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(S)CARS AND THE GREAT RECESSION

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United States households' consumption expenditures and car purchases collapsed during the Great Recession and more so than income changes would have predicted. Using CEX data, we show that both the extensive and the intensive car spending margins contracted sharply in the Great Recession. We also document significant cross-cohort differences in the impact of the Great Recession including a stronger reduction in car spending by younger cohorts. We draw inference on the sources of the Great Recession by investigating which shocks can explain household choices in a 60 period life-cycle model with idiosyncratic and aggregate shocks fitted to aggregate and life-cycle moments. We find that the Great Recession was caused by a combination of large aggregate income and wealth shocks, while cross-cohort adjustment patterns imply a role for life-cycle income profile shocks. We also find a role for car loan premia shocks in accounting for car spending and car loans.

KEYWORDS: Consumption, durables adjustment, Great Recession.

1. INTRODUCTION

IN DECEMBER 2007, the U.S. economy entered the Great Recession (GR), one of the deepest and most persistent business cycle contractions in recent U.S. history. It is well recognized that this episode was associated with a sharp reduction in aggregate U.S. consumption spending, but which shocks to economic circumstances, and beliefs about these, triggered households to reduce consumption spending so strongly remains an open question. In this paper, we develop a methodology for addressing this question. It rests upon interpreting both aggregate outcomes *and* cross-agent differences, as summarized by cohort-level patterns, through the lens of a rich life-cycle model with multiple sources

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of shocks and frictions. This allows us to reverse engineer the unobserved determinants of consumer choices, such as expectations of future income.

We document that the consumption reduction during the GR was particularly dramatic for consumer durables and that its composition in terms of intensive and extensive margin adjustments was atypical for U.S recessions. We argue that such adjustments of spending on durables is particularly informative for drawing inference on shocks to current economic circumstances and expectations about their future paths. For this purpose, we fix attention on a large-ticket item, cars, for which there is high-quality household level data, and which can be decomposed into an extensive and an intensive adjustment margin. Our life-cycle model includes many salient features of car ownership such as transactions costs, car credit, and breakdown risk. We show that the information contained in durables adjustment and the combination of aggregate and cohort-level adjustments enables us to more plausibly explain the underlying shocks and mechanisms that triggered household choices during the GR.

A key motivation for studying car spending is that significant adjustment costs introduce a strong motive for households to consider their future economic conditions when deciding on spending. It is well known that consumer durables spending is much more volatile at the aggregate level than spending on nondurables and services.[1] Caballero (1993) shows how non-convex adjustment costs at the microeconomic level generate lumpy purchases and inaction at the individual level, while inducing excess smoothness in aggregate quantities. We argue that these features imply that cars spending choices are informative about households' beliefs about future economic conditions in a direct and visible manner. Indeed, successive Chairs of the Federal Board of Governors have highlighted automobile expenditures as an important forecasting variable for the macroeconomy and household behavior.[2]

We go considerably further in the use of household durables data than is common in the literature by studying both its extensive margin, variations in the share of households adjusting durables over time, *and* the intensive margin, the amount spent conditional on buying. Following Bar-Ilan and Blinder (1992), the literature on durable consumption dynamics has focused on the former of these. Instead, partly motivated by an atypical pattern of car purchasing behavior that, as we document, took place during the GR, we argue that the intensive margin contains information crucial for the mapping between shocks and choices central to our contribution. As pointed out by Bertola, Guiso, and Pistaferri (2005), the two margins are driven by different economic factors. The probability of adjustment depends upon the dynamic history of shocks experienced by the household, whereas conditional on wealth the intensive margin is based on forward looking considerations.

We apply this framework to propose an explanation for the dramatic (and differentiated across consumers) fall in consumption during the GR.[3] As in previous recessions, expenditure on durables consumption fell by more than nondurables, declining by 14% on a

[1] Kydland and Prescott (1982) report that the variance of U.S. durables consumption spending is more than nine times that of output over the business cycle. Galí (1993) finds that durables spending is both more volatile than nondurables consumption and *excessively smooth* relative to permanent income.

[2] Greenspan and Cohen (1990) argue that motor vehicle sales are a useful forecasting tool. Bernanke (1984) tests the permanent income hypothesis (PIH) for car expenditures using panel data from the Survey of Consumer Finances (SCF). Bernanke (1985) rejects the PIH *jointly* for durables and nondurables consumption expenditures (using aggregate data) due to excess volatility.

[3] The underlying causes of the GR are still debated; see Hall (2011), Stock and Watson (2012), Christiano, Eichenbaum, and Trabandt (2015), Krueger, Mitman, and Perri (2016), and Ravn and Sterk (2017).

year-on-year basis in 2008Q4. The corresponding decline for spending on motor vehicles was 24%. The car spending decline was persistent and derived from both a large contraction in the extensive margin and, unusually, a significant decline in the intensive margin. Motivated by this novel observation, we map observed consumption, car expenditures, savings, and car loans, into a rich choice model, to identify and decompose households' perceptions of economic prospects.[4] We study household consumption choices using data from the Consumer Expenditure Survey (CEX). By constructing synthetic cohort panel data, we examine life-cycle and business cycle features of the data. We decompose the CEX car spending data into its extensive and intensive margins and make use of the power of this decomposition for identifying shocks.

We document five facts about household choices and behavior during the GR. First, consumption expenditure contracted more than would have been expected given the income reduction. Second, the extensive car spending margin contracted significantly. Third, unlike in other recessions, the intensive margin *also* declined significantly. Fourth, controlling for life-cycle trends, distinct cohort patterns of adjustment of car spending are visible, with younger and middle-working-aged households adjusting more than older households. Additionally, the youngest households adjusted more on the extensive margin while middle aged households adjusted most strongly on the intensive margin. Finally, while savings of middle-aged and older cohorts fell, the proportion of younger households consuming less than current income increased.

In the life-cycle model that we formulate, households choose expenditures on nondurables and cars and save in a liquid asset subject to budget and borrowing constraints. Adjustments of the car stock are associated with nonconvex costs and cars are subject to stochastic depreciation shocks. There are permanent and transitory shocks to labor income of working-age households and occasional shocks to its drift, which tilt the life-cycle income profile. Income shocks may be idiosyncratic, cohort-specific or aggregate, allowing us to account for both income heterogeneity across households and business cycle fluctuations. Households face wealth shocks in the form of unexpected changes in asset prices, such as house price shocks and equity price fluctuations. Finally, households can access collateralized car loans subject to stochastic changes in the car loan interest premium.

The presence of adjustment costs generates (S, s)-type dynamics of household car stocks, as studied by Eberly (1994), Caballero and Engel (1999), Attanasio (2000), and more recently, by Berger and Vavra (2015). We show that alternative sources of aggregate shocks affect the car expenditure margins and households at different points of the life cycle disparately. For example, while large shocks to permanent income and the life-cycle profile reduce the intensive margin, especially for younger households, shocks to the car loan premium operate almost entirely on the extensive margin. A rise in uncertainty, while contracting the extensive margin, may actually induce a positive intensive margin response.

We estimate the structural parameters by matching moments of the pre-GR data. We then use the model to derive *combinations* of shocks and beliefs about future conditions that explain the patterns of consumption, saving, and car adjustments observed during the GR, including differences across cohorts. We find that an unexpectedly large and persistent sequence of aggregate income shocks matters for the large decline in consumption expenditures. Furthermore, the collapse in housing and equity markets at the onset of the GR contributed significantly to the sharp contraction in household spending. However,

[4]On income and consumption dynamics see, for example, Blundell and Preston (1998), Heathcote, Storesletten, and Violante (2014), and Kaplan, Mitman, and Violante (2020).

to account for the cohort features of the consumption adjustments, car loans, and savings, we show that it is important to allow for car loan premium shocks and a negative shock to the household life-cycle income profile. This latter shock does not impact on the level of income (restricted to equal the actual U.S. income decline during the GR) but it does influence expected future income, especially for younger households. A flattening of the life-cycle income profile leads younger households to increase their savings, as observed in the data. The importance of such declining long-run income expectations is consistent with survey evidence on consumer expectations: the Michigan's Survey of Consumers indicate that income expectations declined sharply during the GR and especially so for younger cohorts.

We use the model to carry out a number of additional experiments, analyzing the role of changes in fuel prices and income uncertainty as well as the impact of the Cash for Clunkers program introduced in 2009. Fuel prices and uncertainty shocks have minor impacts. As for Cash for Clunkers, its main impact is to bring forward car purchases but once the subsidy is terminated, its positive impact on expenditures quickly reverts.

Our work complements research on the root causes of the GR and follows a line of work, which has argued that household consumption dynamics can be highly informative of the shocks perceived by households. While we confirm the importance of the combination of wealth and income shocks during the GR as highlighted by, for example, Mian, Rao, and Sufi (2013), our analysis also stresses the role played by shifts in subjective expectations about future income. These shocks are key to explain cross-sectional heterogeneity in consumption responses. Our emphasis on beliefs about future income prospects echoes Kaplan, Mitman, and Violante (2020), who argue worsening expectations about housing demand matter for the house price boom and bust cycle during the GR. The quantitative importance of the wealth channel is also in line with Berger, Guerrieri, Lorenzoni, and Vavra (2018) who analyze of the impact of income uncertainty in a life-cycle setting.

Our use of consumption choices to infer household perceptions of income shocks and their implications for future income extends the seminal contributions of Blundell, Pistaferri, and Preston (2008) and Guvenen and Smith (2014) in a number of dimensions. First, we argue that consumer durables are particularly informative, while these authors focus on nondurable consumption. Second, we add aggregate shocks. Third, we go beyond labor income risk and show that the model has sharp predictions about the impact of other shocks. Similar to Wong (2021), we exploit cohort responses to understand aggregate shocks. However, our context differs (real shocks rather than monetary policy) and we study a substantially richer set of consumption responses. Olivi (2019) develops a general framework for making inference on preferences and beliefs from consumption and savings choices. Our approach differs from his in the use of durables' consumption choices and the stress on cohort-level and aggregate moments. Finally, unlike Berger and Vavra (2015) who examine the role of transaction costs in consumer durables dynamics, we examine both the extensive and intensive margins of car adjustment. This aspect of our analysis is new to the literature on durable goods, which following the seminal work of Caballero and Engel (1999), has focused on the extensive margin.[5]

[5] Harmenberg and Öberg (2021) consider the impact of unemployment shocks in a model with nonconvex costs of consumer durables. Our set-up is significantly richer and a major difference is that we use the model for drawing inference on the shocks rather than understanding the impact of income risk.

2. CONSUMPTION AND THE GREAT RECESSION

We start by documenting some salient facts about life-cycle dynamics and the impact of the GR on consumption and other household choices.

2.1. *Data*

Data for aggregate variables are from NIPA while household data are obtained from the CEX. The CEX is attractive for our purposes both because the sample is long and because of its detailed information on consumption at the household level.[6] We study the CEX sample of households with heads between the age of 25 and 84 for the 1981–2012 period, which contains around *234,000* household observations, with each household's consumption observed for a maximum of four quarters. Section S1 of the Appendix in the Online Supplementary Material (Attanasio, Larkin, Ravn, and Padula (2022)) discusses sources and definitions of the data and Table A.2 contains summary statistics.

2.2. *Life-Cycle Dynamics*

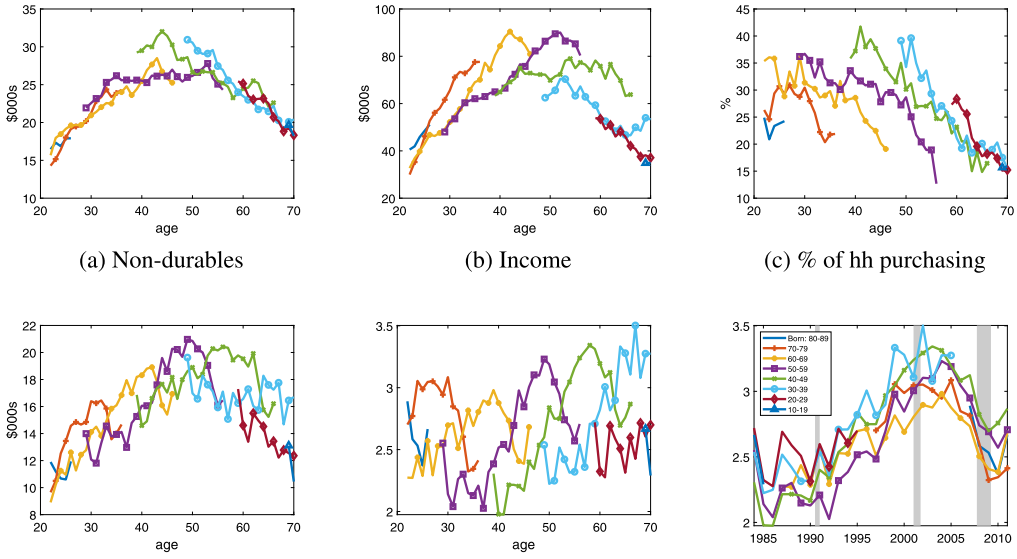
We first document life-cycle patterns in the CEX data. An obstacle in this regard is that each household in the CEX is followed only for four consecutive interviews. We address this issue by using a synthetic panel approach, grouping households by the birth year of the household head. We use 10 year groupings, see the Appendix for details.

Figure 1 plots the life-cycle profiles of household spending on nondurables and services, total after-tax household income (including financial income apart from capital gains), the value of households' cars stocks, the percentage of households purchasing a vehicle, as well as the ratio of household car stocks to consumption spending. We use the CPI to convert the first three variables in 2014 dollars.[7] The age profiles of nondurable consumption and the car stock value increase in the first part of the life cycle and peak for households when the head is aged mid-forties, or early fifties for cars. The profiles then flatten out and start declining in the last part of the life cycle. Income also increases in the first part of the life cycle and declines in later life. The differences across cohorts at the same age seem more pronounced for income than for consumption. The share of households purchasing a car displays a downward trend after age 30, and particularly so after the age of 50.

