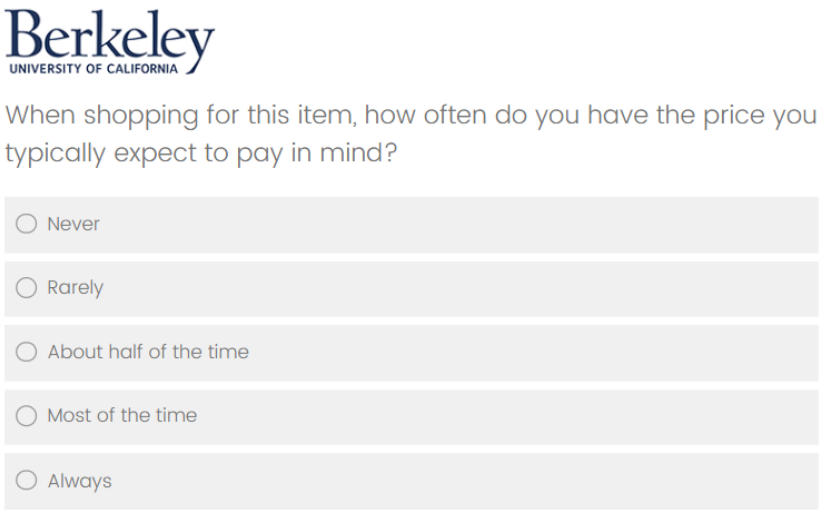
Notes: Whether, once the higher price has persisted for a full month, it feels too low, about right, or too high. This screen underlies the diagnostic separating price expectations from the internal benchmark.

Figure C.13: Reference-Price Formation



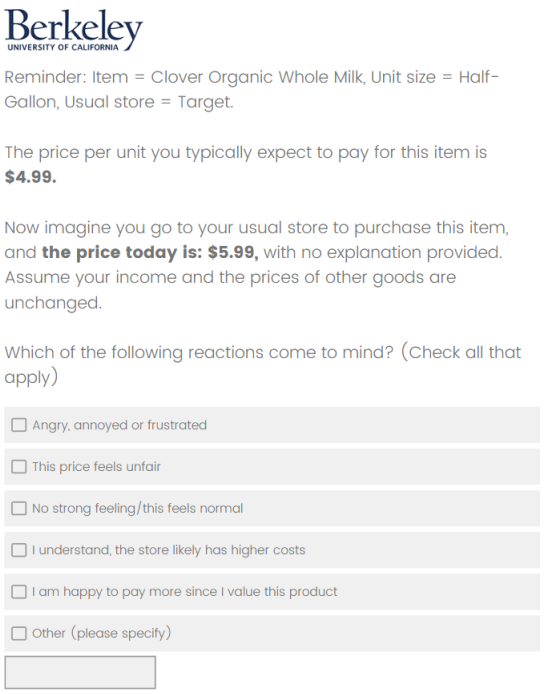
Notes: The factors the respondent reports as influencing the price they expect to pay (select all that apply). This question underlies Figure 2.

Figure C.14: Reference-Price Salience



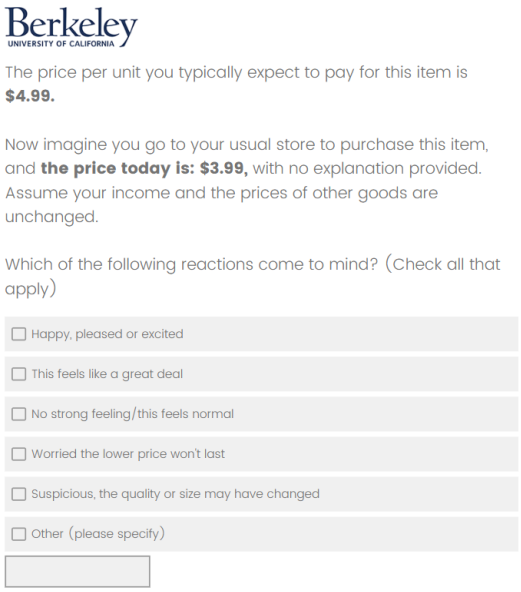
Notes: How often the respondent has the expected price in mind while shopping. This question underlies panel (b) of Figure 1.

Figure C.15: Emotional Response to a Surprise Price Increase



Notes: Reactions to paying 20% above R_{i0} with no explanation (check all that apply). Reproduced for completeness of the instrument; these responses are not analyzed in this paper.

Figure C.16: Emotional Response to a Surprise Price Decrease



Notes: Reactions to paying 20% below R_{i0} with no explanation (check all that apply). Reproduced for completeness of the instrument; these responses are not analyzed in this paper.

D Survey Identification and Additional Results

D.1 Derivation of Proposition 3

This appendix derives Proposition 3 from the choice problem (3.1), maintaining the assumptions stated in Section 3.2. The argument applies separately within the loss and gain domains, $b \in \{L, G\}$, with elasticity Γ_b.

Setup. Let $A_i \equiv \exp(\delta_{if} - \varepsilon \log P_i)$ denote the exponential of respondent i's deterministic baseline utility from their selected product f in (3.1). The scenarios keep the selected product and its next-month posted price P_i fixed. Under the maintained assumption that δ_{if} is unchanged, A_i is therefore constant across scenarios for a given respondent. Let $D_{i,-f} \equiv \sum_{j \neq f} e^{\delta_{ij}}$ denote the contribution of the outside option and all other alternatives to the denominator of the logit choice probability; because all δ_{ij} are held fixed, it too is fixed across scenarios. At baseline the reference price equals the posted price, so the transaction-utility term in (3.1) is zero and the baseline denominator is $D_{i0} = D_{i,-f} + A_i$. In a survey scenario the posted price remains P_i while the reference moves to R_{ib}; define

$$x_{ib} \equiv \log\left(\frac{R_{ib}}{P_i}\right), \qquad s_{ib} \equiv e^{\Gamma_b x_{ib}}, \qquad \omega_i \equiv \frac{A_i}{D_{i0}}, \tag{D.1}$$

so that s_{ib} is the transaction-utility shifter, ω_i is the selected product's baseline share in the respondent's choice set, and the scenario denominator is $D_{i1} = D_{i,-f} + A_i s_{ib}$.

Step 1: choice probabilities. The i.i.d. standard Type I extreme-value taste shocks imply multinomial logit choice probabilities. For respondent i's selected product f, these are:

$$\Pr_{i0}(f) = \frac{A_i}{D_{i0}} \quad \text{at baseline}, \qquad \Pr_{i1}(f) = \frac{A_i\, s_{ib}}{D_{i1}} \quad \text{in the scenario}, \tag{D.2}$$

because moving the reference multiplies the selected product's exponentiated utility by $s_{ib} = e^{\Gamma_b x_{ib}}$ and leaves every other term unchanged.

Step 2: expected quantities. The respondent faces M_i purchase occasions during the scenario month. At baseline and in scenario b, expected monthly purchases equal M_i times the corresponding choice probability per purchase occasion:

$$\mathbb{E}[q_{i0}] = M_i \frac{A_i}{D_{i0}}, \qquad \mathbb{E}[q_{ib}] = M_i \frac{A_i\, s_{ib}}{D_{i1}}. \tag{D.3}$$

Step 3: the exact ratio. Because only the selected product's term changes, the scenario denominator decomposes around the baseline denominator:

$$D_{i1} = D_{i,-f} + A_i s_{ib} = D_{i0} + A_i\,(s_{ib} - 1) = D_{i0}\big[1 + \omega_i(s_{ib} - 1)\big]. \tag{D.4}$$

Dividing the two expressions in (D.3) and using (D.4), the occasion count M_i, the attractiveness A_i—and with it every fixed respondent–product taste δ_{if}—and the baseline denominator D_{i0} all cancel:

$$\frac{\mathbb{E}[q_{ib}]}{\mathbb{E}[q_{i0}]} = \frac{s_{ib}}{1 + \omega_i(s_{ib} - 1)} = \frac{e^{\Gamma_b x_{ib}}}{1 + \omega_i\,(e^{\Gamma_b x_{ib}} - 1)}. \tag{D.5}$$

This is the exact finite-share counterpart to the limit in Proposition 3.

Step 4: the small-share approximation. Taking logs of (D.5),

$$\log\left(\frac{\mathbb{E}[q_{ib}]}{\mathbb{E}[q_{i0}]}\right) = \Gamma_b x_{ib} - \log\Big[1 + \omega_i\left(e^{\Gamma_b x_{ib}} - 1\right)\Big]. \tag{D.6}$$

The scenario design bounds the elicited gap—the reference-price filter restricts R_{ib} to a corridor around P_i of width proportional to the announced shift—so $e^{\Gamma_b x_{ib}} - 1$ is bounded and the argument $u_{ib} \equiv \omega_i(e^{\Gamma_b x_{ib}} - 1)$ is of order ω_i. Using $\log(1 + u) = u + O(u^2)$,

$$\log\left(\frac{\mathbb{E}[q_{ib}]}{\mathbb{E}[q_{i0}]}\right) = \Gamma_b x_{ib} - \omega_i\left(e^{\Gamma_b x_{ib}} - 1\right) + O(\omega_i^2) = \Gamma_b x_{ib} + O(\omega_i). \tag{D.7}$$

The finite-share correction reduces the magnitude of the purchase response in both domains. Relative to the small-share prediction, purchases increase by less in the gain scenario and decrease by less in the loss scenario because the reference-price change affects both the numerator and denominator of the logit choice probability. For a given reference-price change, matching the same expected purchase response would therefore require a larger reference-price elasticity in either domain if baseline choice shares were not negligible.

To approximate the continuum of varieties in Section 2, I consider the limit in which the selected product's baseline choice share, ω_i, tends to zero. In this limit, the finite-share correction vanishes.

Step 5: the estimating equation. Rearranging (D.7), the conditional mean of the scenario quantity is

$$\mathbb{E}[q_{ib} \mid i, x_{ib}] = \mathbb{E}[q_{i0}]\; e^{\Gamma_b x_{ib}}\,\big[1 + O(\omega_i)\big], \tag{D.8}$$

so $\log \mathbb{E}[q_{ib} \mid i, x_{ib}] = \alpha_i + \Gamma_b x_{ib} + O(\omega_i)$ with respondent-level intercept $\alpha_i \equiv \log \mathbb{E}[q_{i0}]$. Holding the rest of the choice environment fixed, the model implies that expected purchases remain unchanged when the respondent's reference price remains at its baseline value, $R_{ib} = R_{i0} = P_i$. In estimation, I treat reported baseline purchases q_{i0} as the baseline conditional mean, so $\log q_{i0}$

enters as an offset. This is the specification estimated in Section 3.2. Letting $\omega_i \to 0$ in (D.7) gives (3.2) and completes the proof of Proposition 3. □

D.2 Sample Construction and Descriptive Supplements

Table D.1: Sample Construction: Exclusion Counts and Analysis Samples

	N
Raw completed responses	1,501
Respondent-level exclusions (may overlap)	
Failed both attention checks	1
Baseline quantity $q_{i0} > 50$ units per month	8
Baseline price outside [\$0.50, \$100]	11
Any scenario quantity above $3q_{i0}$	25
Any price or reference elicitation $\leq$ \$0.01	27
Full descriptive sample after baseline exclusions	**1,432**
Γ *estimation: row-level reference-price filter*	
Loss scenario, $R_{iL} \in [P_i(1-1.5g_i),\ 1.03P_i]$	1,238
Gain scenario, $R_{iG} \in [0.97P_i,\ P_i(1+1.5g_i)]$	1,223
Balanced (both scenarios retained)	1,137
ρ *estimation*	
After dropping post-shock reference below the original reference	1,330
E arm with $\hat{\rho}_{\text{trip}} \in [0,1]$	651
N arm with $\hat{\rho}_{\text{trip}} \in [0,1]$	629

Notes: Respondents who meet any of the respondent-level exclusion criteria are excluded from all analyses. A respondent may meet more than one criterion, so the exclusion counts can overlap. The reference-price filter applies separately to the loss and gain scenarios: an observation is excluded if the reported reference price falls outside the corresponding interval. Here, P_i is the posted price and g_i is the assigned proportional gap between the usual and posted prices. The balanced sample includes respondents whose reported reference prices satisfy the filter in both scenarios. The ρ sample additionally drops respondents whose post-shock reference report lies below the original reference price, and the in-range rows drop $\hat{\rho}_{\text{trip}} \notin [0,1]$ (28 E-arm and 22 N-arm respondents).

The baseline filters referenced in the main text are the five preregistered respondent-level exclusion rules, applied before any analysis. The instrument contains two attention checks, and I drop respondents who fail both. I further exclude respondents who report a baseline quantity above 50 units per month, report a baseline price outside $[\$0.50, \$100]$, report any scenario quantity above three times their baseline quantity, or enter a price or reference response at or below one cent. The quantity cap excludes the entire respondent if either scenario exceeds $3q_{i0}$; a response exactly equal to $3q_{i0}$ is retained. The cap screens out implausibly large purchase responses that may reflect misunderstanding of the scenarios, especially given that the posted price, income, and other prices are held fixed and respondents are asked to consider purchases for next month's use only. The main conclusions hold when the cap is removed (Tables D.6–D.7).

Table D.2: Main product categories in the survey analysis sample. Each respondent in the analysis sample ($N = 1{,}432$) named one frequently purchased everyday product in a free-text field. I classify the reported products into categories using keywords.

Category	N	Share (%)
Milk (dairy)	498	34.8
Eggs	230	16.1
Soda, water, and energy drinks	135	9.4
Fresh produce	80	5.6
Milk (plant-based)	68	4.7
Pantry, frozen, and prepared foods	68	4.7
Bread	67	4.7
Snacks and sweets	48	3.4
Coffee and coffee creamer	44	3.1
Other dairy (cheese, butter, ice cream)	42	2.9
Meat, poultry, and seafood	34	2.4
Juice, tea, and other beverages	33	2.3
Yogurt	25	1.7
Paper and paper products	16	1.1
Cereal	4	0.3
Other	40	2.8
Total	1,432	100.0

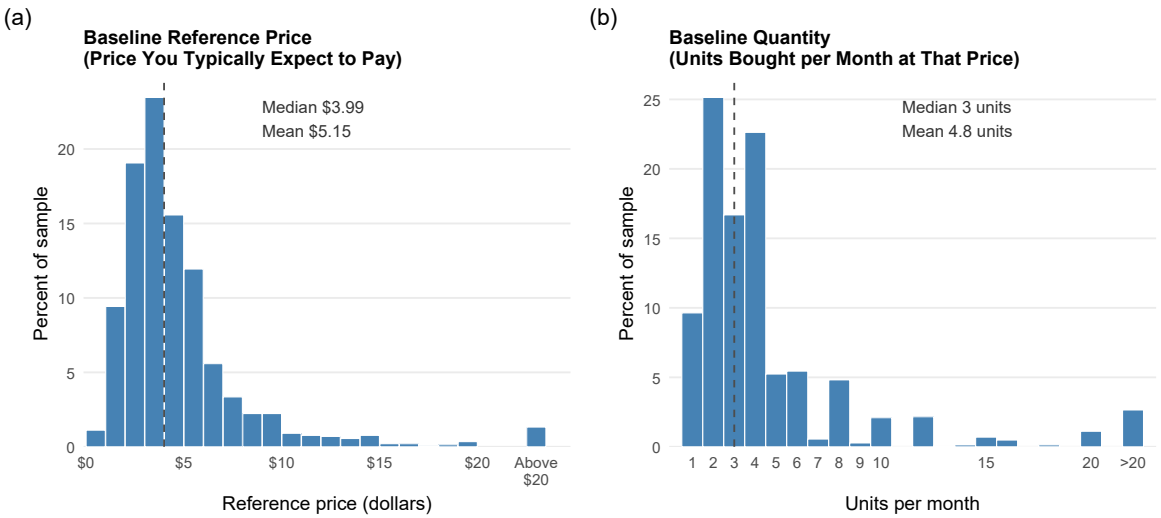
Notes: "Other" comprises non-paper household and personal-care items, alcohol and tobacco, pet food and medical items, and responses too vague to classify (e.g., a bare number or store-brand name). Energy drinks are grouped with soda and water; sweet bakery items (muffins, croissants, donuts) with snacks; granola and hot cereal with pantry; and half-and-half with other dairy.

Table D.3: Raw Demand Responses by Reference-Price Domain

Scenario	N	Mean %	Median %	% Decrease	% Unchanged	% Increase
Panel A: posted price above the reference (loss domain)						
Pooled	1,238	−12.1	0.0	30.8	64.1	5.1
12% temporary increase	412	−8.0	0.0	26.5	67.5	6.1
20% temporary increase	423	−13.3	0.0	31.2	64.3	4.5
28% temporary increase	403	−14.9	0.0	34.7	60.5	4.7
Panel B: posted price below the reference (gain domain)						
Pooled	1,223	11.7	0.0	11.1	60.7	28.2
12% temporary decrease	407	11.7	0.0	9.8	65.1	25.1
20% temporary decrease	413	11.0	0.0	10.9	62.2	26.9
28% temporary decrease	403	12.5	0.0	12.7	54.6	32.8

Notes: Each cell summarizes the percentage change in the stated scenario quantity relative to the baseline quantity, $q_{ib}/q_{i0} - 1$. Results are reported separately for each assigned price gap g_i. The sample applies the baseline exclusions and reference-price filter reported in Table D.1. Both scenarios hold the posted price fixed at its baseline level. In Panel A, this price is framed as a temporary increase above the usual price, making the purchase appear less favorable. In Panel B, it is framed as a temporary decrease below the usual price, making the purchase appear more favorable. The model therefore predicts lower expected purchases in Panel A and higher expected purchases in Panel B relative to baseline.

Figure D.1: Baseline Reference Prices and Monthly Quantities



Notes: Descriptive sample after baseline exclusions ($N = 1{,}432$). Panel (a) shows baseline reference prices, R_{i0}, in \$1 bins, with prices above \$20 grouped in the last bar (median \$3.99, mean \$5.15). Panel (b) shows reported baseline monthly purchases, q_{i0}, in unit bins, with quantities above 20 grouped in the last bar (median 3, mean 4.8). Dashed lines mark the medians. Means and medians use the original reported values.

Table D.4: Baseline Validation and Post-Shock Feeling (Percent of Respondents)

	Too low	About right	Too high	N
A. Baseline: a posted price equal to the elicited R_{i0} feels...				
All respondents	1.1	83.1	15.8	1,432
B. E arm, after a month at the 20% higher price, it feels...				
Baseline price felt about right	0.2	21.6	78.3	575
and expectation moved ≥95% of the way	0.3	23.3	76.4	301
Expectation moved ≥95%, any baseline feeling	0.3	20.1	79.7	359

Notes: Panel A uses the descriptive sample after baseline exclusions (question in Figure C.9). Panel B uses E-arm respondents in the persistence sample who answered the follow-up question (Figure C.12); "moved at least 95% of the way" means $\hat{\rho}_{\text{trip},i} \leq 0.05$ in equation (D.11). Rows sum to 100 up to rounding.

These rules remove 69 of the 1,501 collected responses and leave the descriptive sample of $N = 1{,}432$; Table D.1 gives the count behind each rule and the resulting analysis samples.

Estimation of the reference-price elasticities applies an additional scenario-level filter. Let $g_i \in \{0.12, 0.20, 0.28\}$ denote the assigned proportional gap between the scenario's usual price and the posted price $P_i = R_{i0}$. I retain loss-scenario observations with $R_{iL} \in [P_i(1 - 1.5g_i),\ 1.03P_i]$ and gain-scenario observations with $R_{iG} \in [0.97P_i,\ P_i(1 + 1.5g_i)]$. These intervals allow reported reference prices to extend beyond the stated usual price by half the assigned price gap, or to lie up to 3% on the other side of the posted price.