Panels (e) and (f) plot shows instead that there are scarring effects across cohorts when inspecting the value of the car stock relative to spending on nondurables and services for the different cohorts considered, against age and year, respectively. There is no easily visible life- cycle pattern to this variable. However, panel (f) shows clear comovements over time among the different cohorts, indicating the importance of aggregate shocks.

[6]The CEX data have been criticized not aggregating up to NIPA statistics. However, the CEX spending categories are very similar to those in NIPA data when controlling for items and population coverage. Furthermore, as shown in Garner, McClelland, and Passero (2009) and in Figure A.1 in the Appendix, CEX car spending closely mirrors NIPA data when aggregated across households, particularly for new cars.

[7]We divide consumption and income by the CPI to convert in 2014 dollars. Figure A.2 shows the life-cycle profiles in Figure 1 for variables measured on an adult equivalent scale. Figure A.3 shows some further information on life-cycle profiles of car ownership such as the value of purchases, the number of cars, car loans, and the value of the household car stock.



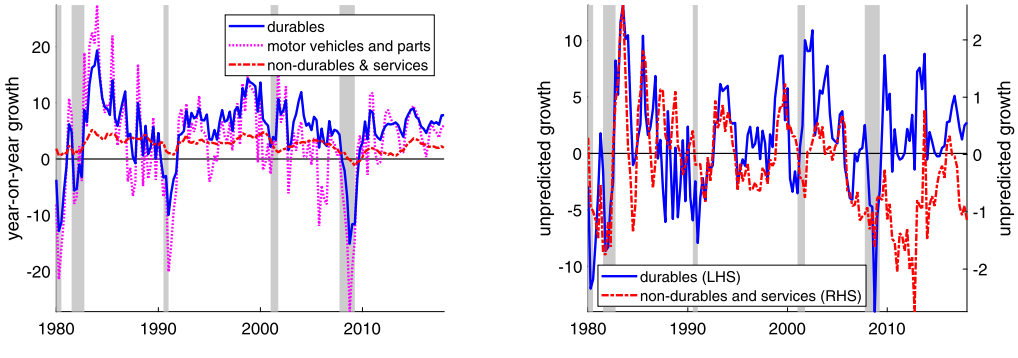
(a) Non-durables (b) Income (c) % of hh purchasing

(d) Value of car stock (e) Cars/non-durables (f) Cars/non-durables

FIGURE 1.—Consumption, Cars, and Income Over the Life Cycle. Notes: Each line is the age profile of a different cohort, defined by a 10-year interval, for the period 1984–2011. In panels (a) to (e), the variables of interest are plotted against age, while in panel (f) it is plotted against time. Nondurable consumption, car stocks, and income are in real terms. .

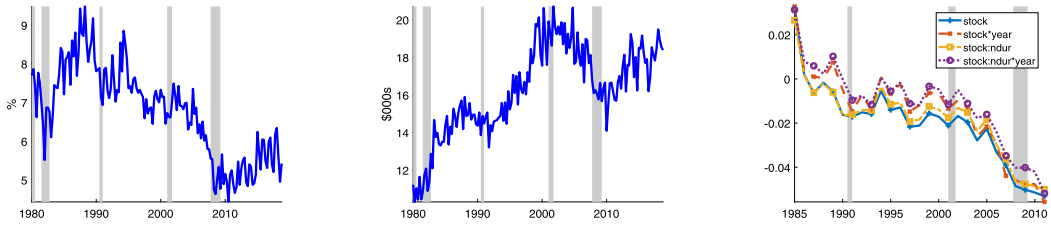
2.3. *Consumption Adjustments During the Great Recession*

Panel (a) of Figure 2 plots NIPA data on year-on-year growth rates of aggregate real consumption spending and its main components; we indicate NBER recessions in grey. Panel (b) shows the residuals of an OLS regression of consumption changes on income changes, which is informative about the extent the consumption adjustments derived from income changes.



(a) NIPA growth rates (b) Unpredicted growth

FIGURE 2.—NIPA Consumption Data. Notes: Panel (a) shows annual growth rates of NIPA data on real spending on nondurables and services, consumer durables, and motor vehicles, quarterly data, 1970–2019, shaded areas indicate NBER recessions. Panel (b) shows the residuals from regressing consumption growth on income growth.



(a) Extensive margin (b) Intensive margin (c) Time fixed effects

FIGURE 3.—CEX Extensive and Intensive Car Spending Margins. Notes: Panel (a) shows percentage of households that purchased a car per quarter. Panel (b) shows the average spending on cars conditional upon purchasing. Data are from the CEX and seasonally adjusted. Panel (c) plots the time-fixed effects from the regressions in Table II.

Consumption expenditures are clearly procyclical. Nondurables and services expenditures are smooth while spending on durables, and motor vehicles, in particular, are very volatile. Consumption adjustments during the GR stand out for a number reasons; spending on non-durables *declined* as opposed to slowing down during previous recessions; the reductions in spending on durables and motor vehicles are the largest in the sample; spending on vehicles declines by a stunning 24% in 2008Q4, on a year-by-year basis. From panel (b), it is clear that the contractions in consumption and, in particular, durables were far bigger than to be expected on the basis of the income drop. Moreover, spending on nondurables and services was very slow to recover in the aftermath of the recession.

Panel (a) of Figure 3 considers the *extensive margin* of car adjustment, the fraction of households in the CEX sample who purchase a car per-quarter (on average 6.8%). While there is a secular decline in the frequency of car purchases, there are evident cyclical variations in the extensive margin of adjustment and particularly so during the GR where the fraction of purchasers falls abruptly from 6% per quarter in 2006 to below 5% per quarter in late 2008.[8]

Panel (b) shows the *intensive margin*, the value of car purchased conditional upon the household buying a car. There is a positive secular trend toward more expensive vehicle purchases peaking in about 2005. The intensive margin remained fairly unaffected by recessions prior to the GR, as argued by Bar-Ilan and Blinder (1992). In contrast, during the GR, the intensive margin drops significantly both for new and used cars (see Appendix Figure A.5). This intensive margin drop occurs almost coincidentally with the GR and persists until around 2013.

Table I shows the results of estimating a linear probability model for the probability of purchasing a car and a regression of the value of car purchases, conditionally on buying one. The explanatory variables are a dummy variable for NBER recession periods, and a dummy for the GR. The latter shows a striking and novel fact that, while in previous recessions, the intensive margin did not change, during the GR the value of the average car purchase fell by almost $1300 dollars and this decline occurred in both new and used car markets. We also find that NBER recessions are associated with a 0.4 percentage point decline in the probability of car adjustment, which is evenly split between new and old purchases. The extensive margin contracts additionally in the GR, although this additional decline is not statistically different from zero.

[8]The fall in the frequency of car purchases during recessions occurs for both transactions in the new car market as well as in the secondhand market; see Figure A.4 in the Appendix

TABLE I

CAR PURCHASING BEHAVIOR IN RECESSIONS.

	Extensive margin			Intensive margin		
Variable	All	New	Old	All	New	Old
Recession	−0.43	−0.22	−0.23	211.3	−751.9	879.9
	(0.11)	(0.06)	(0.10)	(204.9)	(343.3)	(174.9)
Great Recession	−0.18	0.09	−0.26	−1311.6	−1974.0	−1426.6
	(0.18)	(0.10)	(0.16)	(363.8)	(605.3)	(311.5)
R^2	0.002	0.001	0.001	0.023	0.058	0.032
N	600,012	600,012	600,012	42,447	12,595	30,299

Note: Standard errors in parentheses. Data are quarterly, 1979.IV–2012.IV. The dependent variables in the first three columns is a dummy variable for households buying a car, in the last three columns it is the value spent on cars conditional on purchasing. Variables are regressed on a dummy for NBER recession dates and a dummy for the GR. Controls include quarter dummies and a quadratic polynomial in time.

One possible explanation for these results is the severity of the income reduction in the GR. To check this, in Table A.3 in the Appendix we report the results when replacing the NBER recession dummies with the GDP growth rate; the results are largely unchanged. Thus, the GR stands out for both a large drop in the extensive margin and an atypical contraction in the intensive margin.

Another factor potentially impacting on car purchase choices are changes in car prices and in car quality. The NIPA price index for new cars dropped by just below 3% from 2007.IV–2008.IV. However, this decline in the price index appears to have come from households choosing cheaper cars as quality adjusted prices of new cars hardly changed; see Gavazza and Lanteri (2021) and Bertolotti, Gavazza, and Lanteri (2021). The NIPA price index change for used cars over the same period dropped more dramatically by 8.2%, and analysis by Gavazza and Lanteri (2021) indicates that the change in the price index did come from lower (quality adjusted) prices. Thus, price discounts for used cars may account for some of the intensive margin decline for used cars but not for new cars, nor for the stark contraction in the extensive margin (which, if anything, one would expect to be stimulated by price discounts).[9]

2.4. *Extensive Margin Behavior*

Next, we estimate probit models for the probability of purchasing a car using individual household data from the CEX. Consistent with an *(S,s)* structure, in columns (1) and (2), we relate the probability of purchasing a car to the value of the household's stock of cars, after controlling for household characteristics such as family size, education, age, and income. In columns (3) and (4), instead of the value of the existing stock of cars, following Attanasio (2000), we control for the ratio of the value of the household's car stock to their annual spending on nondurables. The model also includes time-fixed effects on their own and interacted with the stock of cars, to capture other unobserved factors.

The average marginal effects reported in Table II show that, consistent with theories of non-convex car adjustment costs, a larger car stock makes car purchases less likely. More

[9]Appendix Figure A.6 illustrates the average purchasing price of new cars for the five most popular brands in the U.S. and the average purchase price of all new and used cars computed from the CEX data. Consistently with Gavazza and Lanteri (2021), these indices indicate that new car prices either increased or remained constant during the GR while used car prices, comparing the indices, appear to have declined.

TABLE II

PROBABILITY OF PURCHASING A CAR (AVG. MARGINAL EFFECTS).

Variable	(1)	(2)	(3)	(4)
Stock ($10,000)	−0.012	−0.008		
	(0.0003)	(0.0014)		
Stock:ndur			−0.010	−0.0068
			(0.0002)	(0.0009)
Log. Income	0.014	0.014	0.011	0.011
	(0.0005)	(0.0005)	(0.0005)	(0.0005)
year F.E	✓		✓	
stock x year		✓		✓
age polynomial	✓	✓	✓	✓
R^2	0.0304	0.0307	0.0369	0.0372
N	458,234	458,234	458,210	458,210

Note: The table reports probit estimation of the probability of car adjustment. Standard errors in parentheses. Stock is the value of the households' stock of cars. Stock:ndur is the ratio of the car stock to nondurables consumption. Log Income is log household income. Stockxyear allows for year fixed effects interacted with the value of the households' stock of cars. Controls include demographics, education, family composition, and a dummy for whether the household head works full-time.

generally, the pattern of the other coefficients, which are reported in Tables A.6 to A.8 in the Appendix, are consistent with standard models of durable expenditure. What is of particular interest here is the set of year fixed effects, which we plot in panel (c) of Figure 3, as they indicate that the GR displayed an unusually sharp decline in the extensive margin unaccounted for by household characteristics, consumption expenditures, and the size of the car stock.

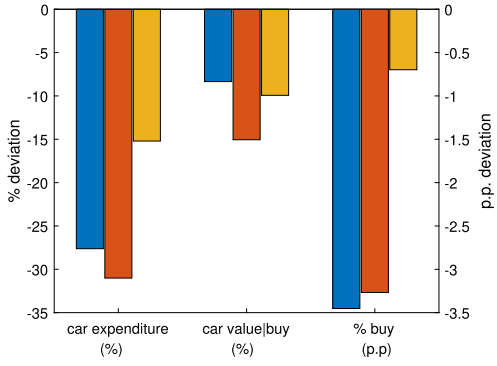
2.5. *Cohort Adjustments*

Finally, we examine how the GR impacted on three 10-year cohorts, those with household heads aged 25–34, 35–44, and 45–54 at the onset of the GR in 2007. For each cohort, we compute growth rates of car spending, consumption, income, and savings in a window around the GR and subtract from these the expected growth rates on the basis of life-cycle profiles estimated using pre-GR data. In this way, we account for the expected consumption and income growth absent the large aggregate shock.

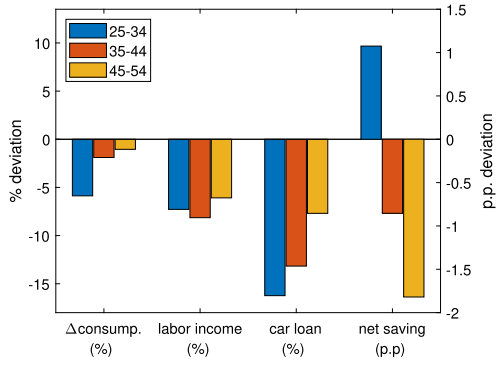
Panel (a) in Figure 4 illustrates the estimates for spending on cars and decomposes this into its intensive and extensive margins. Younger cohorts reduced their overall spending as well as both margins more than the oldest of these cohorts. As far as the intensive margin is concerned, the middle cohort witnessed the strongest contraction while the youngest cohort reduced the extensive margin the most.

Panel (b) shows the estimates for nondurables and services consumption, labor income, car loans, and a savings measure. The savings measure is the share of each cohort with positive net savings during the GR.[10] Nondurables consumption growth and car loans dropped far more for the youngest cohort than for the middle cohort, while the oldest cohort saw only a mild decline in consumption. In contrast to this, labor income changes

[10]See Section S1 in the Appendix for details. For consumption growth, we exploit the short panel dimension of the CEX and compare the log change of nondurables consumption of a household in the last quarter they are interviewed to the first quarter: $\log C_{\text{int:4}} - \log C_{\text{int:1}}$. Net savings is after-tax income less spending on nondurables goods and cars.



(a) Car spending



(b) Other

FIGURE 4.—Cohort Adjustments. Notes: Plots show deviations during the GR relative to the estimated life-cycle growth. The baseline year is the average in 2006–2007. Deviations are measured as the average during 2008–2010. All data except income from the CEX. Income data are from the CPS.

were only slightly larger for younger cohorts. Moreover, while the proportion of savers in the two oldest cohorts declined, this share actually rose for the youngest cohort.