For example, a respondent with a \$5 baseline reference price assigned a 20% loss-scenario gap is told that the item usually costs \$4, costs \$5 next month, and returns to \$4 thereafter.

Elicited reference prices between \$4 and \$5 reflect partial updating. The filter retains values between \$3.50 and \$5.15, excluding an answer such as \$6, which exceeds every price specified in the scenario. In the corresponding gain scenario, the usual price is \$6 and next month's price is \$5; the filter retains values between \$4.85 and \$6.50, excluding an answer such as \$4. The filter leaves 1,238 loss-scenario respondents and 1,223 gain-scenario respondents, with 1,137 respondents (2,274 scenario observations) retained in both scenarios for the balanced sample.

Table D.2 summarizes the products respondents chose to answer about: everyday staples dominate, led by dairy milk (35%), eggs (16%), and soda, water, and energy drinks (9%), consistent with the design's request for a frequently purchased item whose price the respondent knows; 75% of the chosen products are perishable. Figure D.1 shows the distributions of the baseline reference price and the baseline monthly quantity in the descriptive sample: the median reference price is \$3.99 (mean \$5.15), the median quantity is three units per month (mean 4.8), and 2.7% of respondents report more than 20 units. The median respondent completed the survey in 470 seconds (mean 567, standard deviation 354). Table D.3 reports the raw demand responses by scenario and assigned gap that the main text summarizes.

Table D.4 collects the validation shares cited in the main text. At baseline, 83% of respondents say a posted price equal to their elicited R_{i0} feels "about right" for the item. The post-shock follow-up responses, trip-level persistence estimates, and conversion to the quarterly frequency are discussed in Appendix D.5.

Table D.5: Asymmetric Reference-Price Elasticities

	PPML (1)	CF (2)	CF + Order (3)	CF + Order (ACS wt.) (4)
$\hat{\Gamma}_G$	0.331***	0.325***	0.329***	0.305**
	(0.111)	(0.113)	(0.112)	(0.144)
$\Delta\hat{\Gamma}$	0.442***	0.511***	0.511***	0.590**
	(0.170)	(0.183)	(0.178)	(0.249)
$\hat{\Gamma}_L$	0.773***	0.836***	0.840***	0.895***
	(0.086)	(0.099)	(0.096)	(0.136)
Observations	2,274	2,274	2,274	2,178
Respondents	1,137	1,137	1,137	1,089
First-stage F		657.3	439.1	410.2

Notes: Poisson pseudo-maximum likelihood on the balanced sample that stacks each respondent's loss and gain scenarios, estimating $\log \mathbb{E}[q_{ib}] = \log q_{i0} + \Gamma_G x_{ib} + \Delta\Gamma\, D_{L,ib}\, x_{ib}$ plus control-function terms, where $x_{ib} = \log(R_{ib}/P_i)$ and $D_{L,ib}$ indicates the loss scenario; $\hat{\Gamma}_L = \hat{\Gamma}_G + \Delta\hat{\Gamma}$ carries a delta-method standard error. Column (1) reports PPML estimates without a control function. Columns (2) and (3) add the control-function residual and its interaction with the loss-scenario indicator. Column (3) also includes the residual's interaction with scenario order. The coefficients on these control-function terms are not reported. Column (4) applies the ACS calibration weights to the sample described in Appendix D.6. Samples, weighting, and standard errors otherwise follow Table 2. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.10$.

D.3 Control-Function Estimation and Asymmetry

First stage. For the assigned proportional gap $g_i \in \{0.12, 0.20, 0.28\}$, the instrument is $z_{iL} = \log(1 - g_i)$ in the loss scenario and $z_{iG} = \log(1 + g_i)$ in the gain scenario. Column (2) of Table 2 omits the order terms from both the first stage (3.4) and the control function (3.5); columns (3) and (4) use the full first stage and include $\hat{v}_{ib}$ and $O_{ib}\hat{v}_{ib}$. The reported first-stage F statistic tests the excluded assigned-gap terms, $\pi_1 = 0$ in column (2) and $\pi_1 = \pi_{zO} = 0$ in columns (3)–(4); the preferred unweighted specification gives $F = 375.6$ on the loss side and $F = 262.0$ on the gain side. First stages are re-estimated in every bootstrap replication, and in the ACS-weighted specifications the calibration weights are re-estimated within each replication as well (Appendix D.6.3).

Asymmetry test. Table D.5 tests the difference directly on the balanced sample that stacks each respondent's two scenarios. Column (1) estimates the plain Poisson specification

$$\mathbb{E}[q_{ib} \mid q_{i0}, x_{ib}, D_{L,ib}] = q_{i0} \exp(\Gamma_G x_{ib} + \Delta\Gamma\, D_{L,ib}\, x_{ib}), \tag{D.9}$$

where $D_{L,ib}$ indicates the loss scenario, so $\Delta\Gamma = \Gamma_L - \Gamma_G$ and its standard error is a direct test of the asymmetry. Columns (2)–(4) add the control function. The first stage is re-estimated on the stacked sample with z_{ib}, $D_{L,ib}$, and $D_{L,ib}z_{ib}$; columns (3)–(4) additionally include O_{ib} and $O_{ib}z_{ib}$. Its residual enters the second stage with domain and order interactions,

$$\mathbb{E}[q_{ib} \mid q_{i0}, x_{ib}, D_{L,ib}, \hat{v}_{ib}, O_{ib}] = q_{i0} \exp(\Gamma_G x_{ib} + \Delta\Gamma\, D_{L,ib}\, x_{ib} + \delta\hat{v}_{ib} + \delta_L D_{L,ib}\hat{v}_{ib} + \delta_O O_{ib}\hat{v}_{ib}). \tag{D.10}$$

The preferred column (3) gives $\hat{\Gamma}_G = 0.329$ (0.112) and $\Delta\hat{\Gamma} = 0.511$ (0.178), significant at the 1% level, with implied $\hat{\Gamma}_L = 0.840$ (0.096): loss-side reference dependence is roughly two and a half times gain-side reference dependence. In the language of Section 2, demand is kinked at the reference price, the case Appendix B analyzes, and $\Delta\hat{\Gamma}$ measures the kink. With ACS weights the asymmetry is larger, 0.590 (0.249), and the gain-side slope is smaller (0.305, standard error 0.144). The estimated loss–gain difference is 0.407 (SE 0.122) using log-linear two-stage least squares on the positive-quantity sample. Restricting the sample to perishable products gives a difference of 0.496 (SE 0.152). Both are significant at the 1% level. Table D.8 reports the corresponding ACS-weighted estimates.

D.4 Robustness of the Reference-Price Elasticities

Tables D.6 and D.7 re-estimate Γ_L and Γ_G under one change at a time to the sample or the estimator, each row in the four columns of Table 2. These checks examine sensitivity to possible errors in reported reference prices, learning or fatigue across scenarios, and the products and quantities represented in the sample. I also examine whether the estimates depend on the

restrictions and functional form of the estimating equation. The estimates quoted below are from the preferred column (3), loss side first.

Table D.6: Robustness of the Loss-Side Reference-Price Elasticity Γ_L

Sample or specification	PPML (1)	CF (2)	CF + order (3)	ACS wt. (4)	N
A. Baseline, loss sample (Table 2)	0.788***	0.873***	0.875***	0.933***	1,238
	(0.084)	(0.095)	(0.097)	(0.131)	
B. Baseline price feels "about right"	0.769***	0.860***	0.864***	0.972***	1,025
	(0.091)	(0.107)	(0.111)	(0.148)	
C. Baseline, loss scenario presented first	0.594***	0.705***	0.718***	0.830***	1,238
	(0.083)	(0.104)	(0.105)	(0.151)	
D. Baseline, loss scenario presented second	0.986***	1.039***	1.033***	1.024***	1,238
	(0.145)	(0.165)	(0.158)	(0.209)	
E. Baseline quantity at most 20 units	0.758***	0.790***	0.791***	0.811***	1,210
	(0.071)	(0.074)	(0.073)	(0.104)	
F. Baseline quantity at most 10 units	0.653***	0.687***	0.688***	0.647***	1,152
	(0.055)	(0.058)	(0.059)	(0.068)	
G. Perishable products only	0.712***	0.764***	0.766***	0.848***	934
	(0.071)	(0.077)	(0.073)	(0.130)	
H. Excluding dairy milk	0.908***	1.007***	1.008***	1.059***	804
	(0.121)	(0.138)	(0.141)	(0.190)	
I. Specific product answers only	0.816***	0.927***	0.922***	1.047***	638
	(0.110)	(0.133)	(0.137)	(0.212)	
J. Specific answers plus fresh produce	0.818***	0.936***	0.933***	1.040***	697
	(0.102)	(0.126)	(0.125)	(0.185)	
K. Generic answers only, excluding fresh produce	0.762***	0.798***	0.810***	0.792***	534
	(0.141)	(0.137)	(0.148)	(0.157)	
L. Implied by Table D.5, $\hat{\Gamma}_G + \Delta\hat{\Gamma}$	0.773***	0.836***	0.840***	0.895***	1,137
	(0.086)	(0.099)	(0.096)	(0.136)	
M. Free intercept	0.479***	0.790***	0.789***	0.937***	1,238
	(0.141)	(0.277)	(0.259)	(0.311)	
N. Log-linear outcome, positive quantities	OLS	2SLS	2SLS + order	ACS wt.	
	0.675***	0.731***	0.732***	0.705***	1,182
	(0.056)	(0.060)	(0.060)	(0.070)	
O. Without respondent-level quantity cap	0.760***	0.821***	0.822***	0.888***	1,255
	(0.084)	(0.100)	(0.098)	(0.126)	

Notes: Column definitions, weighting, and inference follow Table 2 and Appendix D.6, with the exceptions noted below. Standard errors are in parentheses. N reports the unweighted sample size. Rows C and D report estimates by presentation order from a single regression. Specific product answers name a brand, product line, or retailer (row I). Row J also includes fresh produce. Row K includes generic answers, excluding fresh produce. Row L uses delta-method standard errors. Row M adds an intercept and, in columns (3)–(4), an order-specific level. Row N estimates the log-linear specification on positive quantities, using respondent-clustered standard errors. Row O removes only the preregistered respondent-level quantity cap. First-stage F statistics exceed 140 in every instrumented column. $^{***}p < 0.01$, $^{**}p < 0.05$.

Measurement of the reference. The identification argument assumes that the elicited baseline price corresponds to the respondent's reference price, so transaction utility is zero at baseline. To assess sensitivity to this assumption, I restrict the sample to respondents who describe

Table D.7: Robustness of the Gain-Side Reference-Price Elasticity Γ_G

Sample or specification	PPML (1)	CF (2)	CF + order (3)	ACS wt. (4)	N
A. Baseline, gain sample (Table 2)	0.347***	0.324***	0.326***	0.310**	1,223
	(0.105)	(0.108)	(0.109)	(0.141)	
B. Baseline price feels "about right"	0.279**	0.259**	0.263**	0.196	1,022
	(0.110)	(0.111)	(0.112)	(0.154)	
C. Baseline, gain scenario presented first	0.455***	0.428**	0.434**	0.508***	1,223
	(0.173)	(0.174)	(0.173)	(0.196)	
D. Baseline, gain scenario presented second	0.225**	0.207*	0.204*	0.067	1,223
	(0.108)	(0.111)	(0.117)	(0.198)	
E. Baseline quantity at most 20 units	0.404***	0.385***	0.386***	0.384***	1,198
	(0.088)	(0.086)	(0.094)	(0.126)	
F. Baseline quantity at most 10 units	0.549***	0.515***	0.517***	0.528***	1,140
	(0.059)	(0.063)	(0.067)	(0.079)	
G. Perishable products only	0.254***	0.244**	0.241**	0.146	916
	(0.092)	(0.095)	(0.094)	(0.199)	
H. Excluding dairy milk	0.505***	0.465***	0.465***	0.549***	801
	(0.141)	(0.138)	(0.142)	(0.169)	
I. Specific product answers only	0.676***	0.662***	0.657***	0.588***	630
	(0.133)	(0.137)	(0.137)	(0.189)	
J. Specific answers plus fresh produce	0.643***	0.617***	0.612***	0.558***	686
	(0.125)	(0.130)	(0.130)	(0.196)	
K. Generic answers only, excluding fresh produce	−0.074	−0.087	−0.085	−0.037	530
	(0.166)	(0.166)	(0.159)	(0.175)	
L. Asymmetric specification (Table D.5)	0.331***	0.325***	0.329***	0.305**	1,137
	(0.111)	(0.113)	(0.112)	(0.144)	
M. Free intercept	0.210	−0.329	−0.318	−0.210	1,223
	(0.205)	(0.363)	(0.365)	(0.367)	
N. Log-linear outcome, positive quantities	OLS	2SLS	2SLS + order	ACS wt.	
	0.348***	0.302***	0.303***	0.365***	1,212
	(0.071)	(0.078)	(0.077)	(0.086)	
O. Without respondent-level quantity cap	0.405***	0.443***	0.448***	0.404***	1,241
	(0.106)	(0.111)	(0.115)	(0.146)	

Notes: Gain-side counterpart of Table D.6: each row re-estimates Γ_G from the gain-side specification of Table 2, Poisson pseudo-maximum likelihood with $\log q_{i0}$ as offset, on a different sample or with a different estimator; standard errors below each estimate. Columns, standard errors, weights and row definitions as in Table D.6. Rows C and D come from one specification with $\Gamma_G^{\text{first}} O_{iG} x_{iG} + \Gamma_G^{\text{second}} (1 - O_{iG}) x_{iG}$, $O_{iG} = 1$ when the gain scenario was presented first; the difference is not significant at the 5% level in any column ($p = 0.28$ in column (3)). Row L reports $\hat{\Gamma}_G$ from the stacked asymmetric specification. In row M the intercept, slope and control-function residual are nearly collinear on the gain side, so the gain-slope estimate is imprecise. Row O relaxes only the preregistered respondent-level quantity cap; all other exclusions remain. First-stage $F > 150$ in every instrumented column. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.10$.

Table D.8: ACS-Weighted Loss–Gain Differences Across Robustness Specifications

Sample or specification	$\Delta\hat{\Gamma}$	SE	p-value	N
A. Baseline	0.590	0.249	0.018	1,089
B. Baseline price feels "about right"	0.758	0.275	0.006	902
C. Scenario presented first	0.202	0.234	0.389	1,089
D. Scenario presented second	0.990	0.290	0.001	1,089
E. Baseline quantity at most 20 units	0.422	0.215	0.049	1,066
F. Baseline quantity at most 10 units	0.101	0.118	0.396	1,013
G. Perishable products	0.687	0.309	0.026	817
H. Excluding dairy milk	0.397	0.314	0.206	703
I. Specific product answers	0.395	0.369	0.285	571
J. Specific answers plus fresh produce	0.403	0.352	0.252	620
K. Generic answers, excluding fresh produce	0.888	0.321	0.006	463
L. Balanced joint specification (same as A)	0.590	0.249	0.018	1,089
M. Free intercept and domain/order levels	1.181	0.553	0.033	1,089
N. Log-linear IV, positive quantities	0.302	0.136	0.026	1,039
O. Without respondent-level quantity cap	0.464	0.232	0.046	1,103

Notes: $\Delta\Gamma = \Gamma_L - \Gamma_G$ is estimated jointly on respondents whose two scenarios pass the reference-price windows, with ACS weights rebuilt within each restricted sample. These are direct balanced-sample contrasts, not differences between the separate-domain coefficients in Tables D.6–D.7. Rows A and L are identical. Row O relaxes only the preregistered respondent-level quantity cap. The specification extends equation (D.10): C–D allow both domain slopes to vary by order; M frees an intercept and domain, order, and domain-by-order levels. Other rows apply the corresponding sample restriction; N uses the balanced positive-quantity log-linear IV specification. Control-function standard errors use respondent bootstrap draws with ACS recalibration. The new fits use 1,000 attempts: H retains 997 and K retains 999 successful draws; B–F, I–J and M retain all 1,000. A, G, L and O reuse the saved corresponding control-function inference; N uses respondent-clustered IV standard errors. Two-sided Wald p-values are unadjusted for multiple comparisons.

a posted price equal to R_{i0} as "about right." This restriction retains 83% of respondents, leaves the loss-side estimate almost unchanged at 0.86, and lowers the gain-side estimate to 0.26 (row B). Completing the first scenario may improve respondents' understanding of the second, while fatigue may reduce their attention. I therefore allow the elasticities to differ by presentation order. The loss-side estimate is 0.72 when the loss scenario is presented first and 1.03 when it is presented second. The corresponding gain-side estimates are 0.43 and 0.20 (rows C and D). In the control-function specifications, the difference by presentation order is not statistically significant at the 5% level in either domain.

The product in mind. Rows E and F check sensitivity to respondents with unusually large baseline quantities. Restricting baseline quantity to at most 20 or 10 units gives 0.79 and 0.69 on the loss side and 0.39 and 0.52 on the gain side, narrowing the estimated loss–gain difference.

Although respondents are asked to report purchases for next month's use, their answers might reflect stockpiling if they overlook or misunderstand these instructions. I therefore restrict the sample to perishable products. The loss- and gain-side estimates are 0.77 and 0.24, respectively (row G).

Dairy milk, which a third of respondents choose, appears as an example in the product-selection question. To check whether the results depend on this product, I exclude these

respondents. The resulting estimates are 1.01 on the loss side and 0.46 on the gain side (row H).

The model describes demand for a single variety, but some respondents name a broader category such as "organic milk." The scope for substitution may differ depending on whether respondents report purchases of a specific product or a broader category. I therefore compare estimates from specific and generic product answers. Specific answers give loss- and gain-side estimates of 0.92 and 0.66 (row I), or 0.93 and 0.61 when fresh produce is included (row J). Generic answers excluding fresh produce give 0.81 and −0.08 (row K). The loss-side estimates are similar across the groups, while the gain-side estimate is much larger among respondents who name a specific product.

The estimator. The stacked specification of Table D.5 implies 0.84 and 0.33 (row L), in line with the single-domain estimates. I set the intercept to zero so that expected purchases equal baseline purchases when the reference price is unchanged. If this restriction is correct, allowing an intercept should not systematically change the estimated elasticity, although it may reduce precision. In the preferred specification, allowing an intercept and an order-specific level lowers the loss-side estimate from 0.88 to 0.79, while its standard error increases from 0.10 to 0.26. The gain-side estimate changes sign and is imprecisely estimated (row M).

Finally, I assess robustness to a log-linear specification, estimated by OLS in column (1) and by 2SLS in columns (2)–(4). This specification excludes zero purchases. The preferred loss- and gain-side estimates are 0.73 and 0.30, respectively (row N).

Across the robustness checks, estimates of Γ_L range from 0.69 to 1.03 in the preferred column and remain statistically significant at the 1% level. Estimates of Γ_G are more sensitive to the specification and sample composition.

Table D.8 reports direct loss–gain differences across the ACS-weighted robustness samples. The baseline difference is 0.590 ($p = 0.018$); restricting baseline quantity to at most 20 units gives 0.422 ($p = 0.049$). The differences are 0.202 when a scenario is presented first and 0.990 when it is presented second. A direct test of the change in the difference gives $p = 0.0011$. This differs from testing each domain's slope by order. The contrasts for specific product answers and for the sample excluding dairy milk are positive but imprecise; the evidence for asymmetry is therefore not uniform across all robustness restrictions. These are unadjusted sensitivity tests, not additional preregistered hypotheses.