These patterns could reflect the shocks experienced by households, their car stock and wealth holdings, or cohort-specific choices, issues that the model will address.

3. A MODEL OF HOUSEHOLD BEHAVIOR

We formulate a computable life-cycle model of household choices and use it for conducting inference about shocks and beliefs during the GR.

3.1. *Household Problems*

Demographics and Preferences. Every period a mass 1 continuum of newborn households enters the economy. These households face mortality risk; $\pi_a \in [0, 1]$ denotes the probability they survive from age $a-1$ to a. At age $\mathbf{T}$, mortality risk goes to 1, $\pi_{\mathbf{T}+1} = 0$. The size of each household varies over the life cycle in a deterministic manner with γ_a denoting household size at age a. Households work the initial $\mathbf{T}_r - 1$ periods of their life cycle after which they retire.

Households maximize expected discounted life-time utility. Let $x^a_{j,s}$ denote variable x for household $j \in [0, 1]$ of age $a < \mathbf{T}$ at date s. Preferences are given as

$$\mathbb{V}^j_{a,t} = \mathbb{E}_t \sum_{s=t}^{t+\mathbf{T}-a} \beta^{s-t} \frac{\pi_{a+s-t}}{1-\varphi} \left\{ \left[\alpha \left(\frac{c^j_{a+s-t,s}}{\gamma_{a+s-t}} \right)^{1-1/\mu} + (1-\alpha) \left(\xi \frac{\mathbf{D}^j_{a+s-t,s+1}}{\gamma_{a+s-t}} \right)^{1-1/\mu} \right]^{\frac{(1-\varphi)}{(1-1/\mu)}} - 1 \right\},$$

where

$$\mathbf{D}^j_{a,s+1} = \left[\alpha^f \left(d^j_{a,s+1} \right)^{1-1/\mu^f} + \left(1-\alpha^f \right) \left(f^j_{a,s} \right)^{1-1/\mu^f} \right]^{1/(1-1/\mu^f)}$$

$\mathbb{V}^j_{a,t}$ is discounted expected life-time utility of an age a household of identity j at date t, $\mathbb{E}_t$ is the mathematical expectations operator, $\beta < 1$ the subjective discount factor. $c^j_{a,s}$ denotes household spending on nondurables and services, and $\xi \mathbf{D}^j_{a,s+1}$ is the service flow

from cars. $\mathbf{D}^j_{a,s+1}$ is a CES aggregate of the household's stock of cars, $d^j_{a,s+1}$, and fuel consumption, $f^j_{a,s}$. α and α^f are preference weights, μ is the elasticity of substitution between consumption of nondurables and the car service flow, φ is the inverse of the intertemporal elasticity of substitution. μ^f is the elasticity of substitution between fuel and cars.

Household Car Dynamics. The law of motion of the household's stock of cars is given as

$$d^j_{a,s+1} = \left(1 - \delta^j_{a,s}\right) d^j_{a-1,s} + i^j_{a,s}$$

$i^j_{a,s}$ is investment in cars and $\delta^j_{a,s}$ is the depreciation rate. To capture realistic car dynamics, we allow for car breakdowns by assuming that the car depreciation rate can be either "normal," $\delta^N \in (0, 1)$, or high, $\delta^B \in (\delta^N, 1]$. Transitions between these two states follow a Markov process. A breakdown occurs with probability τ and is an absorbing state. The first period after adjusting the car stock, the depreciation rate starts at δ^N.

When a household "actively" adjusts its car stock, it incurs a cost of adjustment, Υ:

$$\Upsilon\left(p_s d^j_{a-1,s}, d^j_{a,s+1}\right) = \begin{cases} 0 & \text{if } d^j_{a,s+1} = \left(1 - \delta^j_{a,s}\varsigma\right) d^j_{a-1,s}, \\ \psi p_s d^j_{a-1,s} & \text{otherwise,} \end{cases}$$

where $p_s > 0$ denotes the price of cars denominated in units of nondurables. $\varsigma \in (0, 1)$ denotes the fraction of depreciation that is maintenance. Households can maintain their car stock, $i^j_{a,s} = \varsigma \delta^j_{a,s} d^j_{a-1,s}$, without incurring any adjustment costs; see, for example, Bachmann, Caballero, and Engel (2013). However, active car adjustment is subject to costs, which are a fraction $\psi > 0$ of the beginning-of-period car stock value. The nonconvex adjustment cost is adopted from Grossman and Laroque (1990) and generates (S, s)-style policy functions for the car stock.[11]

Budget and Borrowing Constraints. Household asset portfolios consist of an illiquid asset (cars), and two liquid assets—savings in a financial asset, $b^j_{a,s+1}$, and car loans, $k^j_{a,s+1}$. The financial asset can be purchased or sold each period at price, $q_{a,s}$, which is age specific. Holdings of the asset generate the period coupon $r > 0$. Households cannot go short on the financial asset but can access collateralized loans to fund car purchases:

$$b^j_{a,s+1} \geq 0,$$
$$k^j_{a,s+1} \leq \eta p_s d^j_{a,s+1},$$

where $\eta > 0$ determines leverage. Thus, households need to provide at least $(1 - \eta) p_s d^j_{a,s+1} > 0$ as down payment when acquiring a car. The interest on cars loans comes at a premium over the return on assets, $r^c_s \geq r$. The car credit account evolves as

$$k^j_{a,s+1} = \left(1 + r^c_s\right) k^j_{a-1,s} + \vartheta^j_{a,s},$$
$$\vartheta^j_{a,s} \in \left(-\left(1 + r^c_s\right) k^j_{a-1,s}, -\left(1 + r^c_s\right) k^j_{a-1,s} + \eta p_s d^j_{a,s+1}\right),$$

[11] Attanasio (2000) and Eberly (1994) estimate the parameters of (S, s) rules for household automobile purchases. Bertola, Guiso, and Pistaferri (2005) and Hassler (2001) look at more indirect evidence such as the impact of uncertainty on automobile purchases.

where $\vartheta^j_{a,s}$ is the change in household car debt incorporating both repayment of existing car loans and any new car debt issued. Households face a sequence of budget constraints:

$$\begin{aligned} c^j_{a,s} + \left(i^j_{a,s} - \vartheta^j_{a,s}\right) + \Upsilon\left(p_s d^j_{a-1,s}, d^j_{a,s+1}\right) + q_{a,s} b^j_{a,s+1} + q_{f,s} f^j_{a,s} \\ \leq \left(1 - \chi(a)\right) y^j_{a,s} + \chi(a) m^j_{a,s} + (1+r) q_{a,s} b^j_{a-1,s}. \end{aligned} \tag{1}$$

The left-hand side of equation (1) is total household expenditures. $q_{f,s} f^j_{a,s}$ denotes spending on fuel where $q_{f,s}$ is the fuel price. The right-hand side is household net income, $\chi(a)$ is an indicator variable, which takes on the value 1 if $a \geq T_r$ and zero otherwise. $y^j_{a,s}$ denotes labor market participants' labor income while $m^j_{a,s}$ is retirement income. $(1 + r) q_{a,s} b^j_{a-1,s}$ is the return on holdings of financial assets. Retirement income is a fixed fraction $\kappa \in (0, 1)$ of terminal permanent income, $p^j_{a,s}$, $m^j_{a,s} = \kappa \exp(p^j_{T_{r-1}, s_j(T_{r-1})})$.

We show the households' dynamic programming problems in Section S2.1 of the Appendix.

3.2. *Shocks*

We consider a rich set of shocks that affect household decisions.

Income. Log labor income is the sum of a permanent component, $p^j_{a,s}$, and an idiosyncratic transitory shock, $u^j_{a,s}$:

$$\log y^j_{a,s} = p^j_{a,s} + u^j_{a,s}, \quad a < T_r, \tag{2}$$

$$p^j_{a,s} = p^j_{a-1,s-1} + g_{a,S} + e^j_{a,s}, \tag{3}$$

$$e^j_{a,s} = \upsilon_s + \eta_{a,s} + \varepsilon^j_s, \tag{4}$$

$$u^j_{a,s} = \nu_s + \zeta_{a,s} + \epsilon^j_s. \tag{5}$$

The innovation to log income is the sum of an economy wide income shock, $\upsilon_s \sim N(0, \sigma^2_{\upsilon,S})$, a cohort-specific shock, $\eta_{a,s} \sim N(0, \sigma^2_{\eta,S})$, and an idiosyncratic permanent shock, $\varepsilon^j_{a,s} \sim N(0, \sigma^2_{\varepsilon,S})$. The income process is also perturbed by a transitory shock, $u^j_{a,s}$, the sum of a common transitory income shock, $\nu_s \sim N(0, \sigma^2_\nu)$, a cohort-specific transitory income shock, $\zeta_{a,s} \sim N(0, \sigma^2_\zeta)$, and an idiosyncratic transitory income shock, $\epsilon^j_s \sim N(0, \sigma^2_\epsilon)$. We assume that $\sigma^2_{\upsilon,S}$, $\sigma^2_{\eta,S}$, $\sigma^2_{\varepsilon,S}$, and $g_{a,S}$ follow two-state discrete Markov processes $S = 1, 2$.

The income process in (2)–(5) generalizes common specifications in the literature. First, we allow for aggregate as well as cohort-specific and purely idiosyncratic income shocks. The correlation of shocks across households allows for aggregate shocks. Cohort specific shocks permit aggregate income shocks to impact differently on households of different age. Second, the drift component, $g_{a,S}$, which determines the life- cycle income profile, is allowed to vary stochastically over time between a normal growth state and a low growth state. Third, we consider shocks to conditional income uncertainty, through changes in the variances of υ_s, $\eta_{a,s}$, and $\varepsilon^j_{a,s}$, which can matter given the nonconvex adjustment costs.

Wealth. We introduce wealth shocks through stochastic capital gains and losses on financial assets. Denote $q_{a,s}$ the price of the financial asset relevant for households with positive wealth. $q_{a,s}$ is a portfolio of housing (indicated by H) and equity (E), $q_{a,s} = \omega^H_{a,s} q^H_s + \omega^E_{a,s} q^E_s$ where $\omega^i_{a,s}$ is the portfolio weight of asset i. The asset prices follow autoregressive processes:

$$\log q^i_s = \log q^i_{s-1} + \varepsilon^{q,i}_s, \quad i = H, E, \tag{6}$$

where $\varepsilon_{q,s} = (\varepsilon^H_{q,s}, \varepsilon^E_{q,s})' \sim N(\mu_q, V_q)$. We assume that $\mu_q = (-0.5\sigma^2_{q,H}, -0.5\sigma^2_{q,E})'$ where $\sigma^2_{q,i}$ denotes the variance of asset price i. Thus, the levels of asset price indices do not display drift. Cohort weights are introduced to allow for differences across the life cycle in the portfolio composition of savings between the shares of housing and equity and the cohort-specific (log) asset price shock is then given as

$$\varepsilon^q_{a,s} = \omega^H_a \varepsilon^H_{q,s} + \omega^E_a \varepsilon^H_{q,s}$$

and its variance computed congruently with this (see Appendix S3.1).

Car Loan Rate. The car loan borrowing spread is stationary around a long-run mean $\overline{r}^c$:

$$\log\left(r^c_s - r\right) = \frac{\log\left(\overline{r}^c - r\right)}{1 - \rho_r} + \rho_r \log\left(r^c_{s-1} - r\right) + \varepsilon^r_s, \tag{7}$$

where $\varepsilon^r_s \sim N(0, \sigma^2_\theta)$ and $\rho_r \in (-1, 1)$.

Fuel Price. The log fuel price also follows an autoregressive process:

$$\log q_{f,s} = \rho_f \log q_{f,s} + \varepsilon^f_s,$$

where $\varepsilon^f_s \sim N(0, \sigma^2_f)$. ρ_f is the persistence of the fuel price.

Initial Conditions. Households enter the economy with initial income and asset portfolios (consisting of cars, car loans, and risk-free assets) drawn from log normal distributions. Let a_0 denote the age at which households enter the economy and

$$S_{a_0} = \left(\log(Y_{a_0}), \log(b_{a_0}), \log(d_{a_0})\right)' \sim N\left(\bar{S}_{a_0}, \sigma^2_{S_{a_0}}\right),$$

where $\sigma^2_{S_{a_0}}$ is diagonal.

3.3. *Parametrization and Policy Functions*

We solve the model numerically by value function iteration assuming discrete and fine grids for cash on hand, the financial asset, and cars (see Section S2 of the Appendix for details). The model is parametrized using a combination of calibration and indirect inference using information for the pre-GR period.

3.3.1. *Calibrated Parameters*

The calibrated parameters are reported in Table III. A model period is a calendar year. Agents enter the economy at age 25, work for 40 years, and live for a maximum of 60 years. Mortality risk is calibrated by matching $(\pi_{25}, \ldots, \pi_{84})$ to their population averages in the 2009 Lifetable of the United States. These probabilities imply a life expectancy of 50 years at age 25. The annual real return on the risk-free asset is 4%. Based on the estimates of Attanasio and Weber (1995) and Eichenbaum, Hansen, and Singleton (1988), we set the elasticity of intertemporal substitution, $1/\varphi$, equal to 2/3. The premium on car loans over the risk-free rate is 1.78% annually, which is the difference between the assumed risk-free rate and the average real interest rate on auto loans issued by Auto Finance Companies and commercial banks in the 1970–2006 sample. The parameters of the stochastic process for the car loan interest premium are derived by fitting an autoregressive process to the Auto Finance Company lending rate premium using monthly data from 1970 to 2006. This gives us estimates of $\rho_r = 0.500$ and $\sigma_r^2 = 0.297^2$. We model car breakdowns by fixing the probability of a car breakdown event to $\tau = 0.15$ and then estimate the resulting severity δ^B below.[12]

The variance of the idiosyncratic income risk is calibrated using the estimates of Blundell, Pistaferri, and Preston (2008) and Gourinchas and Parker (2002). We set $\sigma_u^2 = 0.246^2$ and $\sigma_\varepsilon^2 = 0.140^2$ so that, for idiosyncratic income risk, transitory shocks dominate. We assume the transitory aggregate income shocks are related to variation in unemployment and, therefore, we calibrate it to the share of households reporting zero annual income in the Current Population Survey, giving a variance of $\sigma_\nu^2 = 0.008^2$. We initially assume that the drift term in the life- cycle income process is constant over time, that is, $g_{a,s} = g_a$. We calibrate g_a so that it implies life-cycle income profiles consistent with a polynomial approximation of average income over the life cycle estimated on CEX data (controlling for cohort, race, education. and year effects).