D.5 Reference-Price Persistence: Estimation and Additional Results

Trip-level estimator. In the persistence scenario of Section 3.3, respondents imagine having paid R_{i0} on previous shopping trips and then encountering a price of $P_{i1} = 1.2R_{i0}$. They report a going-forward price, $\hat{R}_{i1}$: the price they typically expect to pay in the E arm, or the price that feels normal in the N arm. Applying the reference law (2.3) at the frequency of shopping

trips gives

$$\hat{\rho}_{\text{trip},i} = \frac{\log \hat{R}_{i1} - \log P_{i1}}{\log R_{i0} - \log P_{i1}}. \tag{D.11}$$

The uncapped estimate equals zero for full adjustment to the new price and one when the reported reference price is unchanged.

With $\rho \in [0, 1]$, the updating rule requires the reported price to lie between R_{i0} and P_{i1}. After applying the baseline exclusions, I therefore exclude 102 respondents whose reported going-forward price is below R_{i0}, and 28 E-arm and 22 N-arm respondents whose reported price exceeds P_{i1}.

Among retained respondents, I cap trip-level persistence at 0.995 before computing trip-level summaries and quarterly persistence. Responses implying no adjustment after one trip remain in the sample, but their persistence is set to 0.995 instead of one.

The arms differ sharply: the mean of $\hat{\rho}_{\text{trip},i}$ is 0.331 in the E arm ($N = 651$) and 0.743 in the N arm ($N = 629$), a difference significant at the 0.1% level in a Welch t-test. Table D.9 reports the means by shopping frequency. Figure 5 shows that respondents tend to report either little change in their reference price or almost full adjustment to the new price. Almost full adjustment is more common in the E arm, while little change is more common in the N arm.

Table D.9: Trip-Level Reference-Price Persistence by Arm and Shopping Frequency

	E arm (expected price)			N arm (normal price)		
Shopping frequency	N	Mean	Median	N	Mean	Median
Twice per week	73	0.351	0.000	63	0.851	0.995
Once per week	281	0.349	0.000	289	0.755	0.995
Every two weeks	235	0.307	0.000	208	0.728	0.988
Once per month	57	0.296	0.000	68	0.634	0.890
Less than once per month	5	0.647	0.771	1	0.995	0.995
Overall (ACS-weighted)	622	0.320	0.000	608	0.756	0.995

Notes: The unweighted sample contains 1,280 respondents after the exclusions described in Appendix D.5. Trip-level persistence is capped at 0.995. Respondents who shop less than once a month are excluded from quarterly estimates. ACS weighting is described in Appendix D.6.

Quarterly persistence. The model uses quarterly periods. I convert each respondent's capped trip-level persistence to quarterly persistence as

$$\hat{\rho}_{\text{qtr},i} = \hat{\rho}_{\text{trip},i}^{\,n_i},$$

where n_i is the number of shopping trips per quarter. Respondents who shop twice a week, weekly, every two weeks, or monthly are assigned 26, 13, 6.5, or 3 trips, respectively (Figure C.8). I exclude respondents who shop less than once a month because this group contains only six

respondents: five in the E arm and one in the N arm.

I then average the quarterly estimates within each arm, obtaining 0.217 for the E arm and 0.531 for the N arm (Table 3). Converting each respondent's estimate before averaging accounts for differences in both persistence and shopping frequency.

The N-arm median is 0.878, both with and without ACS weights. This gives the median-based calibration of $\rho = 0.88$ used in Section 4.

Persistence without the quantity cap. Table D.10 relaxes the same respondent-level quantity exclusion while retaining the persistence restrictions. The unweighted quarterly means change from 0.217 to 0.216 in the E arm and from 0.531 to 0.532 in the N arm; the ACS-weighted means change from 0.211 to 0.211 and from 0.544 to 0.546, respectively. The persistence estimates are therefore little affected by this exclusion.

Table D.10: Quarterly Persistence With and Without the Preregistered Quantity Cap

	E-arm mean (SE)	N_E	N-arm mean (SE)	N_N
Unweighted				
Preregistered cap	0.217 (0.015)	646	0.531 (0.018)	628
Without quantity cap	0.216 (0.015)	653	0.532 (0.018)	638
ACS-weighted				
Preregistered cap	0.211 (0.019)	617	0.544 (0.022)	607
Without quantity cap	0.211 (0.019)	623	0.546 (0.022)	616

Notes: Only the respondent-level quantity cap changes between the two samples. Both retain the other baseline exclusions and the valid persistence range, cap trip-level persistence at 0.995 before compounding over each respondent's shopping trips, and exclude the less-than-monthly shopping bin. E elicits the expected price; N elicits the price that feels normal. Parentheses contain standard errors of the quarterly mean. ACS weights are calibrated on each pooled valid trip-level sample and carried into the quarterly mean; its linearized Hájek standard error treats weights as fixed. Weighted samples are restricted to the ACS calibration universe.

D.6 Population Weighting

D.6.1 Target Population and Benchmarks

I construct population benchmarks from the 2024 American Community Survey one-year Public Use Microdata Sample, using ACS person weights. The target population is U.S. residents aged 18–65 living in housing units or noninstitutional group quarters. The weights match ten age-by-sex cells, formed from five age groups (18–24, 25–34, 35–44, 45–54, and 55–65), and the shares employed, unemployed, and not in the labor force.

Prolific's full-time and part-time categories are classified as employed, "unemployed (and job seeking)" as unemployed, and "not in paid work" as not in the labor force. Respondents about to start a job, reporting "other," or missing employment information are classified as unclassified. Their weighted share is held at its sample value, and the ACS employment

proportions are applied to the remaining share. I do not weight by ethnicity because Prolific's categories do not separately identify Hispanic origin and are not directly comparable to the ACS categories.

D.6.2 Weight Construction

Weighted estimates use respondents whose age and sex match the calibration categories. I rebuild weights for each regression sample. To estimate the speed at which reference prices update, I construct weights on the pooled E- and N-arm sample after applying the sample restrictions. I retain these weights for the quarterly estimates after excluding respondents who shop less than once a month.

I use bounded logit calibration to match the demographic shares described above (Deville and Särndal, 1992; Deville et al., 1993). Weights have mean one and bounds of $[1/8, 8]$. Table D.11 reports the weight distributions, demographic balance, and Kish effective sample sizes (Kish, 1992).

Table D.11: Weight Diagnostics and Achieved Demographic Balance

Sample	Scheme	N	Max. weight	Kish N_{eff}	N_{eff} (%)	Mean age	Female (%)	Unemployed (%)	Not in LF (%)
Reference sample	Unweighted	1,375	1.00	1375.0	100.0	37.83	52.58	14.04	7.93
Reference sample	Age × sex	1,375	2.20	1142.2	83.1	40.66	50.28	14.47	8.34
Reference sample	Age × sex + employment	1,375	4.36	927.1	67.4	40.70	50.28	3.13	18.44
Balanced Γ sample	Unweighted	1,089	1.00	1089.0	100.0	38.46	52.98	12.67	8.91
Balanced Γ sample	Age × sex	1,089	2.00	924.9	84.9	40.65	50.28	13.47	9.09
Balanced Γ sample	Age × sex + employment	1,089	3.62	773.8	71.1	40.70	50.28	3.11	18.32
ρ estimation sample	Unweighted	1,230	1.00	1230.0	100.0	38.01	52.36	13.01	8.13
ρ estimation sample	Age × sex	1,230	2.12	1036.0	84.2	40.63	50.28	13.74	8.36
ρ estimation sample	Age × sex + employment	1,230	4.27	845.6	68.7	40.67	50.28	3.13	18.46
ACS target	Target	–	–	–	–	40.98	50.28	3.57	21.00

Notes: The reference sample is the descriptive sample eligible for weighting. The other samples apply the corresponding estimation restrictions. Employment targets account for each sample's unclassified share as described above; the final row reports the unadjusted ACS benchmarks. N_{eff} denotes Kish's effective sample size.

D.6.3 Inference and Interpretation

In the joint specification, each respondent's weight is applied to both scenario observations. In the control-function specifications, I weight both stages and use a respondent-level bootstrap with 1,000 draws, rebuilding the weights in each draw. PPML without the control function, OLS, and 2SLS use respondent-clustered standard errors. For persistence means, I use weighted averages (Hájek means) and linearized standard errors that hold the calibration weights fixed.

The employment adjustment treats Prolific's self-reported categories as comparable to the ACS categories, which use job-search and availability criteria. Comparing weighted and unweighted estimates assesses sensitivity to differences in age, sex, and employment composition. Weighting cannot correct selection on education, income, or other characteristics outside the calibration.

E Reference-Dependent Demand in Retail Scanner Data

This appendix estimates the RD–CES demand system of Section 2 on the store-level NielsenIQ Retail Measurement Services (RMS) scanner data. Where the survey of Section 3 identifies Γ_L and Γ_G from responses to hypothetical scenarios, the scanner data identify them from transactions: 22 grocery categories, 62 NielsenIQ product modules, and 1.16 billion UPC×store×week observations. The reference price is an exponentially weighted moving average of a product's own past posted prices in that store, and identification comes from comparing a UPC's price with the prices of other UPCs in the same module, store and week, instrumented by the same product's price in other markets.

The expenditure-weighted estimate is $\Gamma = 0.943$ (SE 0.014). Allowing separate responses to gains and losses gives $\Gamma_G = 1.117$ and $\Gamma_L = 0.761$, both with standard errors of 0.023. The estimate of Γ_L is close to the survey estimate of 0.875, while Γ_G is substantially higher than the survey estimate of 0.326. Thus, sales respond more strongly to gains than to losses in the scanner data. Stockpiling may explain this difference: scanner purchases include goods bought during sales for future use, whereas the survey asks about purchases for next month's use and instructs respondents to ignore stockpiling.

E.1 Data and sample

I use NielsenIQ RMS scanner data for 2006–2020, distributed by the Kilts Center at the University of Chicago Booth School of Business. The data report weekly unit sales, prices, advertising, and in-store displays for products sold by participating grocery, drug, and mass-merchandise chains across the United States. Products are grouped into roughly 1,000 modules containing close substitutes, such as ready-to-eat cereal or canned tuna. I use years with consistent module definitions because identification relies on comparisons within modules. The sample is restricted to national-brand grocery products, as described below.

Quantity, price, and the reference price. Let q_{ist} denote unit sales of UPC i in store s during week t. The data contain no observations for UPC–store–weeks with zero sales, so the outcome $y_{ist} = \log q_{ist}$ is defined for every observation. I calculate the unit price P_{ist} by dividing NielsenIQ's volume-weighted weekly price by its multi-buy multiplier. This price is measured after loyalty-card discounts and before manufacturer coupons. Let $p_{ist} = \log P_{ist}$.

For each UPC–store pair, I construct the log reference price from past log prices:

$$r_{ist} \;=\; \rho_w \, r_{is,t-1} \;+\; (1-\rho_w)\, p_{is,t-1}. \tag{E.1}$$

This applies the reference law (2.3) with zero trend inflation at each observation of the UPC–store pair. The parameter ρ_w governs updating in the scanner data, while ρ in the main text

refers to quarterly persistence. The reference price uses only lagged prices, and I exclude each pair's first 52 observations from estimation. I consider $\rho_w = 0.6$ and $\rho_w = 0.9$, corresponding to half-lives of about 1.4 and 6.6 updates. The reference price updates once per observed UPC–store–week, so these half-lives need not correspond to the same number of calendar weeks. I report results for $\rho_w = 0.9$, which fits slightly better. Appendix E.5 discusses this comparison, and Table E.2 reports aggregate estimates for both values.

Controls. I control for advertising in weekly store flyers and special in-store displays, which can increase sales independently of the posted price. Because these promotions often accompany discounts, omitting them could attribute their effects to consumers' response to prices below their reference prices, overstating Γ_G.

After a sale, households may reduce purchases as they use up inventories. At the same time, the posted price may rise above the reference price, which has fallen during the sale. Without accounting for inventories, the decline in purchases could be attributed to reference dependence, overstating Γ_L. I therefore include indicators for one, two, and three-to-four weeks after a temporary price reduction ends. I define a price reduction as a price at least 5% below the UPC–store pair's 13-week rolling median.

Before 2013, NielsenIQ collected advertising and display information only for audited store-weeks. I therefore include audited store-weeks from 2006–2012 and all available store-weeks from 2013–2020.

Categories and filters. I select scanner categories to match the products named by survey respondents. The sample includes 22 categories spanning 62 NielsenIQ modules, covering 1,180 of the 1,432 survey responses (82.4%).[32] Soda and water accounts for 20.4% of observations and 26.3% of expenditure, giving this category substantial weight in the aggregate estimates.

I focus on packaged national-brand products that can be matched across markets using UPCs, as required by the price instrument. Fresh produce, butcher-counter meat, and in-store bakery products are excluded because their product codes do not consistently identify comparable goods across markets. Differences in grade, size, and variety also complicate the construction of a consistent price history. I exclude private-label products because their masked UPCs cannot be matched across retail chains.

After the 52-observation burn-in, I exclude free-with-purchase items and data errors; UPC–store pairs averaging fewer than one unit sold per week, observed in fewer than 104 weeks, or with gaps exceeding 13 weeks; UPCs sold in fewer than two markets; and observations missing a reference price or instrument. I apply these filters to every specification.

[32] Seven categories (bacon, canned tuna, eggs, frozen pizza, ice cream, peanut butter, and liquid tea) consist of a single module, so for them the module×store×week fixed effects below collapse to store×week.

E.2 The estimating equation and identification

Consider a consumer allocating expenditure across the UPCs i within a product module. Under CES preferences with elasticity of substitution ε, demand for i in store s at week t is $q_{ist} \propto P_{ist}^{-\varepsilon}$, conditional on the module price index and total expenditure. Reference dependence enters as in Section 2: the consumer evaluates the posted price against the reference price R_{ist} of equation (E.1), and gain-loss utility shifts the marginal value of purchase by a term proportional to $\log R_{ist} - \log P_{ist}$. Taking logs of the demand schedule (B.1) under the symmetric restriction $\Gamma_L = \Gamma_G \equiv \Gamma$ gives an equation linear in the two prices,

$$y_{ist} \;=\; -(\varepsilon + \Gamma)\, p_{ist} \;+\; \Gamma\, r_{ist} \;+\; \gamma' X_{ist} \;+\; \alpha_{is} \;+\; \delta_{m(i)st} \;+\; u_{ist}, \tag{E.2}$$

where $y = \log q$, $p = \log P$ and $r = \log R$. The term α_{is} is a UPC×store effect and $\delta_{m(i)st}$ a module×store×week effect. The model predicts the signs of both price coefficients: demand slopes down in the posted price, and holding the posted price fixed, a higher reference price makes the same price look like a better deal and raises quantity, so the coefficient on r, which is Γ itself, is positive.

I allow reference-price effects to differ when the posted price is below or above the reference price. Define $g_{ist} = r_{ist} - p_{ist}$, with $g^{+}_{ist} = \max(g_{ist}, 0)$ for gains and $g^{-}_{ist} = \min(g_{ist}, 0)$ for losses. The estimating equation is

$$y_{ist} \;=\; -\varepsilon\, p_{ist} \;+\; \Gamma_G\, g^{+}_{ist} \;+\; \Gamma_L\, g^{-}_{ist} \;+\; \gamma' X_{ist} \;+\; \alpha_{is} \;+\; \delta_{m(i)st} \;+\; u_{ist}. \tag{E.3}$$

The coefficients Γ_G and Γ_L measure the reference-price elasticities in the gain and loss domains. Holding the reference price fixed, the corresponding price elasticities have magnitudes $\varepsilon + \Gamma_G$ and $\varepsilon + \Gamma_L$. Once the reference price fully adjusts to a permanent price change, the price elasticity has magnitude ε. I define $\Delta = \Gamma_L - \Gamma_G$ and describe a category as gain-dominant when $\Delta < 0$.

Fixed effects, controls, and the instrument. All specifications include UPC×store fixed effects, α_{is}, to account for persistent differences in demand across product–store pairs. Module×store×week fixed effects, $\delta_{m(i)st}$, account for shocks common to products in the same module, store, and week. In specifications with controls, X_{ist} includes advertising and display indicators and the three post-sale indicators.[33] I cluster standard errors by store and by week.

Retailers may time discounts using information about demand that is not captured by the fixed effects and controls, making posted prices endogenous. Reference prices are constructed from past posted prices and can also be endogenous if demand shocks persist or retailers anticipate future demand when setting prices. I instrument the posted price with the average

[33] I do not include an indicator for whether a product is currently on sale, since it would absorb some of the promotional price variation used to estimate reference dependence.

log price of the same UPC in the same week at stores outside its own Nielsen DMA, denoted z_{it}^{P}.[34] Following Hausman (1996), the instrument uses common cost shocks that move prices across markets. Identification requires these other-market prices to be uncorrelated with unobserved demand shocks in the store's market, conditional on the fixed effects and controls.

Applying the same reference-updating rule to this price series gives the reference-price instrument z_{it}^{R}. For the asymmetric specification, I construct $z_{it}^{g} = z_{it}^{R} - z_{it}^{P}$ and use its positive and negative parts as instruments for the gain and loss gaps. Both specifications are just-identified. The minimum Sanderson–Windmeijer conditional F-statistic is at least 591 in the symmetric specifications and 258 in the asymmetric specifications. OLS estimates of Γ are lower than the corresponding 2SLS estimates in every category, with a median OLS-to-2SLS ratio of about 0.4.

E.3 Results

Table E.1 reports the 2SLS estimates at $\rho_w = 0.9$ with controls and both sets of fixed effects: the symmetric Γ from equation (E.2) and the gain- and loss-side elasticities from equation (E.3). The no-controls counterparts, and the OLS estimates that serve the reference-speed comparison in Appendix E.5, are in the replication package and summarized below.

Reference dependence is present everywhere. Γ is positive and precisely estimated in all 22 categories, ranging with controls from 0.49 in milk to 2.02 in ice cream, and the CES null $\Gamma = 0$ is rejected everywhere. Adding the controls lowers Γ in all 22 categories, with the expenditure-weighted mean falling from 1.109 (0.014) to 0.943 (0.014).

The asymmetry is heterogeneous, and mostly gain-dominant or symmetric. With controls, eight categories are gain-dominant, eleven show no statistically significant difference between Γ_G and Γ_L, and three are loss-dominant. Without controls, the corresponding counts are ten, nine, and three. The loss-dominant categories are paper products, snack bars, and juice.

The categories with the strongest gain dominance include soup and ramen, ice cream, butter and margarine, and bread. This pattern is consistent with stockpiling: households may buy extra during discounts for future use, increasing current purchases without a corresponding increase in current consumption.

Adding the advertising, display, and post-sale controls lowers Γ_G in 21 of 22 categories and Γ_L in 17. Their expenditure-weighted means fall by about 0.23 and 0.08, respectively. The larger decline in Γ_G is consistent with advertising and displays accounting for part of the increase in sales during discounts that would otherwise be attributed to reference dependence.

[34] Nielsen DMAs (designated market areas) divide the United States into 210 media markets. The instrument excludes the DMA containing the store.

Table E.1: **Reference dependence by category**, 2SLS, $\rho_w = 0.9$, with controls, UPC×store and module×store×week fixed effects. Γ is the symmetric estimate from equation (E.2); Γ_G and Γ_L from equation (E.3) are the responses to a price below the reference (a gain) and above it (a loss); $\Delta = \Gamma_L - \Gamma_G$, with p from the Wald test of $\Gamma_G = \Gamma_L$. Class: Gain = gain-dominant ($\Delta < 0$, $p < 0.05$), Loss = loss-dominant ($\Delta > 0$, $p < 0.05$), Sym. = not distinguishable. Standard errors two-way clustered by store and week. The minimum Sanderson–Windmeijer conditional F is 885 across the symmetric and 315 across the asymmetric regressions. † single-module category.