We do not model portfolio choices. However, we impose portfolio shares to follow a life-cycle pattern that matches the observed data by matching the shares of housing, ω_a^H, and stocks, ω_a^E, to the 2004 Survey of Consumer Finance shown in Figure 5. Among households with positive wealth, the weight on housing is declining over the life cycle apart from households below the age of 35. Moreover, households below the age of 45 typically hold leveraged housing portfolios. The equity portfolio share, instead, rises until households come close to retirement age and then declines. We estimate the variance of innovations to the (linearly detrended) log of the house price index produced by the Federal Housing Finance Association. For the 1975–2007 sample, this delivers an estimate of $\sigma_{q,H}^2 = 0.031^2$. We obtain the variance of innovations to the log of the stock price, from the S&P500 for the period 1960–2007. This gives us a value of $\sigma_{q,E}^2 = 0.133^2$. We set the means of the asset price innovations to $\mu_q^H = -0.5\sigma_{q,H}^2$ and $\mu_q^E = -0.5\sigma_{q,E}^2$. Finally, the covariance of the shocks is $\sigma_{q,HE} = -0.0002$.

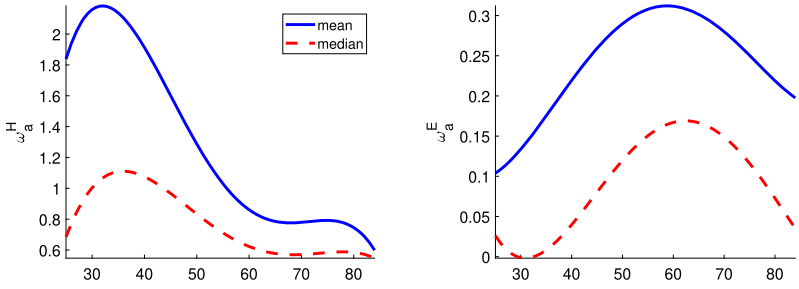
Log initial income is normally distributed with mean zero and variance $\sigma_{Y_0}^2 = 0.582^2$. This variance matches the cross-sectional variance of (log) income residuals of households aged 24–26 in the CEX. The distribution of initial assets is also assumed to be normal with a mean $\overline{b}_0 = 0.086$ and variance $\sigma_{b_0}^2 = 1.036^2$, which match the mean and variance observed in the 2007 sample of the SCF for households at age 24 rescaled by income of households aged 24–26. The logarithm of households' stock of cars at birth is drawn from a normal distribution with mean $\overline{d}_0 = -1.39$ and variance $\sigma_d^2 = 1.040^2$, values

[12]The results are robust to assuming alternative values of the breakdown probability.

TABLE III

EXTERNALLY CALIBRATED PARAMETERS.

	Parameter	Value
a_0	age agents enter the economy	25 years
$a_{\max}$	maximum lifespan	85 years
T_r	retirement age	65 years
π_a	survival probability	match 2009 Life Table
$1/\varphi$	intertemporal elasticity of substitution	2/3
r	annual real return on savings	4%
r^c	annual car loan interest rate	5.78%
κ	pension replacement rate	66.8%
τ	probability of car breakdown	0.15
σ_u^2	variance of transitory idiosyncratic income shock	0.246^2
σ_ε^2	variance of persistent idiosyncratic income shock	0.140^2
σ_ν^2	variance of transitory aggregate income shock	0.01^2
$\rho_{\nu,\upsilon}^2$	correlation of aggregate income shocks	0.44
$\sigma_{Y^{25}}^2$	cross-sectional variance of initial log. income	0.582^2
$\bar{b}_{25}$	mean initial assets	0.086
$\sigma_{b_{25}}^2$	cross-sectional variance of initial assets	1.036^2
$\bar{d}_{25}$	mean initial log. car stock	−1.39
$\sigma_{d_{25}}^2$	cross-sectional variance of initial log. car stock	1.04^2
P_{adj24}	share of HHs allowed to adjust car in period 0	70.5
g_a	life-cycle income factor	matched to CEX
γ_a	household equivalent size	matched to CEX
$\rho_{r^k}^2$	persistence of car loan spread	0.500
$\sigma_{r^k}^2$	variance of car loan spread	0.297^2
σ_{house}^2	variance of house price shocks	0.031^2
σ_{stock}^2	variance of stock price shocks	0.133^2
$\sigma_{\text{house,stock}}$	covariance of asset and stock price shocks	-0.0002^2
s_a	life-cycle portfolio weightings	matched to 2004 SCF
g_a^{post}	life-cycle growth shock	0.566
ρ_{fuel}	persistence of fuel process	0.909
σ_{fuel}^2	variance of fuel process shocks	0.099^2



(a) housing share (b) stock share

FIGURE 5.—Household Portfolio Weights. Notes: Calculated from the 2004 SCF. Only applies to households with positive assets.

that match the average value of cars per household at age 24 (rescaled by income as well) from the CEX.[13]

The retirement replacement rate, κ, is set such that in the absence of shocks, the household would receive 60% of their average income in the last 5 years of working life; see Bernheim, Skinner, and Weinberg (2001). This gives a value of $\kappa = 0.668$.

3.3.2. *Estimated Parameters*

We estimate the remaining parameters by indirect inference targeting a number of household and aggregate statistics. We initially ignore fuel prices (setting $\alpha^f = 1$) and assume that the aggregate income shocks impact equally on all cohorts, that is, that $\sigma_\eta^2 = 0$ and $\sigma_\zeta^2 = 0$. Therefore, the estimated parameters initially consist of the vector $(\alpha, \xi, \mu, \varrho, \psi, \delta^N, \delta^B, \sigma_\upsilon^2, \beta)$. In Section 5.1, we also estimate α^f and μ^f fitting some additional moments. Model moments are computed by simulating the model for 2000 periods with 2000 households per birth year. We minimize a quadratic form in deviations of model moments (averaged over panels of cohorts) from the empirical targets, weighted by the identity matrix. The targets all refer to the pre-GR period so that the model, including agents' expectations, refers to "normal" circumstances.

The first subset of targets relate to household-level moments derived from the CEX and the SCF. We target the average share of households who purchase a car annually (19.1%); the average spending on cars per year relative to nondurables, 9.9%; the mean spending on cars relative to their (beginning of period) car stock of households that purchase a car, 83.3%; the standard deviation of aggregate real car purchases in the CEX data (2.7%). We also target life- cycle moments including the growth in household nondurables spending from age 25 to its peak, 41.9% on average, and the share of households below the age of 45 years who do not have a car loan, 55.5% according to the SCF. The second set of moments are aggregate ones, computed from annual NIPA data (in constant prices) for the sample period 1970–2006.[14] We target the standard deviation of real nondurable consumption goods expenditure (0.77), the standard deviation of real car expenditure (5.91), and the cross-correlation of these two time series (0.72).

Targets and model equivalents are summarized in Table IV. The column labeled "Base" in Table V, contains the structural parameter estimates. We estimate α to be 82.7% and the elasticity of substitution between nondurables and cars just above one, $\mu = 1.14$. The normal car depreciation rate, δ^N, is 14.6% per year, while the breakdown value is estimated as $\delta^B = 20.7\%$. This implies an average depreciation rate close to the value of earlier estimates such as Attanasio (2000). The introduction of car breakdown, nonetheless, is important as it realistically "forces" a fraction of car owners to adjust their car stocks. The estimate of the proportion of depreciation that correspond to maintenance, ς, is 81.7%. These parameters imply that a passive strategy of simply carrying out maintenance induces a net depreciation rate of cars of 11.9% per year.

Transactions costs, ψ, are estimated as 13% of the car value. Given this, we calibrate η, which determines the minimum car purchase down payment, by ruling out default (due to inability to pay) setting it equal to $\eta = (1 - \delta - \psi)/(1 + r^c)$. This implies a value of 68.4%. Finally, the volatility of nondurables consumption implies that $\sigma_\upsilon^2 = 0.02^2$.

[13] To avoid excessive car purchases in the first period of life, 70% of the households entering the economy can optimally adjust their car stocks conditional upon their initial asset draw. We impose that no household breaks its collateral constraint at the initial asset allocation.

[14] We detrend the three time-series with the Hodrick–Prescott filter using a smoothing parameter of 6.25, Ravn and Uhlig (2002).

TABLE IV

EMPIRICAL AND MODEL MOMENTS.

Moment	Source	Data	Model
Targeted Moments			
Percentage of households purchasing a car	CEX	19.1	18.0
Ratio of car spending to nondurables spending	CEX	0.099	0.098
Ratio of car purchases to car stock | purchase	CEX	0.833	0.756
Growth in nondurables from age 25 to peak	CEX	41.9	43.8
Percentage of households under 45 without car loan	SCF	55.5	49.5
Std dev. of aggregate nondurables	NIPA	0.77	0.90
Std dev. of aggregate car expenditure	NIPA	5.91	5.40
Std dev. of aggregate car intensive margin	CEX	2.69	2.42
Correlation of aggregate nondurables and car spending	NIPA	0.72	0.78
Nontargeted Moments			
Age at peak of nondurables spending	CEX	45	46
Age at peak of car stock	CEX	53	52
Growth of car stock from age 25 to peak (percent)	CEX	60.5	68.9
Cross-sectional standard deviation of value of car stock	CEX	94.7	94.7

The model does an excellent job at matching the targets (see Table IV). We also report the match of the model to the data for a few nontargeted moments, the ages at which household spending on nondurables and cars peak, the growth of the household car stock from age 25 to peak, and the cross-sectional variance of the value of car stocks. The model matches each of these nontargeted moments closely.

3.3.3. *Policy Functions*

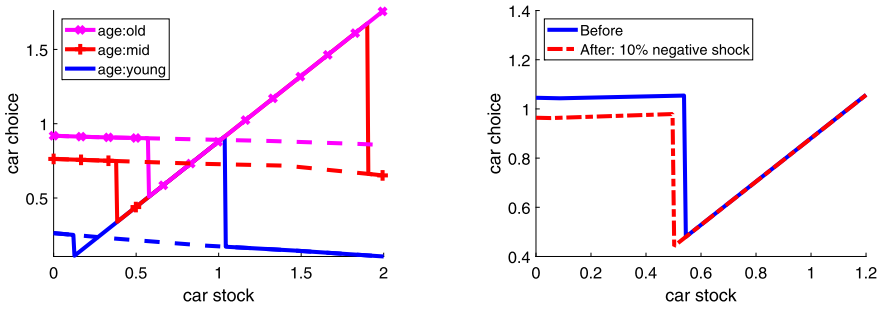
The policy functions for nondurables consumption are reasonably standard and are shown in the Appendix, Figure A.8. In Figure 6, we report the policy functions that determine the adjustment of the car stock. Panel (a) shows the policy function for a households' current choice of the value of their car stock plotted against their beginning of period car

TABLE V

ESTIMATED PARAMETERS.

	Parameter	Base	Income	Fuel
α	weight on nondurables in utility function	0.827	0.814	0.775
μ	elasticity of substitution	1.145	1.258	1.088
ξ	service flow from durables	0.724	0.719	0.685
ψ	car adjustment cost parameter	0.130	0.148	0.136
ς	car maintenance cost parameter	0.817	0.773	0.782
δ^N	normal car depreciation rate	0.146	0.155	0.149
δ^B	breakdown car depreciation rate	0.207	0.225	0.212
σ_v^2	variance of aggregate permanent income shock	0.020^2	0.023^2	0.021^2
β	subjective discount factor	0.944	0.944	0.946
α_f	weight of cars in subutility function			0.905
μ_f	fuel elasticity of substitution			0.738

Note: Column "Base" is the baseline model. Column "Income" excludes wealth and car loan premium shocks. "Fuel" allows for fuel price shocks.



(a) (S,s) rule (b) Response to income shock

FIGURE 6.—Policy Functions. Notes: The figures are the policy functions generated by the parameters in column "Base" of Table V.

stock. The policy functions bring out in a very clear fashion the (S, s) properties of car adjustments. There are upper and lower bounds on the household's car stock and whenever the car stock is outside this zone, it is adjusted to d^*. Inside this zone, the car stock declines gradually over time as the household pays for maintenance costs only. The adjustment point is higher for older and middle-aged households because of the household size and lower permanent income risk. Since younger households find themselves on the part of the life cycle where income is expected to rise, the optimal adjustment point is increasing over time and the policy function for these households displays significant asymmetry insofar as households tolerate much more deviation of the actual car stock from its target on the upside than on the downside.

Panel (b) shows the policy function for an agent who has experienced a 10% drop in income. This triggers a downward revision in the no-adjustment zone of the policy function as well as in d^*. Consequently, in recessions where many households experience negative income shocks, the extensive margin contracts as households delay adjusting their car stock. Moreover, high idiosyncratic income variance implies that those who purchase cars during recessions tend to be households that, despite the economy-wide contraction, are doing well. Thus, in "normal" recessions, the drop in car spending derives chiefly from the extensive margin.