Category	Γ (s.e.)	Γ_G (s.e.)	Γ_L (s.e.)	Δ (s.e.)	p	Class
Bacon†	1.823 (0.052)	1.872 (0.084)	1.764 (0.101)	-0.108 (0.153)	0.481	Sym.
Bread	0.537 (0.040)	0.940 (0.072)	0.091 (0.043)	-0.848 (0.089)	0.000	Gain
Butter & margarine	1.438 (0.094)	1.954 (0.142)	0.351 (0.147)	-1.602 (0.236)	0.000	Gain
Canned tuna†	0.713 (0.076)	0.423 (0.226)	1.055 (0.227)	0.632 (0.427)	0.139	Sym.
Cereal	1.248 (0.037)	1.464 (0.095)	0.990 (0.091)	-0.474 (0.173)	0.006	Gain
Cheese	1.189 (0.077)	1.184 (0.125)	1.196 (0.099)	0.012 (0.169)	0.943	Sym.
Coffee & creamer	0.977 (0.033)	0.938 (0.073)	1.020 (0.062)	0.083 (0.118)	0.484	Sym.
Crackers	1.027 (0.048)	0.946 (0.095)	1.111 (0.088)	0.166 (0.156)	0.289	Sym.
Eggs†	0.622 (0.079)	0.953 (0.122)	0.168 (0.110)	-0.785 (0.177)	0.000	Gain
Frozen pizza†	1.662 (0.056)	1.582 (0.103)	1.813 (0.136)	0.231 (0.212)	0.277	Sym.
Ice cream†	2.016 (0.079)	2.947 (0.140)	0.924 (0.125)	-2.023 (0.222)	0.000	Gain
Juice	0.628 (0.039)	0.269 (0.090)	1.052 (0.081)	0.783 (0.154)	0.000	Loss
Milk	0.487 (0.059)	0.363 (0.112)	0.633 (0.119)	0.270 (0.198)	0.174	Sym.
Paper products	1.075 (0.056)	0.634 (0.108)	1.665 (0.100)	1.031 (0.178)	0.000	Loss
Pasta	1.143 (0.041)	1.177 (0.074)	1.105 (0.064)	-0.072 (0.113)	0.522	Sym.
Peanut butter†	1.257 (0.089)	1.426 (0.194)	1.033 (0.176)	-0.393 (0.332)	0.237	Sym.
Salty snacks	0.528 (0.044)	0.643 (0.083)	0.407 (0.071)	-0.236 (0.126)	0.062	Sym.
Snack bars	0.763 (0.042)	0.261 (0.087)	1.385 (0.081)	1.124 (0.148)	0.000	Loss
Soda & water	0.813 (0.042)	1.255 (0.056)	0.404 (0.065)	-0.851 (0.108)	0.000	Gain
Soup & ramen	0.868 (0.046)	1.647 (0.098)	-0.213 (0.079)	-1.859 (0.161)	0.000	Gain
Tea (liquid)†	0.649 (0.035)	0.828 (0.083)	0.478 (0.066)	-0.351 (0.132)	0.008	Gain
Yogurt	1.185 (0.061)	1.049 (0.111)	1.378 (0.115)	0.329 (0.191)	0.086	Sym.

The Wald test of $\Gamma_G = \Gamma_L$ rejects at the 5% level in 13 categories without controls and 11 with controls. All eleven rejections with controls also hold at the 1% level.

Weighted aggregates. Table E.2 averages the category estimates using expenditure weights,

$$w_c = \frac{R_c}{\sum_k R_k},$$

where R_c is category c's total revenue over the sample period. These weights measure expenditure shares within the estimation sample, not the overall consumer basket. Weighting by observation counts or estimation precision instead changes the aggregate estimates by at most 0.08. The reported standard errors ignore covariance across category estimates and may therefore understate uncertainty.

Table E.2: Expenditure-weighted reference dependence, 22 categories, 2SLS, at both reference speeds. Γ is the symmetric estimate; Γ_G and Γ_L the gain- and loss-side estimates. Soup & ramen enters at its estimated Γ_L, a precise small negative value at $\rho_w = 0.9$.

Specification	Parameter	$\rho_w = 0.9$	$\rho_w = 0.6$
No controls	Γ	1.109 (0.014)	0.820 (0.012)
	Γ_G	1.350 (0.024)	1.126 (0.024)
	Γ_L	0.840 (0.027)	0.512 (0.026)
With controls	Γ	0.943 (0.014)	0.767 (0.015)
	Γ_G	1.117 (0.023)	0.920 (0.023)
	Γ_L	0.761 (0.023)	0.599 (0.028)

E.4 Comparison with the survey

The scanner estimate of Γ_L is 0.761 (SE 0.023), compared with 0.875 in the survey. The two approaches measure reference prices differently. In the scanner data, I construct the reference price from a moving average of the product's past prices at the same store. The survey instead elicits respondents' reference prices directly. These may reflect shopping experiences at other stores and the prices of competing products, so they need not coincide with the constructed scanner measure.

The scanner estimate of Γ_G is 1.117 (SE 0.023), compared with 0.326 in the survey. The five largest category-level estimates are for ice cream (2.95), butter and margarine (1.95), bacon (1.87), soup and ramen (1.65), and frozen pizza (1.58). These products can be stored or frozen, allowing households to buy extra during discounts for later use. Stockpiling could therefore contribute to their large gain-side purchase responses.

Giving each category equal weight yields $\Gamma_L = 0.900$ and $\Gamma_G = 1.125$. The loss-side estimate is closer to the survey estimate of 0.875, while the gain-side estimate changes little.

I use the survey estimates for calibration in Section 4. The model describes consumption choices and does not include inventories of individual products. The survey asks respondents about purchases for next month's use and instructs them to ignore stockpiling, so these responses more closely match the demand response in the model. Scanner data record purchases that may include goods bought for future use. I therefore use the scanner estimates as supporting evidence on the magnitude of Γ_L.

E.5 Evidence on the reference-updating speed

The slower reference ($\rho_w = 0.9$) yields a higher within-R^2 than $\rho_w = 0.6$ in 65 of the 88 comparisons across 22 categories and four OLS specifications. I therefore use $\rho_w = 0.9$ as the baseline. The differences in fit are small, however, so Table E.2 reports estimates at both updating speeds.

I use the survey to calibrate ρ because it measures updating per shopping trip and records respondents' shopping frequency, allowing conversion to quarterly persistence.

F Quantitative Model, Numerical Solution, and Sensitivity

This appendix states the equilibrium conditions used in Section 4, describes the solution algorithm, and reports sensitivity checks.

F.1 Equilibrium conditions and calibration

Physical output is Y_t, composite output is Y_t^U, and composite consumption is C_t^U. Let $d_t = \log(P_t/R_t)$, $\Pi_t = P_t/P_{t-1}$, $\pi_t = \log \Pi_t$, and $\Lambda_t = (C_t^U)^{-\sigma}$. The reference wedge and reference-price law are

$$\chi_t = \begin{cases} \Gamma_L d_t/(\varepsilon - 1), & d_t > 0, \\ \Gamma_G d_t/(\varepsilon - 1), & d_t < 0, \\ 0, & d_t = 0, \end{cases} \qquad R_{t+1} = R_t^{\rho} P_t^{1-\rho}, \qquad P_t^{\mathrm{RD}} = P_t e^{\chi_t}. \tag{F.1}$$

The cost-push factor satisfies $\log \upsilon_t = \rho_u \log \upsilon_{t-1} + \varepsilon_t^u$, with a single initial innovation. Productivity remains at $A_t = 1$ throughout these experiments. Under perfect foresight, household optimality and market clearing imply

$$1 = \beta I_t \left(\frac{C_t^U}{C_{t+1}^U} \right)^{\sigma} \frac{e^{\chi_t - \chi_{t+1}}}{\Pi_{t+1}}, \qquad \frac{W_t}{P_t} = e^{\chi_t} (C_t^U)^{\sigma} N_t^{\varphi}, \tag{F.2}$$

$$Y_t = A_t N_t^{1-\alpha} = e^{\chi_t} Y_t^U, \qquad C_t^U = Y_t^U \left[1 - \frac{\psi_p}{2} (\Pi_t - 1)^2 \right], \tag{F.3}$$

$$mc_t = \frac{(1-\tau) W_t}{P_t (1-\alpha) A_t N_t^{-\alpha}}, \qquad z_t = \upsilon_t mc_t. \tag{F.4}$$

Here mc_t is subsidized real marginal cost in posted-price units, and z_t additionally includes the cost-push factor. The gross nominal interest rate I_t follows

$$I_t = I_{t-1}^{\rho_i} \left[\beta^{-1} \Pi_t^{\phi_\pi} \left(\frac{Y_t}{\bar{Y}} \right)^{\phi_y} \right]^{1-\rho_i}. \tag{F.5}$$

Thus policy responds to physical output relative to steady state. There is no monetary-policy innovation in the cost-push experiments. In logs, with $i_t \equiv \log(I_t/\bar{I})$ and $\bar{I} = 1/\beta$, the rule is $i_t = \rho_i i_{t-1} + (1-\rho_i)[\phi_\pi \pi_t + \phi_y \log(Y_t/\bar{Y})]$, which reduces to (2.16) without the policy shock when $\rho_i = 0$.

The factor υ_t is implemented as a tax on the subsidy-adjusted wage bill. Firm profits and

the government's net lump-sum transfer are

$$D_t^F(i) = P_t(i)Y_t(i) - \upsilon_t(1-\tau)W_tN_t(i) - \frac{\psi_p}{2}\left(\frac{P_t(i)}{P_{t-1}(i)} - 1\right)^2 P_t^{\mathrm{RD}}Y_t^U, \tag{F.6}$$

$$T_t = \left[(\upsilon_t - 1)(1-\tau) - \tau\right]W_tN_t. \tag{F.7}$$

Fiscal flows cancel when household income and firm profits are aggregated. The cost-push factor therefore changes pricing incentives without adding a resource cost to equation (F.3) or a separate term to household welfare.

Pricing and the costate. Let Γ_{b_t} equal Γ_L on the loss branch and Γ_G on the gain branch. Let η_t^+ and η_t^- denote the reference-price elasticities on the branches reached by a current price increase or cut, respectively. Both equal Γ_{b_t} off the kink; at $P_t = R_t$ they equal Γ_L and Γ_G, respectively. Define

$$\mathcal{M}_{t+1} = \frac{\Lambda_{t+1}Y_{t+1}^U}{\Lambda_tY_t^U}, \qquad \mathcal{A}_t = -\psi_p(\Pi_t - 1)\Pi_t + \beta\psi_p\mathcal{M}_{t+1}(\Pi_{t+1} - 1)\Pi_{t+1}. \tag{F.8}$$

Holding inherited states and the aggregate path fixed, the right and left derivatives of the firm's Bellman return with respect to its current log posted price, normalized by $\Lambda_tY_t^U$, are

$$\mathcal{D}_t^{\pm} = 1 - (\varepsilon + \eta_t^{\pm})(1 - z_t) + \mathcal{A}_t + \beta(1-\rho)\mathcal{M}_{t+1}\Theta_{t+1}. \tag{F.9}$$

Here Θ_t is the partial derivative of optimized firm value with respect to its log reference price, holding the inherited posted-price state fixed and normalizing by $\Lambda_tY_t^U$. The continuation derivative is common when the date-$t+1$ value function is differentiable in its reference state. Otherwise, the corresponding one-sided derivative $\Theta_{t+1}^{R,\pm}$ replaces Θ_{t+1}, as in Appendix B.2. Continuation choices are optimized after each deviation. The first-order pricing conditions are

$$\begin{aligned} P_t > R_t: &\quad \mathcal{D}_t^+ = 0, \\ P_t < R_t: &\quad \mathcal{D}_t^- = 0, \\ P_t = R_t: &\quad \mathcal{D}_t^+ \le 0 \le \mathcal{D}_t^-. \end{aligned} \tag{F.10}$$

Where firm value is differentiable, the costate recursion on a smooth branch and under the locally optimal tracking policy is

$$\begin{aligned} P_t \neq R_t: &\quad \Theta_t = \Gamma_{b_t}(1 - z_t) + \beta\rho\mathcal{M}_{t+1}\Theta_{t+1}, \\ P_t = R_t: &\quad \Theta_t = 1 - \varepsilon(1 - z_t) - \psi_p(\Pi_t - 1)\Pi_t \\ &\qquad + \beta\mathcal{M}_{t+1}\left[\Theta_{t+1} + \psi_p(\Pi_{t+1} - 1)\Pi_{t+1}\right]. \end{aligned} \tag{F.11}$$

At the kink, the second recursion applies in the interior of the tracking region, where the optimal posted price follows the reference, $P_t = R_t$. Raising both prices raises next period's reference one for one, so the normalized continuation multiplier is $\beta\mathcal{M}_{t+1}$ rather than $\beta\rho\mathcal{M}_{t+1}$. The adjustment-cost terms account for the change in the posted price. The cost-push factor enters both pricing and costate conditions through z_t.

Steady state. In RD-RANK, I set the employment subsidy to the midpoint of the interval in Proposition B.1, $\tau = (1/\varepsilon^{\uparrow} + 1/\varepsilon^{\downarrow})/2$, and $\bar{mc} = 1 - \tau$, so the steady-state one-sided pricing inequalities are strict. Firm optimality is checked numerically as described below. The terminal costate is $\bar{\Theta} = [1 - \varepsilon(1 - \bar{mc})]/(1 - \beta)$. RANK sets both reference-price elasticities to zero and uses $\tau = 1/\varepsilon$. The Rotemberg coefficient is calibrated in RANK to a three-quarter Calvo-equivalent price duration and held fixed across the two models.

F.2 Solution and numerical verification

I solve the nonlinear perfect-foresight system over 200 quarters, starting from the deterministic steady state and imposing steady-state terminal conditions. For a given sequence of pricing regimes, I solve the equilibrium equations and costate recursion. I then update the regime assignments until the conditions in (F.10) hold at every date. The procedure finds a locally valid equilibrium path but does not establish global uniqueness.

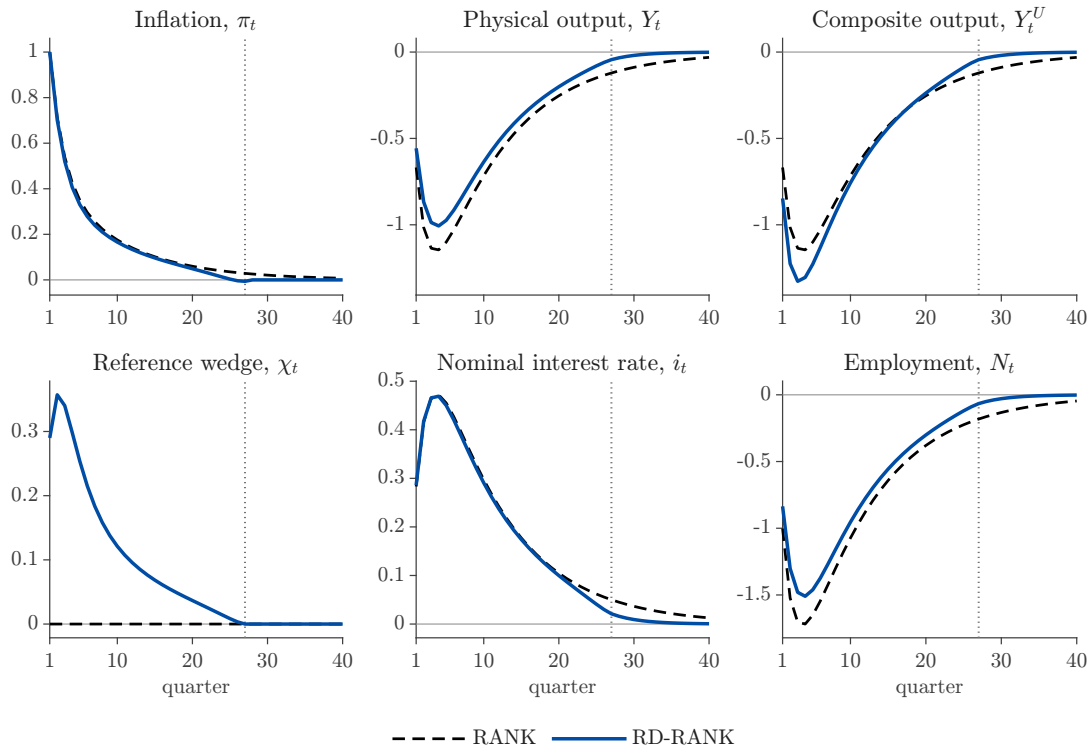
I use a tolerance of 10^{-8} for pricing and regime conditions and 2×10^{-6} for equilibrium identities and terminal convergence. The baseline and sensitivity exercises satisfy these tolerances and pass feasibility checks.

Firm optimality. Conditional on the solved aggregate paths, I solve a single firm's dynamic pricing problem by backward induction from the terminal steady state. The objective is single-peaked on each side of the reference price at all tested states and dates, providing numerical support for Assumption B.1. Along the equilibrium path, setting the firm's price equal to the aggregate price is optimal within numerical tolerance over a grid extending ± 20 log points around the aggregate price, in steps of 0.1 log point. Expanding the grid to ± 50 log points, in steps of 0.25 log point, gives the same result.

Welfare computation. Exact discounted utility losses ΔW are evaluated from C_t^U and N_t along the nonlinear path, with the steady-state continuation contributing zero additional loss. Appendix B.4 derives their conversion to permanent consumption-equivalent losses λ, holding labor at its steady-state level. For the cost-push experiment, the order-consistent approximation used in Table 5 is

$$\lambda^{(2)} = (1 - \beta)\mathcal{L}^{(2)} - \frac{\sigma}{2}(1 - \beta)^2 \left(\sum_{t=0}^{T-1} \beta^t \chi_t \right)^2 . \tag{F.12}$$

Figure F.1: Matched-peak cost-push shock at baseline persistence: $\rho_u = 0.90$



Notes: Responses to a cost-push shock with persistence $\rho_u = 0.90$, scaled separately in each model to produce a 1% peak in quarterly inflation (innovations ε_0^u of 8.36 log points in RANK and 7.89 in RD-RANK). Reference-price persistence is $\rho = 0.53$; all other parameters are those of Table 4. Quarter 1 is the quarter of the shock, $t = 0$. Physical output Y_t, composite output Y_t^U, employment N_t, and the gross nominal interest rate are expressed as log deviations from steady state multiplied by 100; inflation is $100\,\pi_t$ and the reference wedge is $100\,\chi_t$. The two output panels share a vertical scale. The vertical dotted line marks quarter 27, when the RD-RANK model returns to $P_t = R_t$; inflation is exactly zero from quarter 28 onward.