3.4. *Inspecting the Mechanism*

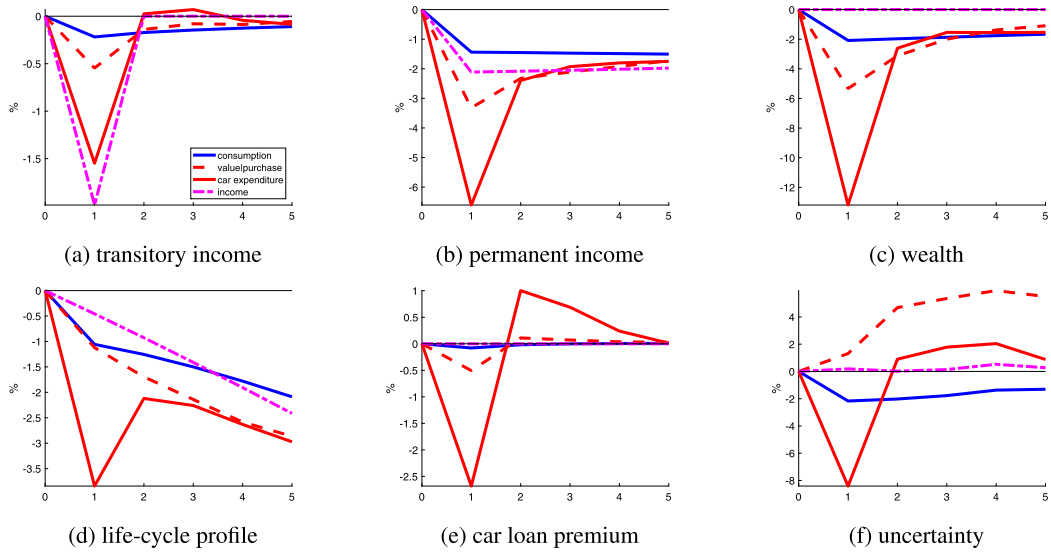
To understand how the model allows one to draw inferences on the nature of the shocks, we first examine impulse response functions to aggregate shocks, computed as

$$IRF_j(y_s) = \mathbb{E}(y_s|\varepsilon_{j,1} = \bar{\varepsilon}_j, \varepsilon_{\neq j,1}, \varepsilon_{s>1}, \epsilon_i) - \mathbb{E}(y_s|\varepsilon_1, \varepsilon_{s>1}, \epsilon_i),$$

where $IRF_j(y_s)$ is the response of variable y at forecast horizon s to a shock to ε_j at date 1, ε is the vector of aggregate shocks, ϵ_i the innovations to the idiosyncratic stochastic variables.[15]

Figure 7 illustrates the paths of income, consumption, and car spending (including the intensive margin) in response to the aggregate shocks in the model. The permanent and

[15]Each simulation allows for the nonshocked aggregate shocks and idiosyncratic shocks to be drawn from their asymptotic distributions. The model is initialized at the ergodic distribution over states. We compute expectations by simulating the model 100 times for 120,000 households and averaging over agents and simulations.



(a) transitory income (b) permanent income (c) wealth

(d) life-cycle profile (e) car loan premium (f) uncertainty

FIGURE 7.—Impulse Response Functions. Notes: The permanent and transitory income shocks are both set to σ_v. The wealth shock corresponds to the present value of the permanent income shock for a household with median wealth, a 37% decline in the asset price. The income profile shock is a 43% decline in the growth rate of the life-cycle income component with an expected duration of 40 years. The car loan premium is a $2\sigma_{r^k}$ positive shock. The uncertainty shock increases the variance of income shocks by a factor of around 1.5; see Section 5.

transitory income innovations correspond to a one standard deviation aggregate income shock. The wealth shock, a 37% asset price drop, equals the present value of a permanent income shock for a household with the average wealth holdings. The life-cycle income profile shock is a decline in the life-cycle income component's growth rate of 43% (with an expected duration of 40 years). The interest rate premium shock is a two standard deviations increase in the spread. The uncertainty shock is a 60% increase in aggregate income risk and a 44% increase in idiosyncratic risk with a mean duration of just under 5 years.

Consistent with the Permanent Income Hypothesis (PIH) logic, transitory income shocks leave consumption almost unchanged while a permanent income shock induces a quite elastic consumption response with permanent scars. Negative transitory and permanent income shocks both reduce car spending, but the effect is much larger for permanent shocks. The decomposition of the car spending channel generates extra identifying power. For example, transitory shocks operate mainly through the extensive margin, while permanent shocks have a significant and persistent effect on the intensive margin due to its impact on future labor income.

Considering consumption and car spending behavior for different cohorts through the lens of the model also allows for the identification of wealth shocks. For one, wealth shocks induce variations in consumption and car spending independently of income variations, a feature that appears important in the data; see Figure 2. Furthermore, wealth shocks trigger different consumption responses from permanent income shocks due to cross-cohort differences in household portfolio compositions: while permanent income shocks impact on all working-age agents, wealth shocks affect mainly middle-aged rich households who are intensive in car consumption (due to family size and savings). There-

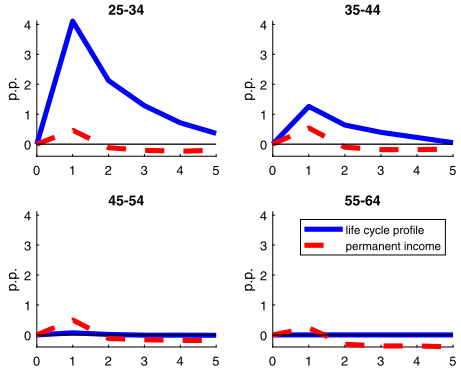
fore, wealth shocks induce a much higher response of car spending relative to consumption expenditures.

Life-cycle income profile shocks, which are usually not considered in this literature, trigger substantial household spending adjustments relative to current income changes, as a large fraction of the income loss occurs in future periods. Consumption expenditures initially contract more than income and car spending falls steeply with an elasticity to income above 10. On impact, car spending adjustments take place mainly through the extensive margin. As time passes and income remains low, the life-cycle income profile shock induces ever larger consumption reductions and lead households to downsize their optimal car size. These adjustments are very different from the shocks above because of the persistence of the shock and its disproportionate impact on the youngest households.

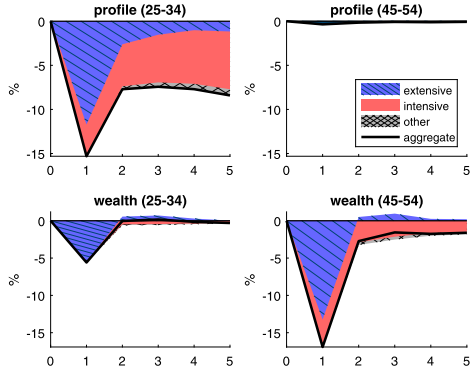
The car loan premium shock affects household choices almost entirely through the extensive car margin because it hits mainly young households who are on the rising part of their life-cycle income profile and, therefore, willing to take on car debt. For these households, more expensive car finance increases savings and induces delayed car acquisition. Further, as the shock has a minimal effect of total household wealth, it does not significantly reduce the target car size.

Higher income uncertainty induces wider (S,s) bands by raising the real option value of waiting, resulting in a significant fall in car expenditures due entirely to the extensive margin; see also Eberly (1994). As uncertainty fades, the intensive margin *increases* due to the extra depreciation incurred while delaying the car purchase. Thus, the uncertainty shock has a distinctly different impact on car choices than any of the other shocks considered.

Figure 8 turns to cohort-level responses focusing on income and wealth shocks. In panel (a), we examine the impact of permanent income shocks and life-cycle profile shocks on the saving ratio across 10-year cohorts, and in panel (b) the impact of the life-cycle profile and wealth shocks on cohort-level car choices. The life-cycle income profile shock increases significantly saving for the youngest cohort while having little impact on older



(a) saving ratio by cohort



(b) Car expenditure: profile & wealth by cohort

FIGURE 8.—Cohort Impulse Responses. Notes: The cohort responses are computed as the average response of a cohort of households defined by their age in the year prior to the shock. In panel (a), the saving ratio is net saving divided by current income. The decomposition in panel (b) is computed by holding alternate car expenditure margin at nonshocked level. For shock definitions, see notes to Figure 7.

cohorts.[16] The responses of younger cohorts derive from the profile shock inducing substantially lower expected future income, which increases savings of these cohorts, an effect that is muted for older cohorts who are beyond the part of the life cycle where their income rises steeply. In contrast, the permanent income shock has little impact on the proportion of savers across all cohorts following the PIH logic.

Panel (b) illustrates that the income profile shock affects mainly younger generations' car spending leaving older generations approximately unaffected. A flatter life-cycle income profile make younger generations reduce car spending initially through the extensive margin but, as the shock persists, increasingly through the intensive margin. Older generations' expected future incomes are approximately unaffected and these cohorts therefore do not adjust their cars spending. On the other hand, younger cohorts tend not to have much wealth, so that the wealth shock impacts mainly on the older cohorts, who initially delay car adjustments but with some longer term scarring. Thus, cross-cohort car choice responses are particularly informative about these two shocks.

4. INFERRING THE SOURCES OF HOUSEHOLD CHOICES IN THE GREAT RECESSION

We now use the model to infer what type of shocks and changes in beliefs and expectations are consistent with the choices observed during the GR. We do this by simulating the model in response to aggregate shocks under alternative assumptions about their nature and origin, and comparing actual household choices with the results of the simulations. In each case, we constrain ourselves by drawing idiosyncratic shocks from their asymptotic distributions and aggregate shocks that match those observed in the data.

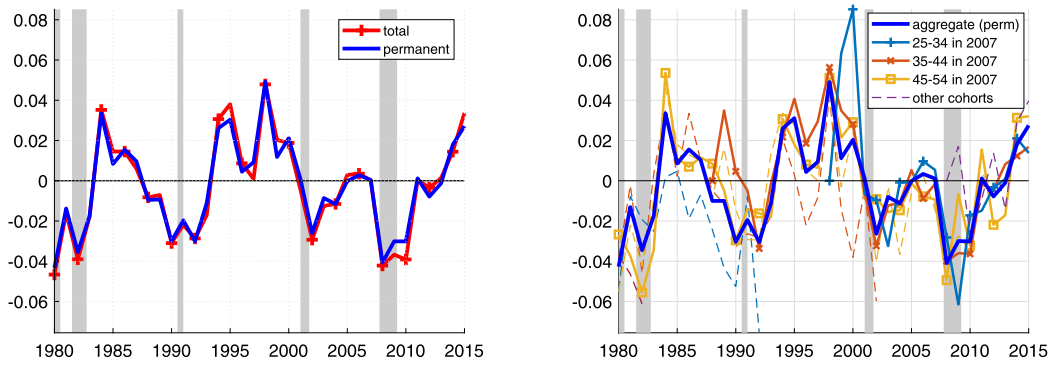
The rich wealth distribution in the model and the presence of nonconvex adjustment costs introduce path dependence. We address this issue by first feeding in a long series of the aggregate shocks pre-GR starting in 1950. To understand the sources of household choices in the GR, we simulate the model from 2007 to 2015 feeding in either one or more aggregate shocks. We use a simulated panel of 120,000 households and aggregate variables at the cohort level and for the whole sample. We repeat this exercise 150 times to compute expectations over idiosyncratic shocks.

In what follows, we assess the impact of different shocks by examining aggregate and cohort level averages for consumption, car choices, and savings. We also evaluate the role different shocks perform when fed into our model, by computing measures of fit on the basis of deviations of the key variables between each set of model simulations and their empirical counterparts. We initially examine the impact of income shocks in isolation. For this exercise, we reestimate structural parameters eliminating other sources of aggregate risk in the estimation sample and in the simulation exercises. These structural parameters are reported in the second column of Table V and they are very similar to the base model, apart from the car adjustment costs and the aggregate income risk being somewhat higher when we focus exclusively on income shocks. We then introduce wealth, interest rate premium, and life-cycle income profile shocks (in that order) using the parameter estimates of the base model.

4.1. *Income Shocks*

Perhaps the most intuitive explanation for the dramatic consumption adjustments during the GR is that the economy experienced a sequence of large and negative aggregate

[16]The saving ratio is net saving divided by current income. Net saving is total income minus consumption, car expenditures (including adjustment costs), and car interest repayments.



(a) Δ log income (b) cohort log income shocks

FIGURE 9.—Income Shocks. Notes: Panel (a) shows the total income innovation and the permanent component for the common shock specification. Panel (b) shows the permanent income shock for different cohorts. The shocks are estimated from the CPS; see the Appendix for details.

income shocks. To examine whether this hypothesis can explain the observed GR data, we estimate, using CPS data, two sets of shocks under the restriction that both sets are consistent with the same level of aggregate income: aggregate and cohort specific income shocks.

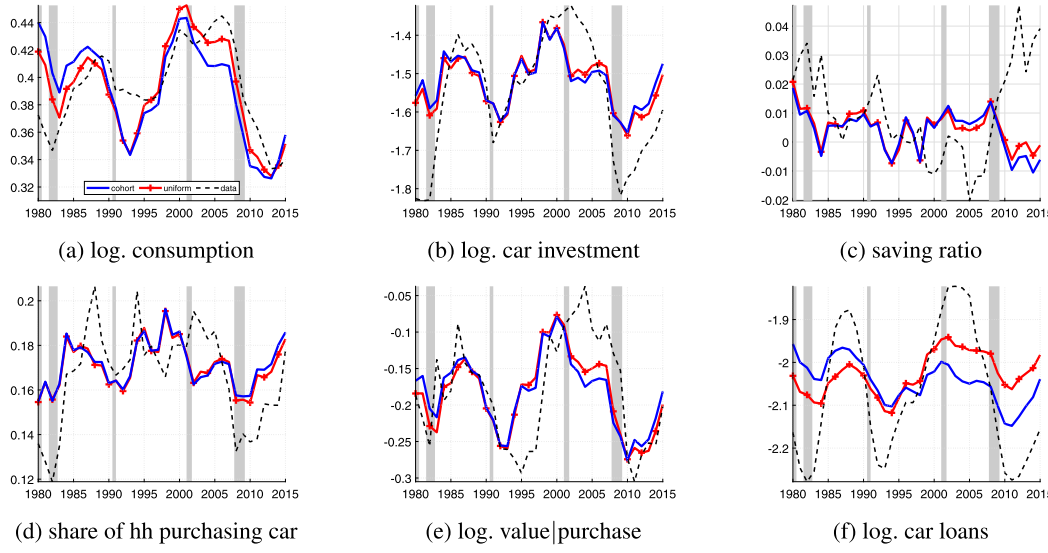
We first estimate cohort-specific shocks. The innovations to cohort-specific income are combinations of permanent and transitory shocks, $\widehat{\eta}_{a,s}$ and $\widehat{\nu}_{a,s}$, respectively. To estimate $\widehat{\eta}_{a,s}$, we first remove aggregate time and life-cycle trends from log income (divided by the PCE deflator). We then divide the CPS households into age-year cohorts defined by the age of the household head and, for each cohort, compute year-on-year income changes, which we then aggregate for decennial cohorts.[17] The transitory income shocks are measured in the CPS data on the basis of the share of households with zero income, again controlling for life-cycle dynamics and aggregating up to decennial cohorts. The common income shocks are derived by aggregating the cohort-level income shocks.[18] In both simulations, we also include idiosyncratic shocks, (u^j, ε^j), which we draw from their respective asymptotic distributions.