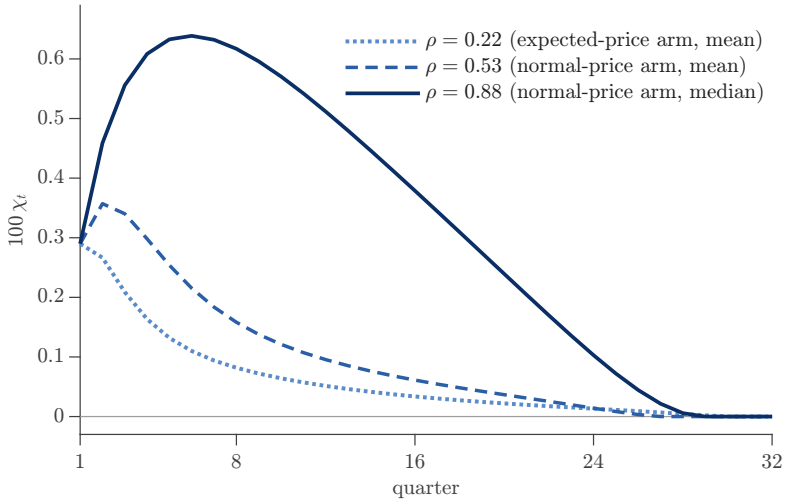
Component shares use the four terms in $\mathcal{L}^{(2)}$ before this conversion correction.

F.3 Sensitivity of welfare results

Baseline impulse responses. Figure F.1 shows the responses to the baseline shock of Table 5, with $\rho_u = 0.90$ and $\rho = 0.53$. RD-RANK stays above its reference price until quarter 26 and returns to $P_t = R_t$ in quarter 27.

Reference persistence. Figure F.2 plots the reference wedge along the baseline cost-push path at the three values of ρ in Table 5. All three paths start from the same wedge, because impact inflation is matched. With slower updating, the wedge decays more slowly; at $\rho = 0.88$ it rises until quarter 6.

Figure F.2: The reference wedge by reference-price persistence



Notes: Reference wedge $100\,\chi_t$ in RD-RANK after a cost-push shock with persistence $\rho_u = 0.90$, scaled to a 1% peak in quarterly inflation, at each value of reference-price persistence ρ; all other parameters are those of Table 4. Quarter 1 is the quarter of the shock, $t = 0$. Multiplying $\sum_t \beta^t \chi_t$ by $1 - \beta$ gives the wedge's contribution to the approximate loss $100 \times \lambda^{(2)}$ in Table 5: 0.018%, 0.029%, and 0.094% at $\rho = 0.22$, 0.53, and 0.88.

Table F.1: Welfare sensitivity to the monetary-policy rule

			$\rho = 0.22$		$\rho = 0.53$	
ρ_i	ϕ_y	RANK loss	RD-RANK loss	Ratio	RD-RANK loss	Ratio
0.80	0.125	0.0087	0.0266	3.052	0.0376	4.310
0.00	0.125	0.0163	0.0495	3.039	0.0722	4.430
0.80	0.000	0.0111	0.0262	2.355	0.0362	3.248
0.00	0.000	0.0209	0.0537	2.572	0.0771	3.691

Notes: Losses are exact permanent consumption equivalents in percent, 100λ. The first row is the baseline. Every row uses $\sigma = 2$, $\rho_u = 0.90$, $\phi_\pi = 1.50$, $\varepsilon = 4$, and $\psi_p = 52.94$, with innovations chosen separately to match a 1% inflation peak. Ratios use unrounded losses.

Monetary-policy rule. Table F.1 compares the baseline rule with rules that remove interest-rate smoothing, output feedback, or both. Each model's cost-push innovation is rematched to a 1% peak in quarterly inflation. Reference dependence raises welfare losses in every case. The complete grid of 12 rules, $\rho_i \in \{0.7, 0.8, 0.9\}$ crossed with $\phi_y \in \{0.075, 0.125, 0.25\}$ plus $(\rho_i, \phi_y) = (0, 0)$, $(0, 0.125)$, and $(0.8, 0)$, gives RD-RANK/RANK ratios of 2.35–3.31 at $\rho = 0.22$ and 3.25–4.71 at $\rho = 0.53$.

Demand elasticity and episode size. Table F.2 varies the calibrated CES elasticity and the target peak inflation rate. For each elasticity, I recalibrate ψ_p to preserve the three-quarter Calvo-equivalent duration in RANK and use the same coefficient in RD-RANK. Higher ε reduces the welfare ratio in these experiments; it also directly reduces the wedge $\Gamma_{b_t} d_t/(\varepsilon - 1)$

Table F.2: Welfare sensitivity to demand elasticity and episode size

				$\rho = 0.22$		$\rho = 0.53$	
ε	ψ_p	Peak (%)	RANK loss	RD-RANK loss	Ratio	RD-RANK loss	Ratio
3	29.41	0.5	0.0014	0.0125	8.800	0.0166	11.733
3	29.41	1.0	0.0056	0.0300	5.375	0.0432	7.740
4	52.94	0.5	0.0022	0.0110	4.948	0.0158	7.100
4	52.94	1.0	0.0087	0.0266	3.052	0.0376	4.310
5	82.35	0.5	0.0033	0.0104	3.169	0.0146	4.471
5	82.35	1.0	0.0127	0.0267	2.100	0.0357	2.802
4	52.94	4.0	0.1255	0.1875	1.495	0.2312	1.843

Notes: Losses are exact permanent consumption equivalents in percent, 100λ, with $\sigma = 2$, $\rho_u = 0.90$, $\rho_i = 0.80$, $\phi_\pi = 1.50$, and $\phi_y = 0.125$. Innovations are rematched separately in each model to the target peak in quarterly inflation. Ratios use unrounded losses. The reference shares at the 4% peak discussed in the text refer to the second-order decomposition, not the exact consumption-equivalent loss.

for a given price-reference gap. Smaller episodes give the first-order wedge greater weight relative to the quadratic terms in the welfare decomposition. At a 4% peak, its share of the second-order RD-RANK loss falls to 50.6% at $\rho = 0.53$ and 38.5% at $\rho = 0.22$.

G The Full Model and Equation System

This appendix states the model of Section 5.1 in the real, recursive form I compute, and lists the full equilibrium system.

Information structure. The equilibrium conditions below apply to each nonlinear perfect-foresight transition. At its initial date, agents observe current aggregate innovations and treat future aggregate innovations as zero, while existing shocks follow their specified laws of motion. The expectation operators in the aggregate pricing and wage-setting equations are therefore redundant: future variables are evaluated along the anticipated aggregate path. That path can be revised when new innovations arrive. Expectations in household decision problems integrate over idiosyncratic earnings and discount-factor transitions, conditional on the household's current state and this aggregate path. The historical exercise retains each transition's current-quarter allocation and updates the inherited states and household distribution before the next innovations arrive (Appendix H.2). The exercise captures nonlinear responses to realized aggregate innovations while abstracting from the effects of anticipated aggregate risk.

G.1 The household block

Euler condition. The decision representation in (5.3), subject to (5.4), implies

$$\frac{c_{it}^{-\sigma}}{P_{z_{it}}^{C}(q_t)} \;\geq\; \frac{\beta_{it}}{\zeta_t}\,\mathbb{E}_{it}\left[R_{t+1}^{b}\,\frac{c_{i,t+1}^{-\sigma}}{P_{z_{i,t+1}}^{C}(q_{t+1})}\right], \tag{G.1}$$

with equality when $b_{it} > 0$. Here $\mathbb{E}_{it}$ conditions on household i's information at date t, including its current individual state. This condition incorporates the aggregate discount-factor shifter ζ_t; the baseline welfare recursions below fix that shifter at one.

Dividend income. Household i's dividend weight in (5.4) is $\xi_{z_{it}}$, where the state-dependent schedule is

$$\xi_z = \frac{e_z^{\lambda}}{\sum_{z'} \pi_z(z')\, e_{z'}^{\lambda}}, \qquad \lambda = 3.054. \tag{G.2}$$

Here $\pi_z(z)$ is the stationary population share in earnings state z. The weights satisfy $\sum_z \pi_z(z)\xi_z = 1$; the share of aggregate dividends received by earnings group z is therefore $\pi_z(z)\xi_z$.

The discount-factor chain. Following Auclert et al. (2025), household i has $\beta_{i,t+1} = \beta_{it}$ with probability $1 - p_\beta$ each quarter. With probability p_β, it draws $\beta_{i,t+1}$ anew, receiving β_H with probability $\pi_\beta(\beta_H)$ and β_L otherwise, independently of its previous discount factor and

the earnings process. The two-point discount-factor process therefore has transition matrix

$$\Pi^{\beta} = \begin{pmatrix} 1 - p_{\beta}\,\pi_{\beta}(\beta_H) & p_{\beta}\,\pi_{\beta}(\beta_H) \\ p_{\beta}(1 - \pi_{\beta}(\beta_H)) & 1 - p_{\beta}(1 - \pi_{\beta}(\beta_H)) \end{pmatrix}, \qquad p_{\beta} = 0.01, \quad \pi_{\beta}(\beta_H) = 0.2295, \tag{G.3}$$

ordered (β_L, β_H). The patient redraw probability $\pi_{\beta}(\beta_H)$ also equals the stationary patient share. The joint state $s_{it} = (\beta_{it}, z_{it})$ follows a fourteen-state Markov chain with transition matrix $\Pi^{s} = \Pi^{\beta} \otimes \Pi_{z}$.

Sectoral demands. The CES composite behind (5.2) is

$$c_{it} = \Big[\omega_R(z_{it})^{\frac{1}{\nu}} \big(c_{it}^{R}\big)^{\frac{\nu-1}{\nu}} + \big(1 - \omega_R(z_{it})\big)^{\frac{1}{\nu}} \big(c_{it}^{S}\big)^{\frac{\nu-1}{\nu}}\Big]^{\frac{\nu}{\nu-1}}, \tag{G.4}$$

with demands

$$\begin{aligned} c_{it}^{R} &= \omega_R(z_{it}) \Big(\frac{q_t}{P_{z_{it}}^{C}(q_t)}\Big)^{-\nu} c_{it}, \\ c_{it}^{S} &= \big(1 - \omega_R(z_{it})\big) P_{z_{it}}^{C}(q_t)^{\nu} c_{it}, \\ q_t c_{it}^{R} + c_{it}^{S} &= P_{z_{it}}^{C}(q_t)\, c_{it}. \end{aligned} \tag{G.5}$$

The block's aggregate outputs are asset demand $A_t = \int_0^1 b_{it}\,\mathrm{d}i$, sectoral consumption $C_{j,t} = \int_0^1 c_{it}^{j}\,\mathrm{d}i$ for $j \in \{R, S\}$, and the wage-equation statistic

$$\ell_t^{L} = \int_0^1 e_{z_{it}}\, \frac{c_{it}^{-\sigma}}{P_{z_{it}}^{C}(q_t)}\,\mathrm{d}i. \tag{G.6}$$

G.2 Firms

Reference-dependent demand. In sector R, let $\mathcal{R}_{R,t}$ denote the inherited reference price and $d_{R,t} = \log(P_{R,t}/\mathcal{R}_{R,t})$ the price-reference gap. Reference updating implies

$$d_{R,t} = \rho_R d_{R,t-1} + \log \Pi_{R,t}. \tag{G.7}$$

The reference wedge and effective relative price are

$$\begin{aligned} X_{R,t} &= \exp(\chi_{R,t}), \qquad q_t = X_{R,t}\tilde{q}_t, \\ \chi_{R,t} &= \begin{cases} \dfrac{\Gamma_G}{\epsilon_R - 1} d_{R,t}, & d_{R,t} < 0, \\ 0, & d_{R,t} = 0, \\ \dfrac{\Gamma_L}{\epsilon_R - 1} d_{R,t}, & d_{R,t} > 0. \end{cases} \end{aligned} \tag{G.8}$$

Here $X_{R,t}$ abbreviates $e^{\chi_{R,t}}$ in the equations below. When posted prices exceed references, $X_{R,t} > 1$: a given physical consumption bundle delivers less utility, and the expenditure needed to attain a given c rises. This welfare interpretation maintains the reference-dependent utility specification of Section 2, including its treatment of transaction utility as welfare relevant.

Price-setting conditions. Sector-S pricing is given by (5.6). The sector-R conditions below adapt the pricing and reference-costate equations (2.10) and (2.9); Appendix B derives their one-sided counterparts. Let $\upsilon_{j,t}$ denote the cost-push factor, $mc_{j,t}$ the subsidy-adjusted real marginal cost, and $\delta_t = (1+i_t)^{-1}$ the nominal discount factor along a conditional perfect-foresight path. Write $\eta_t = \Gamma_G$ when $d_{R,t} < 0$ and $\eta_t = \Gamma_L$ when $d_{R,t} > 0$. At the kink, $\eta_t \in [\Gamma_G, \Gamma_L]$ is selected by the one-sided optimality conditions. The reference costate $\Theta_{R,t}$ summarizes the continuation effect of changing the reference. The pricing condition and off-kink costate recursion are

$$\begin{aligned}\psi_R(\Pi_{R,t}-1)\Pi_{R,t} = 1 - (\epsilon_R+\eta_t)(1-\upsilon_{R,t}\,mc_{R,t}) \\ + \delta_t\,\mathbb{E}_t\Big[\frac{X_{R,t+1}Y_{R,t+1}}{X_{R,t}Y_{R,t}}\Big((1-\rho_R)\,\Theta_{R,t+1}\,\Pi_{R,t+1} + \psi_R(\Pi_{R,t+1}-1)\,\Pi_{R,t+1}^2\Big)\Big],\end{aligned} \tag{G.9}$$

$$\Theta_{R,t} = \eta_t(1-\upsilon_{R,t}\,mc_{R,t}) + \rho_R\,\delta_t\,\mathbb{E}_t\left[\frac{X_{R,t+1}Y_{R,t+1}}{X_{R,t}Y_{R,t}}\,\Pi_{R,t+1}\,\Theta_{R,t+1}\right]. \tag{G.10}$$

At a reference-tracking date, the equivalent costate condition is

$$\begin{aligned}\Theta_{R,t}\Big|_{d_{R,t}=0} = 1 - \epsilon_R(1-\upsilon_{R,t}\,mc_{R,t}) - \psi_R(\Pi_{R,t}-1)\Pi_{R,t} \\ + \delta_t\,\mathbb{E}_t\left[\frac{X_{R,t+1}Y_{R,t+1}}{X_{R,t}Y_{R,t}}\,\Pi_{R,t+1}\Big(\Theta_{R,t+1} + \psi_R(\Pi_{R,t+1}-1)\,\Pi_{R,t+1}\Big)\right].\end{aligned} \tag{G.11}$$

The branch and tracking forms agree at a solution with a common selected slope, as shown in (H.5). Appendix H.4 states the complementarity condition and the numerical directional checks. Reference tracking need not imply an unchanged nominal price when the inherited reference moves.

Production, marginal costs, and dividends. Physical production is linear in labor:

$$X_{R,t}Y_{R,t} = Z_t Z_{R,t} N_{R,t}, \qquad Y_{S,t} = Z_t Z_{S,t} N_{S,t}, \qquad N_t = N_{R,t} + N_{S,t}. \tag{G.12}$$

Real marginal costs, inclusive of the constant production subsidies $\bar{mc}_j$, are

$$mc_{R,t} = \bar{mc}_R\,\frac{w_t}{Z_t Z_{R,t}\,\tilde{q}_t}, \qquad mc_{S,t} = \bar{mc}_S\,\frac{w_t}{Z_t Z_{S,t}}, \tag{G.13}$$

where $mc_{R,t}$ measures nominal cost per physical unit relative to the posted price. Sector-R nominal revenue is $P_{R,t}X_{R,t}Y_{R,t}$ and its operating margin is $1 - \upsilon_{R,t}mc_{R,t}$. The cost-push factors $\upsilon_{R,t}$, $\upsilon_{S,t}$, and $\upsilon_{w,t}$ equal one in steady state. The sector-R disturbance is implemented as a structural tax with receipts rebated through aggregate dividends. Dividends include these receipts and sectoral revenues net of wage bills, the structural tax, and price-adjustment costs. The rebate therefore reaches household i through $\xi_{z_{it}}\mathcal{D}_t$, with incidence weights (G.2), and leaves the government budget (G.16) unchanged.

Steady-state objects of the reference-dependent block. The zero-inflation steady state has $d_{R,\text{ss}} = 0$. I select the midpoint slope $\bar{\Gamma} = (\Gamma_G + \Gamma_L)/2 = 0.60$ and the associated production subsidy. The sector-R counterpart of the steady-state calculation in Section 2 gives

$$\Omega = \frac{\delta_{\text{ss}}(1-\rho_R)}{1-\delta_{\text{ss}}\rho_R}, \qquad \epsilon^{\text{eff}} = \epsilon_R + \bar{\Gamma}(1-\Omega), \qquad \bar{mc}_R = \frac{\epsilon^{\text{eff}}-1}{\epsilon^{\text{eff}}}, \qquad \Theta_{R,\text{ss}} = \frac{\bar{\Gamma}(1-\bar{mc}_R)}{1-\rho_R\delta_{\text{ss}}}. \tag{G.14}$$

At $r_{\text{ss}} = 0.005$, these expressions give $\Omega = 0.989$, $\epsilon^{\text{eff}} = 4.0063$, $\bar{mc}_R = 0.7504$, and $\Theta_{R,\text{ss}} = 0.317$; in sector S, $\bar{mc}_S = (\epsilon_S - 1)/\epsilon_S = 6/7$. Applying Proposition B.1 with δ_{ss} and ρ_R in place of β and ρ gives the admissible subsidy range $\bar{mc}_R \in [0.7502, 0.7506]$. The midpoint selection lies within this range. This selection is a calibration choice: the steady-state conditions alone do not select a slope and subsidy pair.

G.3 Policy details

Wages. Following Auclert et al. (2021), each union represents all households and sets the nominal wage for a differentiated labor service. Union k incurs the utility cost

$$\frac{\psi_w}{2}\left[\log\left(\frac{W_{k,t}}{W_{k,t-1}}\right)\right]^2, \qquad \psi_w = \frac{\epsilon_w}{\kappa_w}, \qquad \epsilon_w = \frac{\mu_w}{\mu_w - 1},$$

where ϵ_w is the elasticity of substitution across labor services. In the symmetric equilibrium, all unions set the same wage and households work the same hours. The resulting wage Phillips curve is (5.7), with the household statistic ℓ_t^L defined in (G.6). The calibration sets $\kappa_w = 0.085$ and $\mu_w = 1.2$. Wage adjustment costs enter no budget constraint or market-clearing condition; Section 5.3 includes them in household welfare. Matching the local Calvo slope through $(1-\theta_w)(1-\beta_w\theta_w)/\theta_w = \kappa_w\varphi_N$, where θ_w is the probability of not resetting a wage, gives a mean wage spell of approximately 4.1 quarters. This comparison matches the local Phillips-curve slope and does not imply equivalence of household welfare. The real wage evolves according to

$$w_t = w_{t-1}\frac{\Pi_{w,t}}{\Pi_{S,t}}. \tag{G.15}$$

Union discounting. The union discounts average household utility and wage adjustment costs at $\beta_w = (1 - \pi_\beta(\beta_H))\beta_L + \pi_\beta(\beta_H)\beta_H \simeq 0.966$, the stationary population mean of household discount factors. This is an institutional assumption rather than an exact aggregation of heterogeneous lifetime preferences. The union discount factor remains fixed when ζ_t changes; aggregate discount-factor shocks affect wage setting through household marginal utilities and equilibrium prices and quantities.

Monetary policy. The Taylor rule (5.8) uses physical output, $Y_{R,t}^{\text{phys}} = X_{R,t}Y_{R,t}$ and $Y_{S,t}^{\text{phys}} = Y_{S,t}$, with fixed sectoral CPI weights ϑ_j^{Π} and steady-state GDP shares ϑ_j^{Y}. The calibration sets $(\rho_i, \phi_\pi, \phi_y) = (0.80, 1.50, 0.125)$, with the output coefficient of Taylor (1993) expressed in quarterly units, and $(\vartheta_R^{\Pi}, \vartheta_R^{Y}) = (0.237, 0.262)$. The monetary-policy shock m_t follows an AR(1) process with persistence $\rho_m = 0.70$ (Appendix H.3). The model's steady state has zero inflation and a quarterly real rate of 0.5%. The rule's fixed-weight inflation aggregate differs from the measured CPI defined in (G.17).