Panel (a) in Figure 9 shows the aggregate income shock and its permanent component for the common shock specification. It is clear that the GR witnessed a sequence of large negative income shocks that would have been perceived as unlikely pre-GR. The permanent income shock dominates much of the income innovation leaving little role for transitory aggregate income shocks apart from during 2009–2010. Panel (b) illustrates the cohort-specific permanent income shocks focusing on the three main working-age cohorts at the onset of the GR. The two younger cohorts were harder hit than those aged 45–54 in 2007, particularly toward the end of the GR.

Panel (a) in Figure 10 reports the model-based time-series for the log of nondurable consumption spending when feeding in either of the two sets of income shocks along with

[17]In identifying life-cycle trends, we use 1-year cohorts rather than the 10-year definition used in the simulations. Full details on the approach used for both transitory and permanent shocks are in Section S3 of the Appendix.

[18]As mentioned, we restrict income levels to be the same under the two-income shock specifications. We aggregate using population weights corresponding to the stationary demographic structure in the model.



(a) log. consumption (b) log. car investment (c) saving ratio

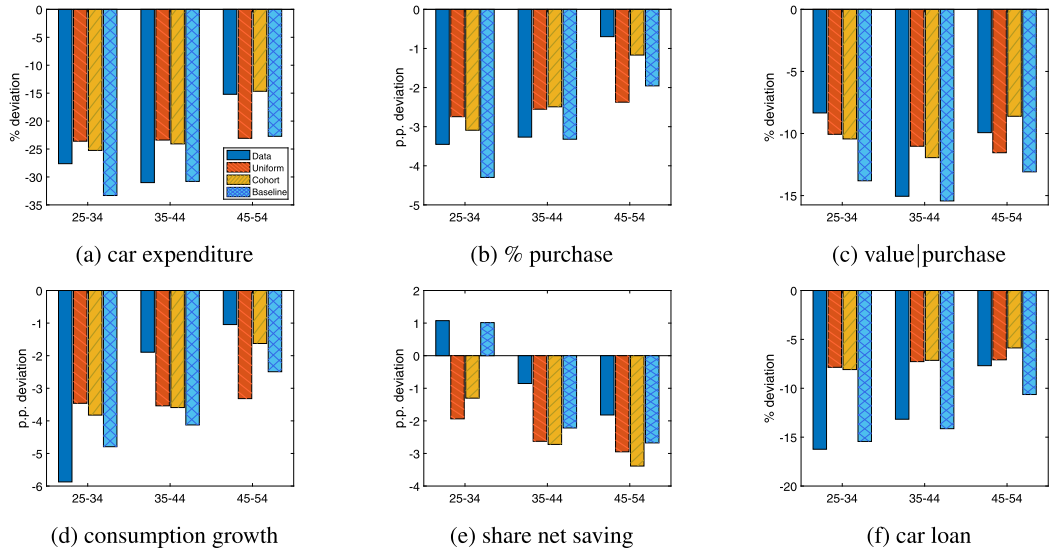
(d) share of hh purchasing car (e) log. value|purchase (f) log. car loans

FIGURE 10.—Aggregate Effects of Income Shocks. Notes: The dotted line shows the data. The solid line shows the model with common aggregate income shocks across cohorts. The line with plus markers shows the model with cohort-specific aggregate income shocks. Data for consumption, car investment and saving from NIPA. Data for intensive and extensive car margin from CEX. Data for car loans from FRB G19 Consumer Credit. Lines are colored in the online version.

the de-trended aggregated log real nondurables and services consumption estimated from the NIPA data. Despite not fully accounting for the early 2000's consumption boom and exaggerating the consequences of the early 1990s recession, aggregate income shocks provide a perhaps surprisingly good fit of the pre-GR *consumption path* regardless of whether we include cohort-specific income weights. Moreover, both sets of shocks fit quite well the observed path of consumption expenditure during the GR, although the peak to trough (2006–2015) decline in the model is somewhat smaller than its empirical counterpart.

However, income shocks in isolation cannot explain the steep decline in car spending (see panel (b) of Figure 10), an insight which is consistent with the abnormal decline in durables spending during the GR relative to the income fall documented in Figure 2. The lack of a strong decline in car spending derives from a combination of a far too small contraction in the extensive margin relative to the data (1.8% in the model vs. 5% in the data), and a decline in the intensive margin that is around 40% smaller than in the data. Thus, car spending choices reveal that a large income shock, be it common to all cohorts or allowing for cohort-specific weights, cannot be the sole source of the expenditure patterns observed in the GR. Although the aggregate shock was large by historical standards, the amount of idiosyncratic risk is sufficiently large that many households do relatively well in a recession.

Figure 11 zooms into the differences between the two specifications of the income shocks for cohort-level responses. In contrast to the data, but consistent with our analysis of impulse responses, the consumption growth rates implied by a uniform aggregate income shock are fairly similar across cohorts. Moreover, and in direct contrast to the data, the oldest of the three cohorts cuts car spending as much as the two younger cohorts. Finally, this shock induces a counterfactual uniform savings decline across cohorts and a much smaller decline in car loans than in the data. Introducing cohort specific income shocks implies (i) that older households reduce their car investment less during the



(a) car expenditure (b) % purchase (c) value|purchase

(d) consumption growth (e) share net saving (f) car loan

FIGURE 11.—Cohort Responses. Notes: Solid bars show cohort-level responses in the data, 2008-2010 relative to baseline. Bars with downward hatching are those in the model with common aggregate income shocks, bars with upward hatching the model with cohort-specific income shocks, bars with cross-hatching the model with cohort-specific shocks, wealth shocks and life-cycle income profile shocks. Baseline year for share net saving set to 2008 in model to capture profile shock. Car loans are car loan holdings conditional upon having a loan. Bars are colored in the online version.

GR than the younger cohorts, and (ii) that the youngest cohort witness the largest extensive car spending margin decline, although by less than in the data. Nonetheless, the model still fails to explain the large decline in consumption growth for the youngest cohort, the increase in net savings for this age group and the magnitude of the response on the intensive margin for the middle cohort.

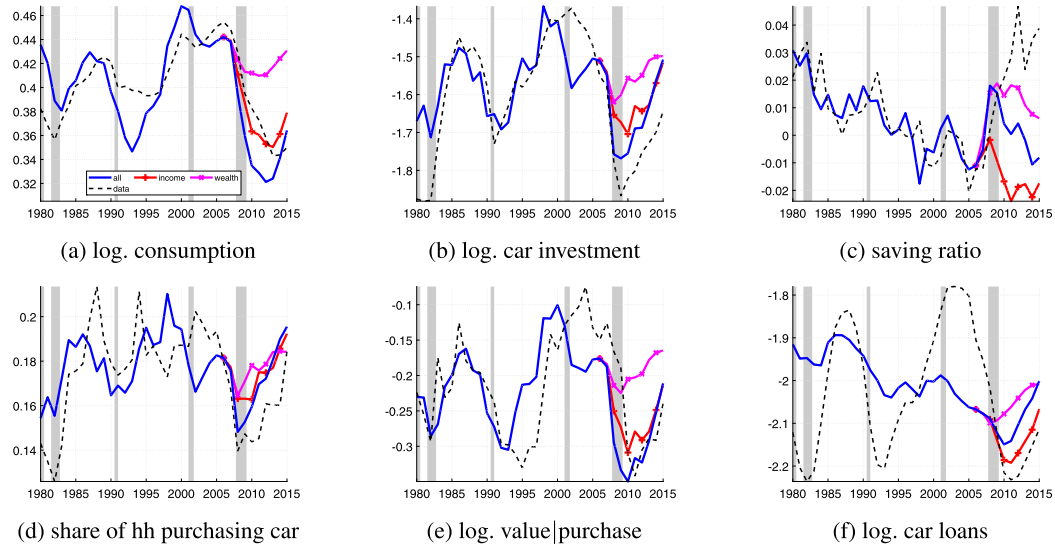
4.2. *Wealth Shocks*

Figure 2 indicates that the consumption and car spending contractions during the GR were driven by more than declining household incomes. We now look at the impact of the wealth shocks associated with the slump in the housing market and the weak stock market during the GR. We consider the effect of these shocks *on their own* and *in addition* to the income shocks considered above. Mian, Rao, and Sufi (2013) argue that the bust of the housing market at the onset of the financial crisis had a large impact on consumption.[19] Dynan (2012) further points out that, consistent with our modeling assumptions, part of the reason for such a strong response of consumption to house price shocks derives from leveraged household positions on housing.

We estimate the asset price shocks as the sequence of innovations to the relevant asset prices after removing a linear trend.[20] Figure A.10 in the Appendix shows that the stock price raised the average (asset-weighted) price in the late 1990s boom, while house prices

[19]Berger et al. (2018) show that incomplete markets models such as ours can potentially generate large marginal propensities to consume out changes in housing wealth.

[20]See the Appendix for details. We use data from the Federal Housing Agency for the housing price index, and the S&P 500 index for equity prices.



(a) log. consumption (b) log. car investment (c) saving ratio

(d) share of hh purchasing car (e) log. value|purchase (f) log. car loans

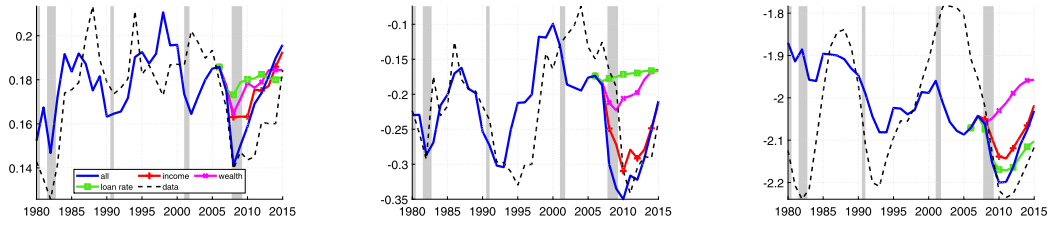
FIGURE 12.—The Impact of Wealth Shocks. Notes: Dotted lines are the data. Solid line is model with income and wealth shocks. Line with plus markers is only income shocks, line with cross markers is only wealth shocks. For data sources see Figure 10. Lines are colored online.

played a significant role in the lead up to the GR. The wealth shocks peak in 2008–2009 where we estimate negative growth rates of 18 and 15%, respectively, with a recovery taking place from 2013 onwards.

Feeding these shocks into the model, we find that, adding the boom-bust asset price cycle, allow us to match the consumption spending boom from the mid-1990s to 2006; see panel (a) of Figure 12. During this period, elevated asset prices increased the wealth of the consumption-intensive middle-aged cohorts. Similarly, rising wealth also helps explaining the boom in car spending during the early 2000s. During the GR, the wealth shocks in isolation (the green line) depress consumption mainly during 2008–2012. When we combine the cohort-specific income shock with the wealth shock (the blue line), we find a peak-to-trough decline in consumption expenditures very similar to what is observed in the data.

Wealth shocks are important for car choices. Panel (b) of Figure 12 shows a markedly better account of the decline in car spending during the GR. The combined impact of lower incomes and falling asset prices imply a drop in aggregate car spending of around 25 log points from 2006 to 2010, a decline which is not quite as large as in the data but much larger than in the absence of wealth shocks. Furthermore, the introduction of the wealth shock allows us to account almost perfectly for the peak-to-trough decline in the extensive margin and to match closely the contraction in the intensive margin. The latter feature, which may be somewhat surprising, given the impulse responses in Figure 7, is driven by the size and persistence of the wealth shocks and the simultaneous negative income shocks, which lead middle-aged cohorts to reduce their car sizes. However, both at the extensive and intensive margin, the simulation of the model produces a recovery that is considerably quicker than in the data.

The last two panels of Figure 12 illustrate the impact of wealth shocks for the aggregate savings ratio and for car loans. The lines in red shows the implied paths of the savings ratio and car loans, respectively, when we feed in only cohort-specific income shocks, while



(a) share of hh purchasing car (b) log. value|purchase (c) log. car loans

FIGURE 13.—Car Loan Premium Shock. Notes: The dotted lines are the data. Solid line is model with income, wealth and car loan premium shocks. Line with plus markers is only income shocks, line with cross markers is only wealth shocks, line with square markers is only loan premium shocks. Lines are colored online.

the lines in green are for the wealth shock. The savings ratio increased in the U.S. during the GR and remained elevated throughout the period we examine, while the aggregate amount of car loans dropped precipitously from the Global Financial Crisis. The income shock in isolation is inconsistent with the increase in the savings rate while it does induce a decline in car loans due to younger households delaying their car purchases. The wealth shock instead helps explaining the increase in the savings ratio but counterfactually implies an increase in car loans as the wealth shock peters out. When we combine the two shocks, the model accounts for neither the strong increase in savings during the GR, nor for the strong drop in car loans.

4.3. *Car Loan Premium Shocks*

During the financial crisis, the spread of interest rates paid on car loans above the risk-free rate jumped from 50% below trend in 2006 to more than 50% above trend in 2010 (see Figure A.11 in the Appendix). We now examine whether these shocks to the car loan premium are important for household choices during the GR. We calculate the sequence of shocks to the interest rate premium using the autoregressive specification in equation (7), which delivers the sequence of interest rate shocks reported in Figure A.11, panel (b), indicating a very large positive shock at the onset of the recession.