Government. Real government debt is a state variable,

$$B_t = R_t^b\, B_{t-1} + G_t + Subs_t + Tr_t^{\text{exog}} - Tax_t^{L} - Tax_t^{\text{tail}}, \qquad Tax_t^{\text{tail}} = \mathbf{1}\{t \geq T_{tail}\}\, \phi_B (B_{t-1} - B_{\text{ss}}), \tag{G.16}$$

with $(T_{tail}, \phi_B) = (80,\ 0.05)$. Purchases G_t and the transfer instrument Tr_t^{exog} are the two exogenous fiscal inputs; labor-tax revenue $Tax_t^{L} = \tau_L \mathcal{T}^w w_t N_t$ moves with the wage bill; $Subs_t$ is the bill for the constant production and wage subsidies; and households receive $Tr_t^{\text{hh}} = Tr_t^{\text{exog}} - Tax_t^{\text{tail}}$. I choose the delayed tail tax so that no part of the government's revaluation gains is rebated to households during the 2021–2023 episode: it is identically zero inside the window and only later retires the debt gap, which allows the economy to eventually reach the steady state in the long run. Because the welfare measure follows the post-window path, the tail tax also enters welfare, from 2041.

The measured CPI aggregates posted prices with the CES weight ϑ_R^{Π}:

$$\frac{P_t^{\Pi}}{P_{S,t}} = \left[\vartheta_R^{\Pi}\, \tilde{q}_t^{1-\nu} + 1 - \vartheta_R^{\Pi}\right]^{\frac{1}{1-\nu}}, \qquad \Pi_t^{\Pi} = \Pi_{S,t}\, \frac{(P^{\Pi}/P_S)_t}{(P^{\Pi}/P_S)_{t-1}}. \tag{G.17}$$

The subsidy bill in (G.16) is

$$Subs_t = (1 - \bar{mc}_R)\, w_t N_{R,t} + (1 - \bar{mc}_S)\, w_t N_{S,t} + (\mathcal{T}^w - 1)\, w_t N_t, \tag{G.18}$$

government purchases fall on the S good ($G_{S,t} = G_t$, $G_{R,t} = 0$), and both fiscal instruments are level processes with zero steady state: transfers are i.i.d., $Tr_t^{\text{exog}} = \varepsilon_t^{Tr}$, and purchases follow $G_t = \rho_G G_{t-1} + \varepsilon_t^G$ with $\rho_G = 0.56$ (Appendix H.3). The steady state runs a primary surplus $(R_{\text{ss}}^b - 1)B_{\text{ss}}$ financed by the labor tax, whose rate $\tau_L = 0.332$ balances the budget.

The structural cost-push tax appears nowhere in (G.16) or (G.18): its receipts never cross the government's books.

G.4 The equilibrium system

Equilibrium. Following the block representation of Auclert et al. (2021, Appendix C.2), let Z collect the conditional paths of aggregate shocks and let

$$U = \{(\Pi_{w,t},\, \Pi_{S,t},\, \Pi_{R,t},\, \Theta_{R,t},\, Y_{R,t},\, Y_{S,t})\}_{t\geq 0} \tag{G.19}$$

denote the six aggregate sequences. Given the initial household distribution and inherited aggregate states, an equilibrium consists of U, household policies and distributions, and the remaining endogenous variables such that:

(i) Each model block is internally consistent. Household policies solve (5.3) subject to (5.4); the distribution Ψ_t evolves under these policies and the joint exogenous transition matrix Π^s; and household aggregates are obtained by integrating individual outcomes over this distribution. Production, reference updating, firm optimization, union wage setting, and fiscal and monetary policy satisfy the conditions stated above.

(ii) The equilibrium residuals vanish at every date, $H(U, Z) = 0$, with the sector-R branch admissibility and one-sided optimality conditions imposed as specified below.

Market clearing. The goods, labor, and bond market-clearing conditions are

$$Y_{R,t} = C_{R,t} + \frac{\psi_R}{2}(\Pi_{R,t} - 1)^2 Y_{R,t}, \tag{G.20}$$

$$Y_{S,t} = C_{S,t} + \frac{\psi_S}{2}(\Pi_{S,t} - 1)^2 Y_{S,t} + G_t, \tag{G.21}$$

$$N_{R,t} + N_{S,t} = N_t, \tag{G.22}$$

$$A_t = \int_0^1 b_{it}\, \mathrm{d}i = B_t. \tag{G.23}$$

Sector-R quantities in (G.20) are in utility units; multiplying both sides by $X_{R,t}$ gives the physical resource constraint. The labor condition uses the normalization of aggregate labor efficiency to one. Sector-S goods clearing follows from Walras' law and is verified ex post rather than imposed as an independent residual.

Equilibrium residuals and block outputs. The six residual equations in $H(U, Z) = 0$ are the wage Phillips curve (5.7), sector-S pricing (5.6), sector-R pricing (G.9), the reference-costate recursion (G.10) (equivalently (G.11) at a tracking date), sector-R goods clearing (G.20), and bond market clearing (G.23). Given U, the shock paths, and an admissible sector-R slope

selection, the remaining aggregate variables follow from the production, reference, wage, and policy blocks. These determine the household inputs $(w_t, R^b_t, q_t, \zeta_t, \mathcal{D}_t, Tr^{\text{hh}}_t, N_t)$, from which the household block generates policies, distributions, and aggregate outcomes.

Reference-price kink. The slope satisfies $\eta_t = \Gamma_G$ when $d_{R,t} < 0$ and $\eta_t = \Gamma_L$ when $d_{R,t} > 0$. At $d_{R,t} = 0$, a common $\eta_t \in [\Gamma_G, \Gamma_L]$ enters the pricing and costate equations, and the firm's objective must have a nonnegative left derivative and a nonpositive right derivative with respect to its log price. The notation $H(U, Z) = 0$ is understood subject to this admissibility requirement. The exact numerical system augments the six residual equations with the slope selector and complementarity condition (H.4). Firm profit maximization remains a requirement of equilibrium; the directional conditions alone do not establish global optimality. Appendix H.4 gives the complementarity formulation and the additional optimality checks.

Aggregate shocks. The model carries ten innovations: aggregate and two sectoral productivities ($\varepsilon^a, \varepsilon^{aR}, \varepsilon^{aS}$, persistence 0.95), three cost-push disturbances—the structural tax ε^{uR} (persistence 0.85) and the wedges ε^{uS} (0.91) and ε^{uw} (0.73)—the discount-factor innovation (ε^{ζ}, persistence 0.76), the monetary-policy innovation (ε^{i}, which drives the state m_t in eq. (5.8), persistence 0.70), and the two fiscal instruments (transfers ε^{Tr}, i.i.d., and government purchases ε^{G}, persistence 0.56), with the persistences estimated as described in Appendix H.3. The estimation of Appendix H.3 activates eight: the sectoral productivity innovations stay at zero because, without sectoral quantity observables, the within-sector split between productivity and markups is not identified.

H Solution and Estimation

The solution combines a sequence-space approximation for initialization with nonlinear pricing and household decisions. Each quarter's innovations are recovered jointly with the conditional equilibrium transition, imposing the reference-price kink exactly at convergence.

H.1 Sequence-space initialization

The household block maps seven aggregate input paths into asset demand, sectoral consumption, and the wage-setting statistic. Its steady-state Jacobian is

$$\mathcal{J}^{o,m}_{t,\tau} = \frac{\partial Y^{HA}_{o,t}}{\partial X^{HA}_{m,\tau}}, \qquad o \in \{A, C_R, C_S, \ell^L\}, \quad m \in \{w, R^b, q, \zeta, \mathcal{D}, Tr^{\text{hh}}, N\}. \tag{H.1}$$

I compute this Jacobian on the joint earnings and discount-factor chain using the fake-news algorithm of Auclert et al. (2021). Let H_U and H_Z denote the Jacobians of $H(U, Z)$ with

respect to the endogenous sequences and aggregate shocks. Composing the block derivatives gives the initial linear equilibrium response

$$\mathrm{d}U = -H_U^{-1} H_Z \, \mathrm{d}Z. \tag{H.2}$$

The linearization uses the steady-state midpoint slope $\bar{\Gamma}$ and supplies starting values for the nonlinear solve. The horizon is $T = 300$ quarters. The household grid contains 1560 asset points from zero to 1640 times steady-state quarterly output and fourteen exogenous states. Backward policy iteration uses the endogenous grid method (Carroll, 2006); forward distribution iteration uses the lottery method of Young (2010).

H.2 The sequential solution

At date t, the economy inherits the shock levels, reference gap, lagged policy rate, relative price, real wage, government debt, and household distribution Ψ_t. Conditional on the current innovations, I solve the equilibrium transition with future innovations set to zero and existing shocks following their autoregressive laws. Reference updating and future pricing regimes are determined within this transition. Only the date-t allocation is retained, and the distribution advances under that date's household policies. I repeat the procedure for the twelve quarters 2021Q1–2023Q4. The transition anticipated in 2023Q4 supplies the subsequent continuation used in welfare calculations.

H.3 Data and identification

Observables. Table H.1 lists the eight series. Inflation rates and the policy rate are quarterly rates throughout the estimation, annualized only for display. Each series is measured against an anchor: wage inflation against a trend of 2.68% per year (a 2.0% price trend plus the 0.70% mean growth of the real employment cost index over 2015–2019); the policy rate against its 2015–2019 mean of 1.10% annual; the fiscal ratios against their 2015–2019 means (10.73% of GDP for transfers, 1.42% for the primary deficit); output and hours against 2015–2019 log-linear trends, with a -3.87% level break in hours anchored on 2023 alone, which keeps 2024 out of every anchor and hence out of the out-of-sample check.

Estimator. At each date, the eight innovations solve

$$y_{\text{model}}(\varepsilon_t \,|\, \text{history}_t) = y_{\text{data},t}, \tag{H.3}$$

using quasi-Newton iteration. Each trial evaluates the nonlinear conditional transition from the inherited states and distribution. The innovation Jacobian is initialized from the steady-state impact responses and updated by secant steps. The maximum fitted-observable residual across

Table H.1: The eight observables, data counterparts, and associated innovations

Model observable	Data counterpart	Innovations (joint)
Sector-R inflation, $\Pi_{R,t}$	BLS CPI items assigned to sector R	ε_t^{uR}
Sector-S inflation, $\Pi_{S,t}$	BLS CPI items assigned to sector S	ε_t^{uS}
Wage inflation, $\Pi_{w,t}$	BLS Employment Cost Index: private-industry wages and salaries	ε_t^{uw}
Policy rate, i_t	Effective federal funds rate, quarterly average	ε_t^{i}
Output, Y_t^{phys}	BEA real GDP	$\varepsilon_t^{a},\ \varepsilon_t^{\zeta}$
Hours, N_t	BLS nonfarm business hours	$\varepsilon_t^{a},\ \varepsilon_t^{\zeta}$
Transfers / GDP	NIPA federal social benefits to persons / nominal GDP	$\varepsilon_t^{Tr},\ \varepsilon_t^{G}$
Primary deficit / GDP	NIPA federal outlays less interest and receipts / nominal GDP	$\varepsilon_t^{Tr},\ \varepsilon_t^{G}$

Notes: Twelve quarters × eight series = 96 targets against 96 free innovations. All eight innovations are identified jointly each quarter. The last column indicates the associated shock groups: sectoral cost-push shocks, a wage-markup shock, a monetary-policy shock, aggregate productivity and discount-factor shocks, and transfer and government-purchases shocks. Output and hours jointly distinguish productivity from the discount-factor shock; the two fiscal observables jointly discipline transfers and purchases. Sectoral CPI indices use fixed December 2020 relative-importance weights and a 2% annual inflation benchmark. The paragraph above describes the remaining transformations. Transfers are NIPA table 3.2 federal social benefits to persons. Model output is physical output, $Y_t^{\text{phys}} = e^{\chi_{R,t}} Y_{R,t} + Y_{S,t}$, as in (G.12).

the four economies is 10^{-9} in model units.

Identification. The eight innovations are identified jointly within each quarter. Output and hours distinguish aggregate productivity from the discount-factor shock; transfers and the primary deficit jointly discipline the two fiscal instruments. Sectoral productivity innovations are held at zero because sectoral quantities are not observed. The exercise is exactly identified, so in-sample fit does not independently validate the shock attribution. An innovation dated t represents news arriving at t under the information structure in Appendix H.2.

Shock persistence. The quarterly innovations are recovered to match the eight observed series over 2021–2023. Shock persistence must therefore be identified separately. I assume that the transfer process is i.i.d. and estimate the persistence of the remaining seven active shock processes jointly using survey expectations in the baseline-basket economy without reference dependence. The resulting persistences are used in all four economies, with innovations recovered separately for each economy.

I use median forecasts from the Survey of Professional Forecasters (SPF) for headline and core CPI inflation, three-month Treasury bill rates, and real GDP growth. Firms' expected unit-cost growth over the next twelve months comes from the Federal Reserve Bank of Atlanta's Business Inflation Expectations (BIE) survey.

Model forecasts follow each quarter's conditional transition with no further aggregate

innovations. Forecasts formed at the end of quarter t are compared with SPF forecasts from the survey conducted in quarter $t+1$, covering the survey quarter and the following three quarters. The SPF surveys run from 2021Q2 through 2024Q1. For unit costs, I use the BIE survey conducted in the first month of the following quarter, from April 2021 through January 2024.

Table H.2: Survey forecasts and model counterparts

Forecast measure	Model counterpart	Forecast horizon
Headline CPI inflation	$0.2370\pi_R + 0.7630\pi_S$	One to four quarters
Core CPI inflation	$0.0504\pi_R + 0.9496\pi_S$	One to four quarters
Three-month Treasury bill rate	Policy rate	One to four quarters
Real GDP growth	Growth of real output	One to four quarters
Unit-cost growth	Growth of nominal unit labor costs	Next twelve months

Notes: π_R and π_S denote the sectoral inflation rates.

Inflation forecasts are expressed as annualized log deviations from a 2% inflation trend. To account for differences between the published CPI measures and the sectoral aggregates, I subtract their respective 2021–2023 mean differences from the survey forecasts. These adjustments are 0.056 annualized percentage points for headline inflation and -0.097 for core inflation. Treasury bill forecasts are measured relative to their 2015–2019 mean, while model policy-rate forecasts are measured relative to the model's steady-state rate.

GDP-growth forecasts enter from the 2022Q1 survey onward because the model abstracts from pandemic reopening dynamics. Real GDP, measured relative to its 2015–2019 trend, remains among the eight observed series matched throughout 2021–2023. Model GDP-growth forecasts include the estimated trend growth rate.

The model's unit-cost counterpart is expected four-quarter wage growth plus hours growth minus real output growth, including the estimated unit-cost growth trend. These expectations help discipline wage-markup persistence. Because the survey counterpart includes non-labor costs, I subtract the mean survey–model difference across the twelve observations from each unit-cost forecast discrepancy. I apply the same adjustment across the 48 Treasury bill forecasts to allow a persistent difference between expected Treasury bill rates and the model's policy rate.

The criterion sums squared forecast discrepancies across 192 moments, after scaling each discrepancy by the 2015–2019 standard deviation of its realized counterpart. These comprise 48 observations each for headline inflation, core inflation, and Treasury bill rates, 36 for GDP growth, and twelve for unit-cost growth. Persistences are restricted to $[0, 0.95]$.

Starting from an initial guess for the persistence parameters, I solve the nonlinear model to recover the quarterly innovations that match the 2021–2023 data and compute the implied forecasts. I then estimate persistence using first-order sequence-space forecasts, adjusted to

match the nonlinear forecasts at the initial guess. Innovations are re-estimated in the first-order model at each candidate persistence vector. At the estimated values, rounded to two decimal places, I solve the nonlinear model again, recover the innovations, update the forecast adjustment, and repeat the estimation. I stop when each re-estimated persistence coefficient is within 0.02 of the value used in the nonlinear solve. At the reported values, the largest difference is 0.018.

The estimated quarterly persistences are $\rho_{uR} = 0.85$, $\rho_{uS} = 0.91$, and $\rho_{uw} = 0.73$ for the cost-push and wage-markup disturbances, $\rho_{\zeta} = 0.76$, $\rho_m = 0.70$, and $\rho_G = 0.56$; productivity persistence is at its upper bound, $\rho_a = 0.95$.

Figure H.1 compares the baseline economy with reference dependence with survey expectations. Table H.3 summarizes its mean absolute forecast discrepancies over the estimation sample. The figure also reports firms' wage expectations, which are not targeted.

Table H.3: Model and survey expectations: mean absolute discrepancies

Forecast measure	Mean absolute discrepancy
Headline CPI inflation	0.49
Core CPI inflation	0.39
Three-month Treasury bill rate	0.57
Real GDP growth	1.23
Unit-cost growth	0.28

Notes: Discrepancies are in percentage points. Inflation and GDP growth are annualized; unit-cost growth covers the next twelve months. Interest-rate and unit-cost discrepancies are measured after subtracting their respective mean survey–model differences. Inflation discrepancies incorporate the fixed measurement adjustments described above. Persistences are estimated in the baseline-basket economy without reference dependence; the fit reported here uses the nonlinear baseline economy with reference dependence.

H.4 Nonlinear pricing at the reference-price kink

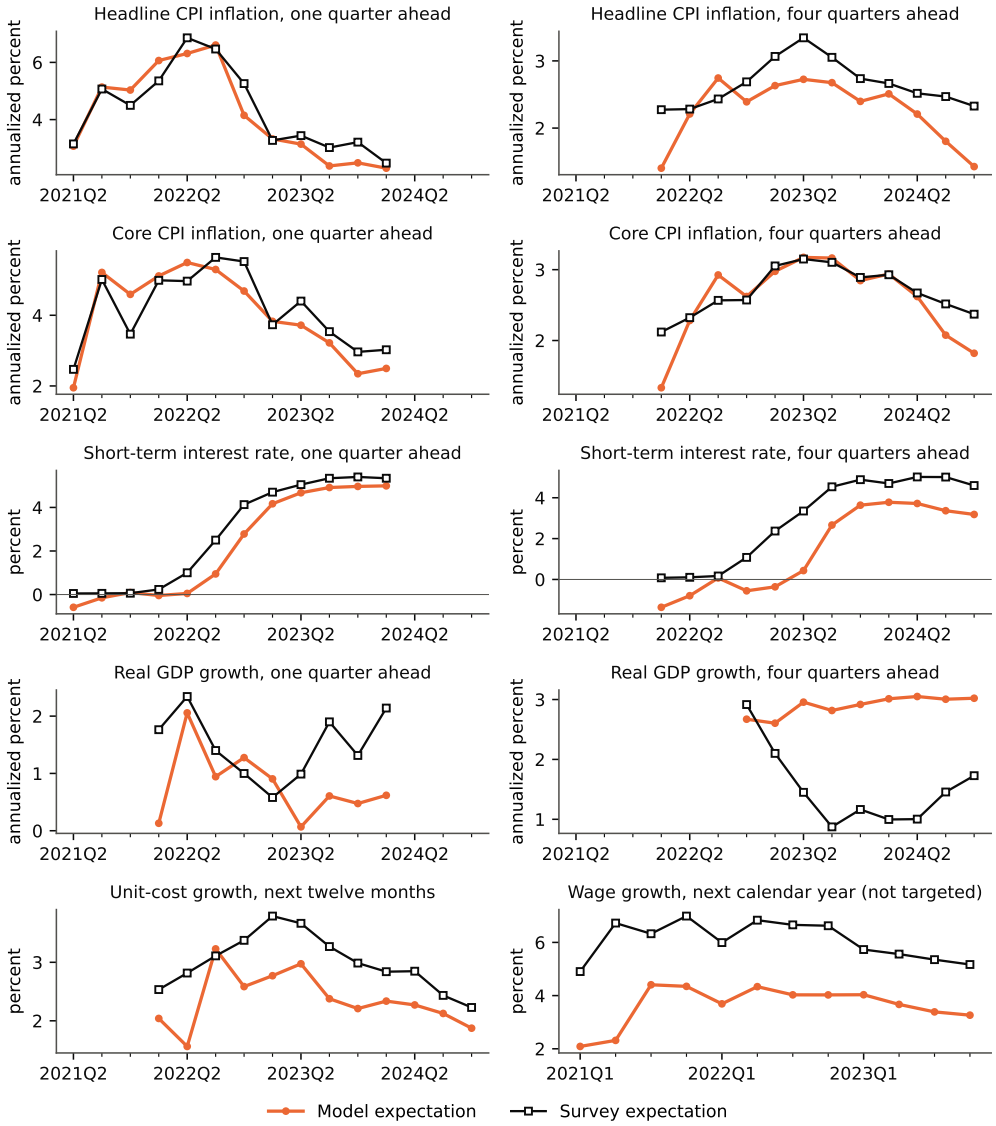
At each date, let $\alpha_t \in [0, 1]$ select the slope $\eta_t = \Gamma_G + (\Gamma_L - \Gamma_G)\alpha_t$. The pricing and reference-costate equations use this same slope, subject to

$$\alpha_t = \text{clip}\left(\alpha_t + d_{R,t}/d_{\text{scale}},\, 0,\, 1\right), \qquad d_{\text{scale}} = 0.01. \tag{H.4}$$

This condition selects the loss branch when $d_{R,t} > 0$, the gain branch when $d_{R,t} < 0$, and allows an interior selector when $d_{R,t} = 0$. The scaling parameter affects numerical conditioning but not the solution set. With a positive operating margin and differentiable continuation value, an interior selector implements the one-sided conditions in Appendix B: the firm's left price derivative is nonnegative and its right derivative is nonpositive.

Let $\mathcal{H}_t^P$ be the right-hand side of (G.9) minus its left-hand side, and let $\mathcal{H}_t^B$ and $\mathcal{H}_t^K$ be the

Figure H.1: Expectations over 2021–2024: the model and survey forecasts



Notes: Each panel plots, against the quarter being forecast, the survey's expectation and the model's. Model forecasts are from the baseline-basket economy with reference dependence; persistences are estimated in the baseline-basket economy without reference dependence. Survey expectations in the first four rows are medians of the Survey of Professional Forecasters from the surveys of 2021Q2–2024Q1, one quarter ahead (left) and four quarters ahead (right); the model's expectations are formed at the end of the quarter preceding each survey, along that quarter's sequential solution with no further innovations. Inflation and real GDP growth are annualized. Model headline and core CPI inflation aggregate the two sectoral inflation rates as described in the text. The short-term rate is the policy rate for the model and the three-month Treasury bill rate for the survey. The unit-cost panel compares firms' expected growth in unit costs over the next twelve months (Federal Reserve Bank of Atlanta, Business Inflation Expectations survey) with the model's expected four-quarter growth of nominal unit labor costs, plotted at the end of the four quarters. The estimation targets the inflation panels over the whole window, real GDP growth from the 2022Q1 survey on (the surveys shown), and the Treasury bill and unit-cost panels in deviations from their means. The wage panel is not targeted. It compares, by survey quarter, the expected growth of firms' wage bills in the next calendar year from the CFO Survey, which includes expected employment growth, with the model's expected growth of the average wage.

Table H.4: Numerical residuals for the four fitted economies

Economy	Obs fit	Equilibrium	Walras	Loss qtrs
Baseline basket	8×10^{-10}	1×10^{-9}	1.7×10^{-7}	11
Baseline, no reference dependence	6×10^{-10}	1×10^{-9}	1.6×10^{-5}	—
Broad basket	8×10^{-10}	1×10^{-9}	1.8×10^{-7}	12
Broad, no reference dependence	8×10^{-10}	1×10^{-9}	2.6×10^{-5}	—

Notes: Every entry is a worst case over the economy's twelve quarter-solves. "Obs fit" is the sup-norm residual of the eight observable targets in their own units; "equilibrium" the sup-norm residual of the exact equilibrium system; "Walras" the sector-S goods-market residual under the fully nonlinear household. The economies without reference dependence reuse the household steady state, policy functions, and Jacobians of the corresponding reference-dependent economy rather than re-solving them at their own firm-side steady state; this small mismatch leaves a residual of order 10^{-5} in sector-S goods clearing that is constant across quarters. Directional-check violations are zero in all forty-eight quarter-solves. "Loss quarters" counts window quarters with a positive reference gap; 2023Q2 is the baseline basket's one gain quarter.

residuals of the branch and tracking costate equations, respectively, with $\Theta_{R,t}$ on the left. Then

$$\mathcal{H}_t^K - \mathcal{H}_t^B = -\mathcal{H}_t^P \tag{H.5}$$

so both costate forms agree when the pricing residual is zero. These are necessary optimality conditions; sufficiency requires concavity of the full Bellman objective and the tail condition. Concavity is not guaranteed by the model's primitives, so residual and directional checks alone do not establish global optimality.

Global optimality. The firm-optimality check of Appendix F, applied to the fitted aggregate path of each window date in both baskets, finds the equilibrium price to be the global maximizer of the firm's objective at every quarter. On the ± 20 log-point price corridor the objective is single-peaked on each side of the kink at every grid state, the refined best response lies within 0.01 log point of the equilibrium price and raises firm value by at most 3×10^{-7} of a quarter's revenue, and a price one log point away lowers it by at least 0.2 percent.

I solve the augmented equilibrium system by damped semismooth Newton iteration, using shock-scale continuation and progressively tighter approximations to the clip function before imposing its exact form. Pricing regimes are endogenous. When using the tracking costate equation, the regime classification is held fixed within each Newton solve and updated between solves until it stabilizes. The residual identity above ensures that the two costate representations share the same roots. Section 4 uses an active-set implementation of the same one-sided conditions; Appendix F describes that algorithm.

The innovation estimation and nonlinear household correction are iterated with this pricing system. Table H.4 reports residuals for the four fitted economies; directional-check violations are zero in the forty-eight quarter-solves. The fitted baseline has eleven loss quarters, with 2023Q2 on the gain branch, and the broad basket has twelve.

H.5 Nonlinear household decisions

To account for nonlinear responses and the evolution of the wealth distribution, I solve household policies backward and the distribution forward from each quarter's inherited distribution. The correction to the sequence-space approximation is

$$\Delta h_t = h_{NL}(X_t) - h_{lin}(X_t), \qquad h \in \{A, C_R, C_S, \ell^L\}. \tag{H.6}$$

I feed this correction into the aggregate system and iterate jointly with the pricing and innovation solves until convergence. Welfare uses the resulting nonlinear household policies and distributions. The maximum asset-market residual is 1×10^{-6}; Table H.4 reports the goods-market residuals, including the offsets in the economies without reference dependence.

H.6 Welfare computation

The welfare recursions and consumption equivalent. Household i starts in state $(\beta_{i0}, z_{i0}, b_{i,-1})$, distributed according to Ψ_{ss}, where $t = 0$ denotes 2021Q1. Both scenarios $x \in \{\text{ss}, tr\}$ use the same idiosyncratic processes and include consumption utility, labor disutility, and wage adjustment costs. The baseline evaluation holds $\zeta = 1$, retaining the household's idiosyncratic discount-factor process β_{it}.

Let $V_{it}^{c,x}$, $V_{it}^{\ell,x}$, and $V_{it}^{w,x}$ denote household i's continuation values of consumption utility, labor disutility, and wage-adjustment costs. They satisfy

$$V_{it}^{c,x} = \frac{(c_{it}^x)^{1-\sigma}}{1-\sigma} + \beta_{it}\, \mathbb{E}_{it}^x \left[V_{i,t+1}^{c,x} \right], \tag{H.7}$$

$$V_{it}^{\ell,x} = \varphi_N \frac{(N_t^x)^{1+\varphi}}{1+\varphi} + \beta_{it}\, \mathbb{E}_{it}^x \left[V_{i,t+1}^{\ell,x} \right], \tag{H.8}$$

$$V_{it}^{w,x} = \frac{\psi_w}{2} \left(\log \Pi_{w,t}^x \right)^2 + \beta_{it}\, \mathbb{E}_{it}^x \left[V_{i,t+1}^{w,x} \right]. \tag{H.9}$$

Here $\mathbb{E}_{it}^x$ integrates over future idiosyncratic transitions conditional on household i's current state and the aggregate history in scenario x. The next individual state is $(\beta_{i,t+1}, z_{i,t+1}, b_{it}^x)$. In the realized scenario the recursions run over $t = 0, \ldots, 299$ and end with the steady-state values at $t = 300$, $V_{i,300}^{a,tr} = V^{a,\text{ss}}(\beta_{i,300}, z_{i,300}, b_{i,299}^{tr})$ for $a \in \{c, \ell\}$ and $V_{i,300}^{w,tr} = 0$; the steady-state scenario's values are the steady-state values themselves. Write $V_i^{a,x} \equiv V_{i0}^{a,x}$ for $a \in \{c, \ell, w\}$. Labor disutility and wage adjustment costs are common across households and are discounted using each household's own β_{it} process. The wage cost is $\frac{\psi_w}{2}(\log \Pi_{w,t})^2$, with $\psi_w = \epsilon_w/\kappa_w = 71$, and vanishes in steady state. Price adjustment costs enter resource constraints and therefore affect welfare through consumption.

The consumption equivalent reduces steady-state consumption in every state of the four quarters 2021Q1–2021Q4, and leaves it unchanged afterwards, until the household is indifferent,

as in (5.10). Let $\underline{V}_i^{c,\mathrm{ss}}$ be the part of $V_i^{c,\mathrm{ss}}$ that accrues in those four quarters and $\overline{V}_i^{c,\mathrm{ss}} = V_i^{c,\mathrm{ss}} - \underline{V}_i^{c,\mathrm{ss}}$. With $V_i^{w,\mathrm{ss}} = 0$,

$$1 - \mathrm{CE}_i = \left(\frac{V_i^{c,tr} - V_i^{\ell,tr} - V_i^{w,tr} + V_i^{\ell,\mathrm{ss}} - \overline{V}_i^{c,\mathrm{ss}}}{\underline{V}_i^{c,\mathrm{ss}}} \right)^{\frac{1}{1-\sigma}}. \tag{H.10}$$

The cost of the episode is the population mean $\int_0^1 \mathrm{CE}_i \, \mathrm{d}i$, with initial states distributed according to Ψ_{ss}. Both economies use the same asset grid and initial household distribution. The comparison therefore holds initial assets, earnings, and discount-factor type fixed, while allowing subsequent consumption and saving to differ. The labor-disutility scale is calibrated separately in the RD and no-RD economies, so episode utility losses are measured relative to the RD and no-RD steady states, respectively, before taking their difference. Through 2023Q4, welfare is evaluated along the realized history using the policies chosen under each quarter's information. From 2024Q1, it follows the equilibrium path anticipated at the end of 2023, with no further aggregate innovations, including the subsequent fiscal adjustment. All reported costs are percentages of 2021 steady-state consumption, $100 \int_0^1 \mathrm{CE}_i \, \mathrm{d}i$.

Continuation values and sensitivity. Replacing the steady-state terminal values in 2096Q1 with zero changes welfare costs by less than 0.01 percentage points of 2021 steady-state consumption. Table H.5 instead varies the date at which household positions are valued using steady-state value functions, net of the first-order value of future taxes retiring the remaining public debt gap. The first row values positions at the end of 2023; later rows retain more of the model's anticipated continuation.

The estimated persistence of the cost-push, wage-markup and monetary disturbances keeps sector-R inflation, hours and the real return away from their steady-state values for several years after 2023. The total welfare cost is 3.74% of 2021 consumption at a 2024Q1 switch, 5.04% at a 2031Q1 switch, and 5.32% under full continuation. The cost of reference dependence is 0.65% at the 2024Q1 switch and 0.97% under full continuation. These estimates depend on the assumed continuation and fiscal rule.

Realized preferences and a re-optimized benchmark. Two variants value both allocations with the realized weights β_{it}/ζ_t in place of β_{it}. The first keeps the steady-state-policy benchmark. The second replaces it with households that face steady-state prices, wages, bond returns, hours, dividends, and transfers but re-optimize consumption and saving against each quarter's ζ_t as it is revealed, with the beliefs of the fitted economy, and follow their own continuation thereafter. Markets need not clear in this partial-equilibrium benchmark. Their within-period consumption bundles are chosen at steady-state relative prices. Under these conventions, each economy's utility loss is normalized by the value of its own 2021 benchmark consumption, evaluated using its own welfare weights, before the normalized losses are

Table H.5: The welfare cost by the date at which steady-state prices resume

	Baseline basket			Broad basket		
Steady-state prices from	Total	No RD	RD	Total	No RD	RD
2024Q1	3.74	3.13	0.65	3.92	3.15	0.81
2025Q1	3.91	3.31	0.63	4.10	3.34	0.80
2027Q1	4.54	3.92	0.67	4.80	3.93	0.96
2031Q1	5.04	4.23	0.90	5.36	4.14	1.35
2040Q4	4.48	3.50	1.02	4.94	3.45	1.54
2043Q3	4.74	3.80	0.98	5.20	3.80	1.47
2051Q1	5.29	4.41	0.96	5.68	4.38	1.43
2096Q1	5.32	4.43	0.97	5.71	4.39	1.45
Full model continuation (baseline)	5.32	4.43	0.97	5.71	4.39	1.44

Notes: Percent of 2021 steady-state consumption (the constant percentage of consumption in each quarter of 2021 that a steady-state household would give up to be indifferent to the episode), using pre-episode aggregate discounting and the steady-state-policy benchmark. "Total" and "No RD" are population-mean welfare costs with and without reference dependence. "RD" is the consumption equivalent of the incremental utility loss, defined in equation (5.11), and is not the difference between the other two columns. The table reports selected switching dates. Each dated row follows the model's continuation until the stated quarter and then values each household's position using steady-state value functions, less the first-order value of its lump-sum share of the taxes retiring the remaining public-debt gap. Repayment begins in 2041Q1 or at the switch date, whichever is later. The full-model baseline includes the fiscal adjustment in the equilibrium path and adds no separate debt charge at its 2096Q1 terminal date. Table H.6 reports the zero-continuation-value comparison and the alternative preference conventions.

differenced and converted into a consumption equivalent.

Table H.6 crosses these two variants and the baseline welfare convention with six treatments of post-2023 values. Besides full continuation and zero value after 2023Q4, the table values household positions at the end of 2023 with steady-state value functions, either without a charge for the remaining public debt or net of the first-order value of lump-sum taxes retiring that debt from 2041Q1 or 2024Q1. These terminal adjustments change welfare valuation without re-solving the fitted equilibrium. The final treatment replaces the baseline's steady-state terminal value in 2096Q1 with zero as a numerical check.

With full continuation, re-optimizing the benchmark reduces total welfare costs by at most 0.25 percentage points of 2021 steady-state consumption relative to following steady-state policies under realized discounting; part of this gap reflects that the percentage is of the re-optimized benchmark's own 2021 consumption, which lies below steady state. The zero-terminal-value comparison gives much larger changes: costs fall from 4.54 to 1.77% in the baseline basket and from 4.60 to 1.94% in the broader basket. That calculation omits the post-2023 consequences of the benchmark households' changed saving decisions. All panels retain the household's idiosyncratic discount-factor process and include wage adjustment costs.

Table H.6: Robustness of welfare costs to valuation and benchmark choices

	Baseline basket			Broad basket		
Post-2023 valuation	Total	No RD	RD	Total	No RD	RD
A. Pre-episode aggregate discounting; steady-state policies						
Full model continuation	5.32	4.43	0.97	5.71	4.39	1.44
Zero terminal value in 2024	4.29	3.69	0.65	4.35	3.59	0.82
Steady state; no debt charge	3.61	2.99	0.65	3.87	3.10	0.81
Steady state; repayment from 2041	3.74	3.13	0.65	3.92	3.15	0.81
Steady state; repayment from 2024	4.12	3.51	0.65	4.06	3.30	0.81
Full continuation; zero value in 2096	5.32	4.43	0.97	5.71	4.39	1.45
B. Realized aggregate discounting; steady-state policies						
Full model continuation	5.61	4.65	1.06	6.02	4.59	1.58
Zero terminal value in 2024	4.54	3.88	0.72	4.60	3.76	0.90
Steady state; no debt charge	3.75	3.08	0.72	4.03	3.19	0.90
Steady state; repayment from 2041	3.90	3.23	0.72	4.09	3.25	0.90
Steady state; repayment from 2024	4.31	3.65	0.72	4.25	3.41	0.90
Full continuation; zero value in 2096	5.62	4.65	1.06	6.02	4.60	1.58
C. Realized aggregate discounting; re-optimized benchmark						
Full model continuation	5.39	4.47	1.02	5.77	4.40	1.51
Zero terminal value in 2024	1.77	1.22	0.57	1.94	1.22	0.73
Steady state; no debt charge	3.56	2.91	0.69	3.82	3.00	0.87
Steady state; repayment from 2041	3.70	3.05	0.69	3.87	3.05	0.87
Steady state; repayment from 2024	4.10	3.45	0.69	4.02	3.21	0.87
Full continuation; zero value in 2096	5.40	4.47	1.02	5.78	4.40	1.51

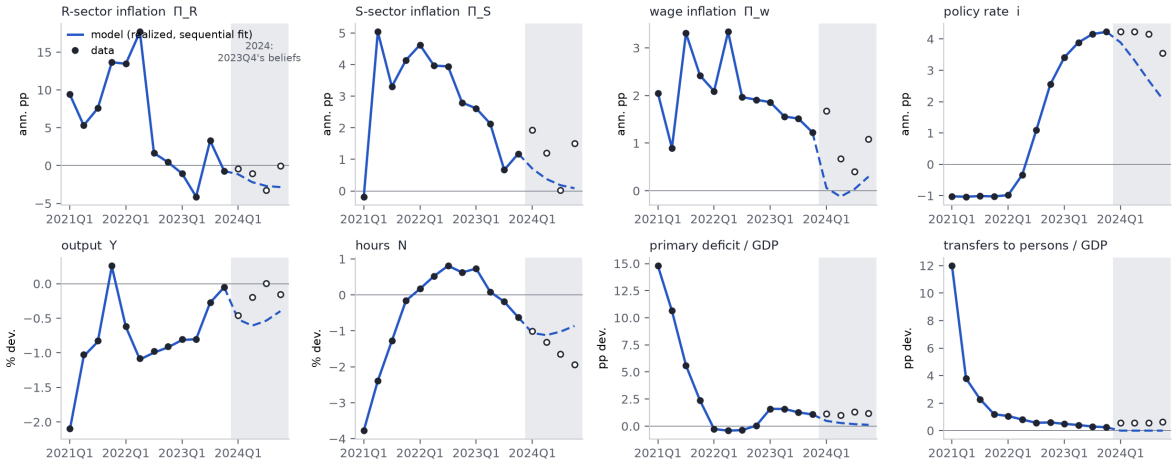
Notes: Percent of 2021 steady-state consumption: the constant percentage of consumption in each quarter of 2021 that a steady-state household would give up to be indifferent to the episode. "Total" and "No RD" are population-mean welfare costs with and without reference dependence. "RD" is the consumption equivalent of the incremental utility loss, defined in equation (5.11), using the convention-specific normalization described in Appendix H.6. It is not the difference between the other two columns. Panel A values both scenarios using β_{it}; panels B and C use β_{it}/ζ_t. In panel C, comparison households re-optimize consumption and saving against sequentially revealed ζ_t, with all other aggregate inputs at steady state; the percentage is of that benchmark's own 2021 consumption. The fitted equilibrium paths are unchanged across panels. Full continuation follows the fitted episode and the path anticipated in 2023Q4, ending with steady-state values in 2096Q1; the last row instead sets those terminal values to zero. Zero value in 2024 counts only 2021–2023 utility. The three steady-state rows value households' end-2023 positions with steady-state value functions, either without a debt charge or net of the first-order value of lump-sum taxes retiring the outstanding debt gap from the indicated date. Wage adjustment costs are included. See Appendix H.6 for the recursions.