The car premium shock matters little for consumption (see Appendix Figure A.11) but does help accounting for car choices during the GR in two dimensions; see Figure 13. First, the increase in the car loan premium induces an additional decline in the extensive margin. Second, the increase in the interest rate on car loans reduces car loan demand (due to a standard substitution effect), which helps significantly in bridging the gap between data and the model discussed above when we considered income and wealth shocks only. The results also indicate that car premium shocks were important in the 1980s recession and, overall, the model now does a remarkably good job of fitting a long time series of rich household choices.

As regards financial frictions, it would be interesting to alternatively examine changes in the down payment requirement. Gavazza and Lanteri (2021) show how tighter borrowing constraints can lead to a contraction in the extensive margin because poorer households exit the secondhand market, inducing a extensive margin contraction also for wealthier households, through a price effect. Extending the model with such equilibrium price effects is, however, beyond the scope of our analysis.

4.4. *Life-Cycle Profile Shocks*

The GR induced a severe deterioration in the labor market prospects of U.S. households. In combination with the slow recovery, the slack labor market raised concerns about secular stagnation; see, for example, Summers (2014). Such expectations of persistently low growth of the aggregate economy may also have spilled over to households and impacted on their consumption choices beyond the direct effects of lower current income.

Thus, we now allow for a stochastic shock to g_a, the life-cycle income profile of different cohorts. We assume that these shocks are rare but persistent; they constitute a source of long-run *household* income risk similar in nature to the long-run risk shocks studied by Bansal and Yaron (2004) in relation to asset pricing. One can think of the combination of the two permanent income shocks, $e^j_{a,s}$ and $g_{a,s}$, as determining household beliefs in a similar fashion to the house price beliefs examined by Kaplan, Mitman, and Violante (2020). We argue that the GR may have induced a flattening of life-cycle income profile expectations. Figure A.13 in the Appendix illustrates the life-cycle income profiles estimated using CEX income data for the 1989–2006 and 2009–2012 samples, which are consistent with g_a declining post recession; see also Kong, Ravikumar, and Vandenbroucke (2018).

We assume that g_a follows a two-state discrete Markov chain with values:

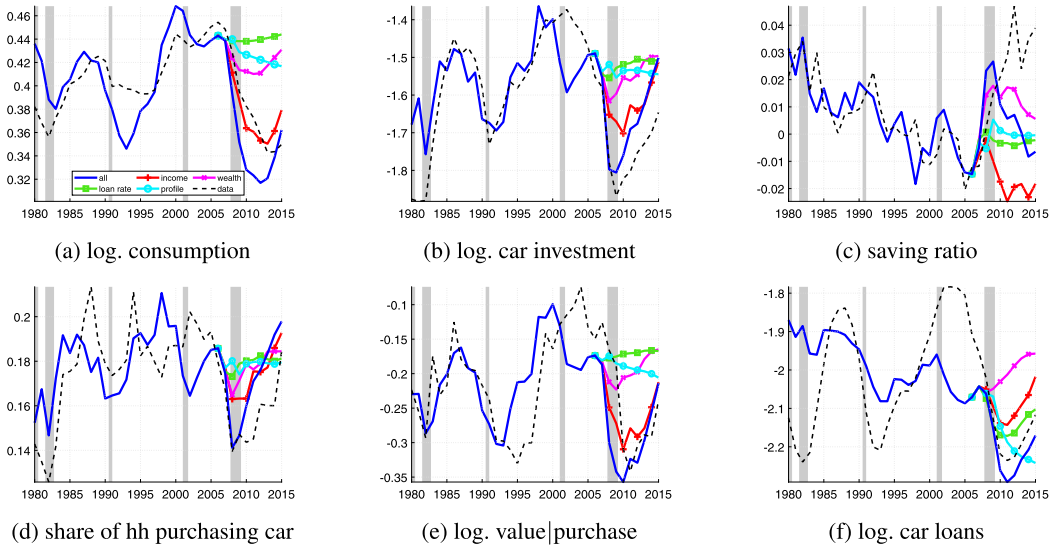
$$g(a)_{\text{low}} = \begin{cases} \gamma g(a)_{\text{high}} & \text{if } g(a)_{\text{high}} > 0, \\ g(a)_{\text{high}} & \text{otherwise,} \end{cases}$$

where g_a is a smooth approximation of the estimates of the life-cycle growth profiles; see Section S3.4 of the Appendix for details.[21] We find $\gamma = 0.566$ indicating a dramatic decline in the life-cycle income growth profiles. We then simulate the model assuming that the economy starts with $g(a)_{\text{high}}$ and switches to $g(a)_{\text{low}}$ in 2009 where it remains for the remainder of the simulation. We assume that the high growth state is absorbing and, therefore, it is not necessary to reestimate the structural parameters. The low income growth state has expected duration of 40 years, such that households expect the state to last for the duration of their working life. The income shocks that hit the economy from 2007 onward are then mixes of the cohort-specific income level shocks, $\eta_{a,s}$, and the growth rate shocks, $g_{a,s}$, constrained so that aggregate income changes by exactly the same amount as in the data.

Figure 14 illustrates the result of feeding these shocks into the model, in addition to the previous ones. At the aggregate level, the long-run income risk shock helps explaining the persistence of the drop in the intensive car spending margin because of the negative impact on younger households' car size choice as shown earlier in Figure 8. Moreover, the model now can fully account for the drop in car loans in the aftermath of the GR and the profile shock also helps explaining why the savings rate rose in this recession.

Importantly, the shocks to income profiles significantly help explaining the cohort patterns of adjustment, as reported in Figure 11. First and foremost, introducing these shocks generates an increase in the proportion of net savers amongst the youngest cohorts, while households in the older cohorts draw down on their asset position exactly as in the data. The reason behind this effect is that a shallower life-cycle income profile makes younger cohorts pessimistic about their life-time prospects, while there is little impact on the two older cohorts. Introducing the income-profile shocks also allows the model to better capture the stronger car expenditure response of the two younger cohorts, driven initially by

[21] We restrict the fall in the growth rate to households on the growing section of the life-cycle profile.



(a) log. consumption (b) log. car investment (c) saving ratio

(d) share of hh purchasing car (e) log. value|purchase (f) log. car loans

FIGURE 14.—Life-Cycle Income Profile Shock. Notes: Dotted lines are the data. Solid line is model with income, wealth, car loan premium and life-cycle profile shocks. Line with plus markers is only income shocks, line with cross markers is only wealth shocks, line with square markers is only loan premium shocks, line with circle markers is only life-cycle profile shock. For data sources see Figure 10. Lines are colored online.

the extensive margin response, which decreases by age, and the large fall in consumption growth of the youngest cohort. Finally, the model now reproduces the U-shaped pattern of intensive margin car spending adjustment across cohorts observed in the data, as well as the substantially stronger reduction in car loans for young cohorts. Overall the baseline model with four shocks now provides a very good fit of the cohort patterns of consumption, car spending, savings, and car loans.

4.5. *Taking Stock and Further Evidence*

We now summarize the relative fit of the simulations these different scenarios generate. In Table VI, we report measures of fit for the following variables: consumption growth rates, total car spending, the intensive and extensive car spending margins, saving rates, and car loans for each of simulations performed. We use as a measures of fit average absolute deviations between the simulation averages and data for each of the variables. In panel (a), we report deviations for overall aggregates, while, in panel (b), we report cohort specific aggregates. [22]The last column of the table contains the mean of the fit measures for the previous variables.

Comparing uniform income shocks with cohort-specific shocks, the latter performs marginally worse in terms of aggregate deviations. However, when looking at cohort specific averages, the introduction of cohort specific shocks improves the fit in most dimensions. Consistently with Figure 13, adding wealth shocks improves significantly the model's ability to account for the aggregate GR variables in all dimensions apart from car loans. The improvement is particularly evident for aggregate car spending thus indicating a key role of wealth shocks in accounting for durable goods adjustment. There is also

[22]To make the numbers comparable across the two panels, we multiply the measures of fit in panel (b) with 10.

TABLE VI

MODEL PERFORMANCE.

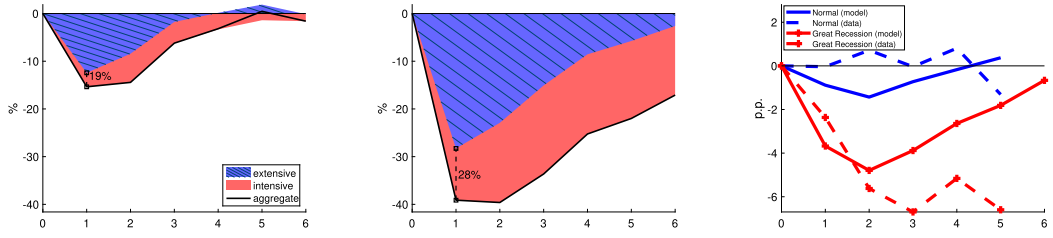
	Average absolute deviation						
	Δc_i	I^d	% buy	val|buy	saving	loans	MEAN
a. Aggregates							
uniform income	0.116	0.716	0.138	0.388	0.339	1.674	0.562
cohort income	0.145	0.993	0.172	0.557	0.388	1.619	0.646
+ wealth	0.121	0.461	0.117	0.296	0.233	1.890	0.520
+ loan premium	0.123	0.392	0.086	0.289	0.228	1.676	0.466
+ life-cycle profile	0.124	0.390	0.101	0.251	0.218	1.018	0.350
b. Cohorts							
uniform income	0.223	0.633	0.080	0.273	0.182	0.588	0.330
cohort income	0.180	0.391	0.055	0.232	0.187	0.608	0.276
wealth	0.180	0.255	0.025	0.186	0.114	0.514	0.212
loan premium	0.180	0.331	0.042	0.197	0.188	0.191	0.188
life-cycle profile	0.137	0.377	0.054	0.248	0.074	0.130	0.170

Note: Panel (a) reports the average absolute deviations for the aggregate series for the period 2007–2015 as shown in Figures 10, 12, 13, and 14 (smaller value preferred). The data and model series are normalized in 2006. For Δc_i only data up until 2014 is used, due to data availability. For value|buy, we realign model forward one year. Saving is the aggregate savings rate. Loans is total loan holdings. Panel (b) is the absolute deviation of the cohort responses as shown in Figure 11, weighted by a (normalized) measure of the size of the response in the data. The deviation is multiplied by 10 to improve comparability with panel (a). Saving is the share of households with income greater than consumption. Loans is average car loan conditional upon having a car loan.

some improvement in fit to car spending at the cohort level. Adding shocks to the car loan interest rate indicates a closer fit to overall car spending deriving predominantly from the extensive margin, as well as to the time-series for car loans. Finally, Table VI shows that the model produces a much better fit overall when we introduce income profile shocks, with significant improvements for the intensive car spending margin, the aggregate savings rate and aggregate car loans, as well as cross-cohort patterns of nondurables consumption spending growth, savings, and car loans adjustment. An important observation here is that the car spending choices are key for inference about the importance of the various shocks impacting on households during the Great Recession. In particular, inspecting only (the growth in) nondurables consumption spending, be it at the aggregate level or the cohort level, would attribute little role to wealth shocks, loan premia shocks, and the life-cycle profile shock. Thus, studying household adjustments at the cohort-level of a large-ticket item like cars adds significant new insights.[23]

Figure 15 presents a sufficient statistic style comparison of the response of car expenditure to the shocks of the GR and a "normal" recession, which we represent, respectively by the combination of shocks in the GR discussed above, and an estimate of the mix of shocks in the three previous recessions. Comparing panels (a) and (b) shows that the model generates a a much larger and more persistent overall response of car expenditure during the GR than in a "normal recession." Further, the intensive margin accounted for a larger fraction of the car spending reduction in the GR and explains much of the persistent decline in cars spending. The contrast between the paths in panels (a) and (b) do not derive mechanically from shocks being larger and more persistent during the GR relative to normal recessions. We show this in panel (c) where we illustrate the intensive margin

[23]In Table VI part (b), we report the absolute deviation of the cohort responses as shown in Figure 11, weighted by a (normalized) measure of the size of the response in the data. In Appendix Table A.9, we show the unweighted moments.



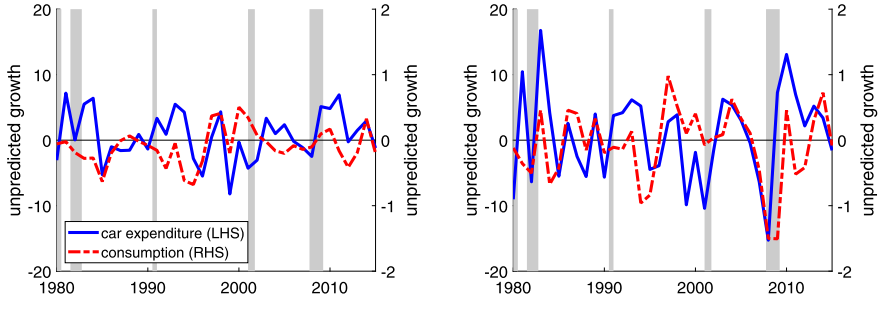
(a) "Normal" recession (b) Great Recession (c) Value:non-durables|buy

FIGURE 15.—Car Expenditures in a "Normal" and in the Great Recession. Notes: "Normal" recession is the average of permanent, transitory, wealth, and car loan premium shocks of recessions beginning in 1982, 1991, and 2001. GR is shocks of the four-shock baseline model. Decomposition is computed by holding alternate car expenditure margin at nonshocked level. Panel c is the ratio of value of car purchased to (annualized) nondurables consumption for households that purchase a car. In panel c, expenditure data for Great Recession shifted to start in 2008.

choice relative to nondurables consumption goods spending for households purchasing a car. We contrast both the GR with normal recessions and model with data. As in the data, the model predicts a much larger relative contraction of the intensive margin in the GR relative to normal recessions.