H.7 The fitted episode and estimated innovations

Figures H.2 and H.3 report the observed and fitted series and the recovered innovations. Monetary-policy surprises keep the rate below the Taylor rule through 2022Q2 and above it thereafter; transfer innovations are largest in early 2021, and the sector-R cost-push innovation is largest in 2021Q1, with further large positive surprises in 2021Q4 and 2022Q2. The baseline reference gap peaks at 0.075 in 2022Q2, raising the effective sector-R price approximately 2.2% above its posted price.

Innovation correlations across the economies with and without reference dependence exceed 0.993 in every channel; the sector-R cost-push peak is 0.15 in both economies. The shocks are

Figure H.2: The eight fitted series and the 2024 out-of-sample check

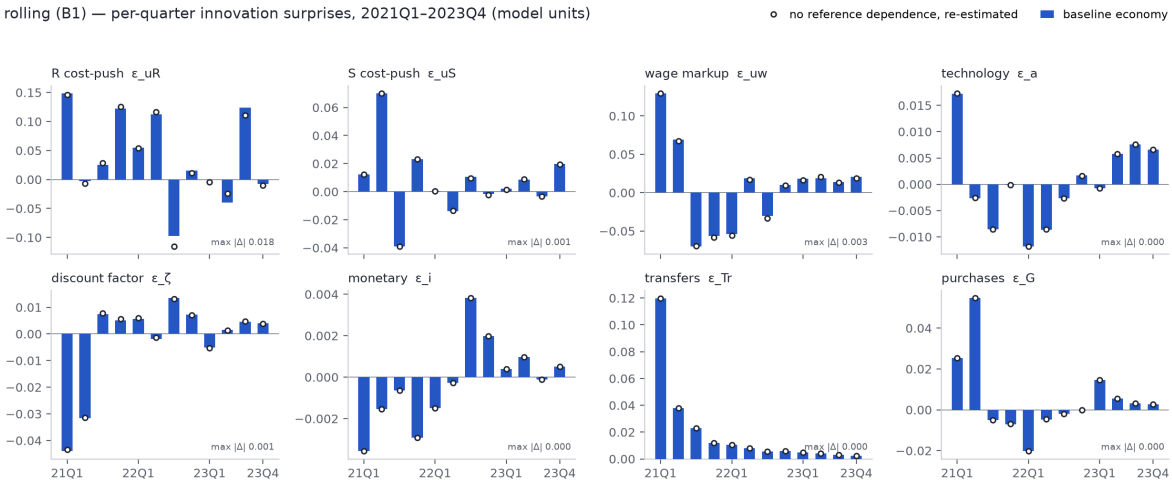


Notes: Filled markers are data; the solid line is the realized path of the sequential fit over the twelve estimation quarters 2021Q1–2023Q4. The dashed line in the shaded region is the model's continuation from 2024Q1 with no further innovations—under sequential information this is 2023Q4's own belief path, the forecast the model's agents held as the window closed—and open markers are the 2024 data, which enter neither the estimation nor the detrending anchors. Inflation rates and the policy rate are annualized percentage points in deviation from their anchors; output and hours are percent deviations from a 2015–2019 log-linear trend; the fiscal series are percentage points of GDP in deviation from 2015–2019 means. Appendix H.3 details the transformations.

nevertheless re-estimated, and exact fit does not independently validate their attribution.

The anticipated continuation lies below realized sector-R inflation in 2024 on average and reduces interest rates faster than the data. Mean absolute errors are 1.3 annualized percentage points for sector-R inflation and 1.1 for the policy rate. Welfare therefore includes the continuation households anticipated at the end of 2023, rather than the subsequent realized history; Appendix H.6 reports sensitivity to this valuation.

Figure H.3: The eight estimated innovation surprises, 2021Q1–2023Q4



Notes: Innovations are in model units—each entry is the news arriving that quarter. Bars are the baseline economy's sequential estimates; open markers are the no-reference-dependence economy's, re-estimated against the same eight series. The annotation in each panel is the largest absolute gap between the two economies: the histories are similar (correlation above 0.993 in every channel), although innovations are re-estimated separately. Panels: sectoral cost-push innovations ε^{uR} and ε^{uS}, wage markup ε^{uw}, aggregate productivity ε^{a}, discount-factor innovation ε^{ζ} (demand), monetary-policy innovation ε^{i}, transfers ε^{Tr}, and government purchases ε^{G}.

I Calibration Details

Table I.1 collects the model's parameters and steady state. The rest of this appendix documents the two survey calibrations behind the household block: the sectoral expenditure weights $\omega_R(z)$ of (5.2), from the 2020 Consumer Expenditure Survey, and the dividend-incidence exponent λ of (G.2), from the 2019 Survey of Consumer Finances.

Untargeted wealth moments. Table I.2 compares the model's steady-state wealth distribution with the 2019 SCF. The model closely matches the wealth share of the bottom half of households but understates concentration at the top.

I.1 Sectoral expenditure shares across earnings states

I calibrate $\omega_R(z)$ from the 2020 Consumer Expenditure Survey (CEX). The baseline basket B1 assigns 200 consumption categories to sector R: food, energy, and frequently purchased nondurables. Basket B2 adds 18 recurring services, including cash rent and communications. Sector S is the complement within a fixed universe of 656 current-consumption categories. Basket membership is common across households; expenditure patterns generate heterogeneity in the weights.

Table I.1: Calibration and steady state

Parameter	Description	Value	Source or target
Households			
σ	Relative risk aversion	2	Standard
φ	Inverse Frisch elasticity	2	Standard
β_H	Patient discount factor	0.99	Assigned
β_L	Impatient discount factor	0.9593	Calibrated (MPC, debt)
$\pi_\beta(\beta_H)$	Patient redraw mass (= ergodic share)	0.2295	Calibrated (MPC, debt)
p_β	Quarterly β-redraw probability	0.01	Auclert et al. (2025)
λ	Dividend exponent, $\xi_z \propto e_z^\lambda$	3.054	SCF 2019 top-7/64 equity
ν	CES elasticity between R and S	0.40	Bobasu et al. (2025)
$\underline{b}$	Borrowing limit	0	Standard
ρ_z	Persistence of log earnings	0.966	Auclert et al. (2021)
σ_z	Unconditional s.d. of log earnings	0.50	Auclert et al. (2021)
n_z	Discretization	7, Rouwenhorst	Standard
Firms			
ϵ_R	Demand elasticity, sector R	4	Scanner-data substitution
ϵ_S	Demand elasticity, sector S	7	Standard
ψ_R, ψ_S	Rotemberg adjustment cost	34.6, 89.7	Price-change freq. 10.6, 8.8%/mo
ρ_a	Productivity persistence	0.95	Estimated; upper bound (Appendix H.3)
$\rho_{uR}, \rho_{uS}, \rho_{uw}$	Cost-push persistence (υ_R structural tax; υ_S, υ_w wedges)	0.85, 0.91, 0.73	Estimated (Appendix H.3)
ρ_ζ	Discount-factor shock persistence	0.76	Estimated (Appendix H.3)
ρ_m	Monetary-policy shock persistence	0.70	Estimated (Appendix H.3)
Reference dependence			
Γ_G	Gain-side loading	0.33	Survey, Section 3
Γ_L	Loss-side loading	0.87	Survey, Section 3
ρ_R	Reference adaptation	0.53	Survey, Section 3
Wage setting			
ϵ_w	Wage-demand elasticity	6	Erceg et al. (2000)
$\mu_w = \mathcal{T}^w$	Wage markup; offsetting subsidy	1.20	Undistorted steady state
κ_w	Wage Phillips-curve slope	0.085	$\psi_w = 71$; annual wage adjustment
β_w	Union discount factor	0.966	Population mean of β_{it}
φ_N	Labor-disutility scale	1.0035	Steady state
Policy			
ρ_i	Interest-rate smoothing	0.80	Standard
ϕ_π	Taylor coefficient on measured inflation	1.50	Standard
ϑ_R^Π	Sector-R weight, measured CPI	0.237	CPI weight
ϕ_y	Taylor coefficient on output	0.125	Standard
ϑ_R^Y	Gap weight: R share of SS nominal GDP	0.262	Steady-state value
T_{tail}	Tail-tax delay (quarters)	80	Assigned
ϕ_B	Tail-tax coefficient on the debt gap	0.05	Terminal condition
ρ_{Tr}, ρ_G	Fiscal-shock persistence (transfers, purchases)	0, 0.56	Assigned; estimated (Appendix H.3)
Basket and exposure (2020 CEX)			
$\omega_R(z_1..z_7)$	Sector-R expenditure weights	0.274, 0.287, 0.290, 0.271, 0.263, 0.228, 0.229	
ξ_{z_1}, ξ_{z_7}	Dividend weights, bottom and top bands	0.008, 14.06	SCF 2019
Steady state (targeted moments first)			
	Aggregate quarterly MPC	0.250	Targeted
	Debt / annual GDP	1.400	Targeted
	Sector-R share of output and hours	0.262	Untargeted
	Labor-income tax rate, τ_L	0.332	Balanced govt. budget, steady state
	Share at exactly zero bonds	0.186	Untargeted
	Real rate r_{ss} (quarterly)	0.005	Standard

Notes: "Standard" and "Assigned" rows are both imposed rather than calibrated, the former at conventional values; β_L and $\pi_\beta(\beta_H)$ are the only calibrated parameters, solved jointly so that the aggregate quarterly MPC equals 0.25 and government debt equals 1.40 times annual GDP (bottom panel). All rates are quarterly. $\pi_\beta(\beta_H)$ is both the probability that a discount-factor redraw lands on the patient state and the ergodic patient share. $\omega_R(z)$ is the sector-R expenditure weight of earnings state z and ξ_z the per-household dividend weight in that state, normalized to have population mean one; ϑ_R^Π is the sector-R weight in the measured CPI, which aggregates posted prices. T_{tail} is in quarters and ϕ_B is a per-quarter coefficient on the debt gap $B_{t-1} - B_{\text{ss}}$.

Table I.2: Untargeted moments of the wealth distribution

	Model		2019 SCF
Moment	Baseline basket	Broader basket	Net worth
Wealth Gini	0.765	0.766	0.852
Bottom-50% wealth share (%)	1.7	1.7	1.5
Top-10% wealth share (%)	59.3	59.5	76.5
Top-1% wealth share (%)	13.9	14.0	37.2

Notes: None of these moments is targeted in the calibration. Model columns report the steady-state distribution of bond holdings in the reference-dependent economies. SCF moments use net worth for all families, with survey-weighted statistics calculated separately in each of the five implicates and then averaged. Households are ranked by wealth within each distribution. Wealth shares are percentages; the Gini is on a zero-to-one scale. SCF net worth includes assets and liabilities absent from the single-asset model.

Expenditure measurement. For each Universal Classification Code (UCC), I use the Interview or Diary survey designated by the BLS to avoid double counting. Interview and Diary expenditures are annualized by four and 52, respectively. For an Interview recall window with m_i months in 2020, expenditure and survey weight are adjusted by $3/m_i$ and $m_i/3$, so calendar overlap enters once. The consumption denominator excludes saving, pension contributions, debt principal, cash gifts, and income records.

Let $v \in \{I, D\}$ denote the survey, w_i^v its sampling weight, and M_{ip}^v household i's fractional membership in percentile cell p. Annual expenditure on UCC j in cell p is

$$\bar{x}_{pj}^v = a_v \frac{\sum_{i \in v} w_i^v M_{ip}^v x_{ij}^v}{\sum_{i \in v} w_i^v M_{ip}^v}, \qquad a_I = 4, \quad a_D = 52, \tag{I.1}$$

where x_{ij}^v incorporates the calendar adjustment. Summing over the designated survey for each UCC gives reference-sector expenditure $\bar{X}_{pk}^R$ for basket k and total consumption $\bar{X}_p^C$.

Income states and aggregation. The sample includes reference persons aged 25–60 and retains zero and negative earners. Labor income combines household wages and members' self-employment income, averaged across five implicates. I construct 100 weighted income-percentile cells from the Interview survey and apply that income-to-percentile map to the Diary sample, splitting tied groups fractionally at boundaries.

The seven earnings states have stationary masses $\{1, 6, 15, 20, 15, 6, 1\}/64$. If A_{pg} is the overlap in percentile points between cell p and state g, the sectoral weights are

$$\omega_{gk}^R = \frac{\sum_{p=1}^{100} A_{pg} \bar{X}_{pk}^R}{\sum_{p=1}^{100} A_{pg} \bar{X}_p^C}, \qquad \omega_{gk}^S = 1 - \omega_{gk}^R. \tag{I.2}$$

These are ratios of expenditure totals, rather than averages of household budget shares. At the

normalized steady-state relative price of one, they equal the CES distribution weights. Table I.3 reports the resulting schedules and sampling uncertainty.

Table I.3: Calibrated sectoral expenditure weights, 2020

Income state	Population mass	Basket B1		Basket B2	
		ω^R	ω^S	ω^R	ω^S
1	0.015625	0.2738	0.7262	0.4643	0.5357
		(0.0159)		(0.0343)	
2	0.093750	0.2871	0.7129	0.5163	0.4837
		(0.0113)		(0.0163)	
3	0.234375	0.2903	0.7097	0.5386	0.4614
		(0.0063)		(0.0074)	
4	0.312500	0.2708	0.7292	0.4457	0.5543
		(0.0046)		(0.0074)	
5	0.234375	0.2629	0.7371	0.3710	0.6290
		(0.0063)		(0.0067)	
6	0.093750	0.2278	0.7722	0.3064	0.6936
		(0.0136)		(0.0136)	
7	0.015625	0.2290	0.7710	0.2989	0.7011
		(0.0177)		(0.0189)	
Stationary mean	1.000000	0.2704	0.7296	0.4415	0.5585

Notes: Author's calculations from the 2020 CEX. The table reports the primary calibration, which ranks consumer units by labor income and restricts the reference person to ages 25–60 while retaining zero earners. Standard errors, shown in parentheses under the R weights, use the 44 CEX balanced-repeated-replication weights. The age restriction and full-sample income-rank map are held fixed across replicates, so the standard errors measure expenditure-sampling uncertainty conditional on sample membership and rank. Since $\omega^S = 1 - \omega^R$, the S weight has the same standard error. The stationary mean weights each state by the population mass in column 2; the seven state-specific rows are the model inputs.

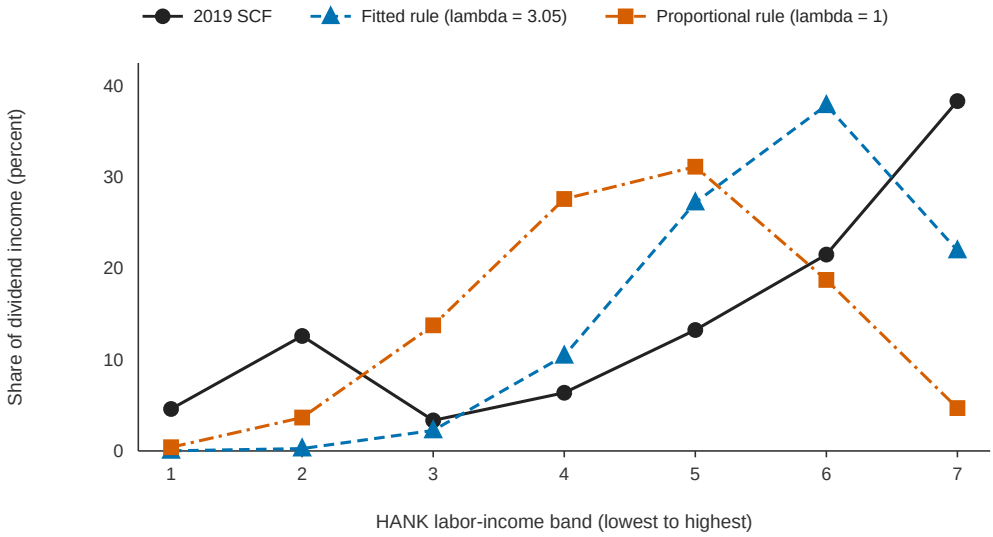
Baseline weights vary modestly across earnings states. The broader basket places more weight on reference-dependent goods among lower and middle earners, reflecting spending on rent and recurring services.

I.2 Dividend incidence from the 2019 SCF

I use the public 2019 Survey of Consumer Finances (SCF), whose income questions refer to 2018, to calibrate dividend incidence across earnings states. The sample includes families with a reference person aged 25–60, retains zero and negative labor income and zero dividends, and does not trim or winsorize the dividend tail. Labor income comprises wages and salaries plus net sole-proprietorship and farm income; it is a proxy for current earnings, since business income can also contain capital returns.

Within each of the five implicates, I rank families by labor income using survey weights and form seven bands with the model's stationary masses π_j. Boundary observations and tied

Figure I.1: Dividend incidence by labor-income band, 2019 SCF



Notes: The black line reports five-implicate average dividend shares for seven survey-weighted labor-income bands whose population masses equal the model's stationary masses. Labor income equals wages and salaries plus net sole-proprietorship and farm income; the sample includes SCF families with a reference person age 25–60. The fitted $\lambda = 3.05$ rule matches the combined dividend share of bands 6 and 7. The $\lambda = 1$ rule is the proportional-productivity benchmark. Income refers to calendar year 2018.

groups are split fractionally to match these masses. Each band's share is its weighted dividend total divided by the sample total, averaged across implicates.

The top two bands, comprising 7/64 of families, receive 59.84% of dividend income. SCF replicate weights and between-implicate variation give a standard error of 4.96 percentage points and a 95% confidence interval of 50.12–69.55%.

Mapping the survey moment to λ. Using the normalized dividend weights in (G.2), I choose λ to match the combined dividend share of the top two states:

$$\frac{\pi_6 e_6^\lambda + \pi_7 e_7^\lambda}{\sum_{j=1}^{7} \pi_j e_j^\lambda} = 0.5984.$$

Here e_j is productivity in earnings state j. The fitted value is $\widehat{\lambda} = 3.054$, with confidence interval $[2.512, 3.654]$ obtained by inverting the empirical moment's confidence limits. The proportional benchmark $\lambda = 1$ assigns 23.43% of dividends to these two states.

Figure I.1 compares both rules with the data. The fitted rule matches only the combined upper-tail share: it assigns 37.87 and 21.96% to bands 6 and 7, compared with 21.51 and 38.33% in the SCF, and 0.27% to the bottom two bands, compared with 17.19%. Low current earners can own substantial portfolios, and current labor income need not equal permanent earnings. The full schedule therefore provides a diagnostic beyond the targeted upper-tail moment.