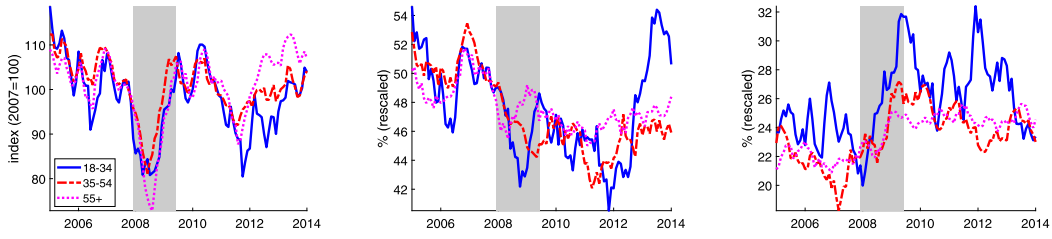
We showed earlier (see Figure 2) that the GR was associated with a large decline in durables and consumption growth not predicted by the labor income decline. Figure 16 replicates this finding in our model: we simulate the model with only income shocks (panel (a)) and with all the shocks we have been considering (panel (b)). Comparing these two simulations shows that, within our model, noncurrent-income related shocks play a very important role in accounting for the sign and size of changes to nondurable consumption and car expenditure observed in the data during the GR. In fact, we match the contribution of other shocks remarkably well.

The consumption choices of households suggest perceptions of a decline in the life-cycle profile was an important source of risk to households during the GR. We now present additional survey evidence on beliefs that points in the same direction. We draw on consumer expectations from the University of Michigan Survey of Consumer Confidence. Figure 17 presents data from this survey for three cohorts, 18–34-year-olds, 35–54-year-olds and 55+-year-olds. We plot attitudes toward purchasing a car, and 5-year



(a) cohort income shocks (b) baseline model

FIGURE 16.—The Role of Noncurrent Income. Notes: The figure shows residuals from regressions of growth in car expenditure and nondurables consumption on aggregate income using simulated model data.

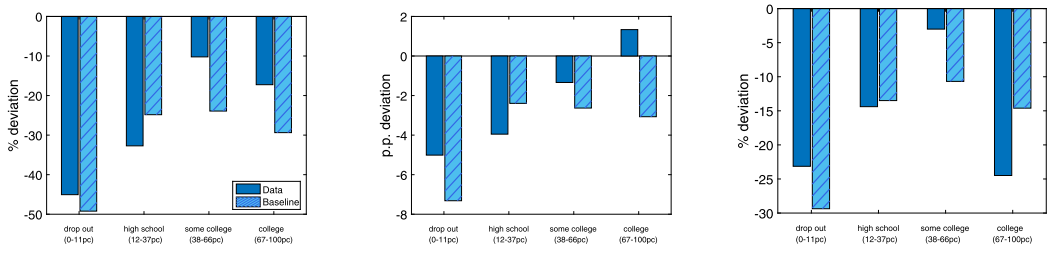


(a) Car sentiment (b) income increase (5 year) (c) job loss (5 year)

FIGURE 17.—Household Expectations and Consumer Confidence. Notes: All data from the University of Michigan's Survey of Consumers. Panel (a) shows household sentiment toward purchasing a vehicle, panel (b) expectations of income growth during the next 5 years, panel (c) expectations of job loss during next 5 years.

ahead expectations about income and job loss. Panel (a) shows a dramatic and persistent decline in sentiments toward purchasing a car at the onset of the GR, consistent with the sharp contraction in the extensive margin of car spending discussed earlier. The next panel shows that income expectations deteriorated from 2007 onward across cohorts. However, the decline in income expectations is much stronger and persistent for the two younger cohorts. Panel (c) further shows that the youngest cohort had much more negative expectations about job loss risk, which would be consistent with the importance of belief shocks generating lower expected life-cycle income growth due to periods of unemployment and "unemployment scars."[24]

Finally, Figure 18, shows car spending in the CEX over the 2008–2010 period relative to 2006–2007 by education level, which proxies net worth, whose measurement is incomplete in the CEX. We consider four levels of education: high-school dropouts, high school graduates, some college, and college. The CEX data indicate an inverted-U shaped pattern of car spending reduction across educational groups with the two lowest educational groups cutting car spending the most (and particularly strongly so for the high-school dropouts) while those with a college degree reduced car spending more than those with some college. The inverted-U shaped pattern of adjustment is reproduced by the inten-



(a) car expenditure (b) % purchase (c) value|purchase

FIGURE 18.—Car Spending by Education and Wealth. Notes: Bars with hatching shocksdData from the CEX. The data splits is by highest education level reported for head of household. In the model, shown with hatched bars, households are grouped in age cohort percentile of the combined wealth (including period return) and car stock distribution in 2007.

[24] Ravn and Sterk (2017) also stress the importance of unemployment risk for the contraction in consumption spending during the GR.

sive margin while the extensive margin is inversely related to educational attainment with strong adjustment by high-school dropouts.

Taking educational levels as a proxy for total wealth, we compute these statistics simulating the baseline model with the four shocks considered above. We order households *within* the three cohorts by the sum of financial wealth and the car stock in 2007 and match high-school dropouts, high-school graduates, some college, and college graduates with the 0–11, 12–37, 37–66, and 67–100 percentiles in the age-cohort wealth distribution. The model reproduces exactly the inverted-U shaped patterns of car spending adjustments and the intensive margin. It is also consistent with the lowest wealth group reducing their car purchases the most.

5. ALTERNATIVE STORIES FOR THE GREAT RECESSION

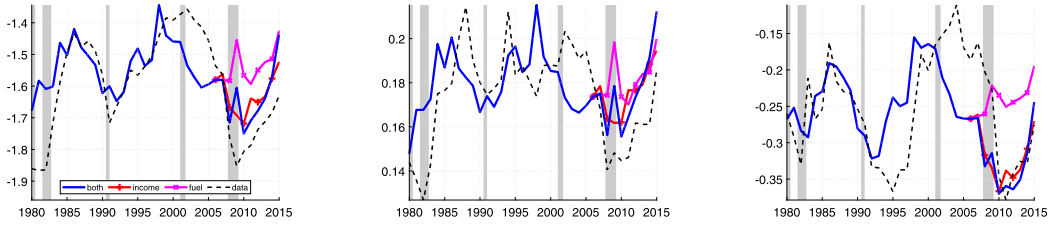
We now consider some further hypotheses that have been discussed in the literature. For computational expediency, we solve the extended model with only income shocks.

5.1. *Fuel Price Changes*

As fuel prices moved dramatically during the GR, they might have impacted on car choices. Thus, we introduce stochastic fuel price shocks in the model. We calibrate the fuel price process using the CPI for gasoline deflated by the total CPI. After detrending over the period 1967–2007, we get a persistence parameter of $\rho^F = 0.907$ and a variance of $\sigma^2_{\varepsilon,F} = 0.092^2$.

Next, we add α^f and μ^f, the parameters that characterize the role of fuel in preferences, to the list of parameters that we estimate with indirect inference. We augment the list of estimation targets with the ratio of fuel expenditure to car expenditure (0.606 in the CEX data) and the correlation between (detrended) car expenditure and the fuel price, -0.308. The resulting set of estimated parameters is reported in the third column of Table V, labeled "Fuel." We find an elasticity of substitution between cars and fuel below one, plausibly indicating complementarity of these two factors in producing car services. The weight on fuel in producing car services, however, is below 0.1, so that the car stock matters more for car services and fuel consumption.

Figure A.16 in the Appendix shows the substantial increase in the cost of fuel between 2001 and 2007. The cost of fuel continued to rise after the onset of the GR, before collapsing precipitously following the decline in demand for oil. Figure 19 reports car spending choices when we feed into the model income and/or fuel shocks. While falling fuel prices



(a) log. car investment (b) share of hh purchasing car (c) log. value|purchase

FIGURE 19.—Fuel Price Shock. Notes: Solid line is model with income and fuel price shocks. Line with plus markers is only income shocks, line with cross markers is only fuel price shocks. For data sources, see Figure 10. Lines are colored online.

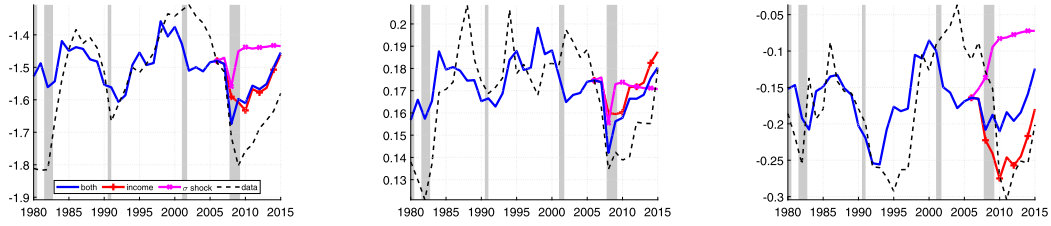
in 2009 do stimulate car spending in that period, relative to income shocks, the extensive and intensive margins of car purchases are fairly insensitive to fuel shocks since most of the production of car services comes from the car stock, which is a slow moving variable. Thus, fuel price changes appear to be of second-order importance for car choices during the GR and, if anything, stimulate both the extensive and intensive margin contrary to the data.

5.2. *Uncertainty Shocks*

An influential literature has argued that elevated uncertainty, observed also during the GR, can have important implications for firm and household choices.[25] As discussed in Section 3.2, we consider changes in uncertainty by introducing state dependence in the variances of the shocks to the permanent income process with $\sigma^2_{v,S}$, $\sigma^2_{\eta,S}$, and $\sigma^2_{\varepsilon,S}$ following two-state Markov processes. In particular, we assume that S moves between a high and low uncertainty regime with transition probability $P(S, S')$.

We adopt the probabilities for the Markov chain over the uncertainty regime estimated in Bloom, Floetotto, Jaimovich, Saporta-Eksten, and Terry (2018) aggregated to an annual frequency. The variance of the shocks in the low uncertainty regime is the same as in the baseline model. In the high uncertainty regime, the variances of the aggregate and cohort shocks increase by a factor of 1.6. For the idiosyncratic shocks, we consider a two-standard deviation increase and use the estimate of Bayer et al. (2019), which implies that a one-standard deviation increase in income uncertainty raises the variance of income shocks by 54%. This gives a scaling factor of 1.44.[26] We assume that prior to the GR the economy was in the low uncertainty state; then in 2008, the economy switches to the high uncertainty regime and remains there for the rest of the simulation. The aggregate shocks are those estimated from the data and, therefore, are unchanged. The idiosyncratic persistent shocks, however, are now drawn from the higher variance distribution.

In Figure 20, we see the main effect of higher uncertainty is to reduce the extensive margin as households choose to delay car purchases due to the option value of waiting. Most of this effect occurs in the first period of the shock, but there is some persistence in the reduction of the extensive margin. However, because of the depreciation effect



(a) log. car investment (b) share of hh purchasing car (c) log. value|purchase

FIGURE 20.—Uncertainty Shock. Notes: Solid line is model with income and uncertainty shocks. Line with plus markers is only income shocks, line with cross markers is only increase in uncertainty. For data sources see Figure 10. Lines are colored online.

[25]See, for example, Storesletten, Telmer, and Yaron (2004), Justiniano and Primiceri (2008), Bloom (2009), Bayer, Luetticke, Pham-Dao, and Tjaden (2019), or Fernández-Villaverde, Guerrón-Quintana, Rubio-Ramirez, and Uribe (1986).

[26]The full list of parameters can be found in Appendix Table A.10.

discussed in Section 3.4, the uncertainty effect stimulates the intensive margin. Given the strong reduction of the intensive car purchase margin observed in the data, the introduction of uncertainty shocks therefore makes it even more important to allow for wealth shocks and long-run risk during the Great Recession (because these shocks lead adjusting households to reduce the size of cars). The additional consideration of the intensive margin, therefore, shows that, while uncertainty might have mattered during the GR, increasing uncertainty in isolation cannot explain all aspects of household choices. In Section S5 of the Appendix, we discuss further the impact of uncertainty for wealth and negative income skewness shocks. The former generates an additional extensive margin decline, the latter increase the intensive margin decline, but reduce the response of the extensive margin.

5.3. *Cash for Clunkers*

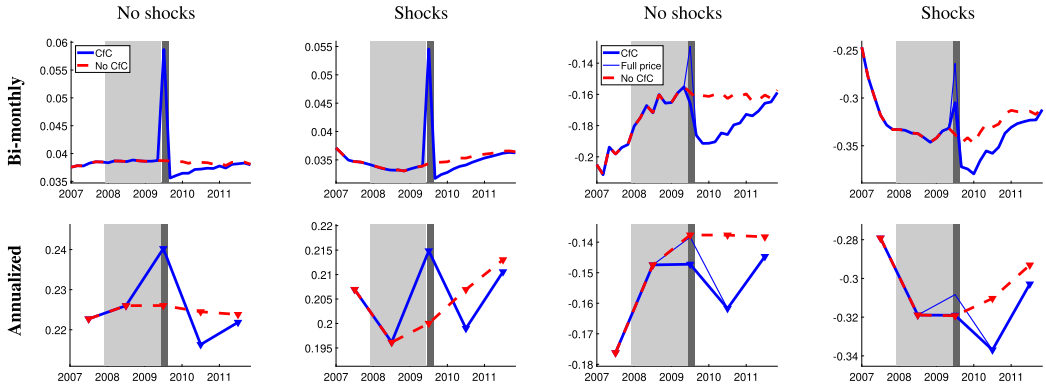
In 2009, the Obama Administration enacted a program to support the automotive sector, the Car Allowance Rebate System, more commonly known as Cash for Clunkers (CfC). Under this stimulus policy, the government provided $3 billion of subsidies worth $3500 to $4500 per household purchasing new cars and trading in an old vehicle, fulfilling certain age and environmental criteria. In empirical analyses, Mian and Sufi (2012), Hoekstra, Puller, and West (2017), and Green, Melzer, Parker, and Rojas (2020) find that this program significantly stimulated car purchases while subsidies were available but mainly through altering the timing of purchases rather than by spurring additional purchases; that the policy design implied a decline in the value of car purchases; and that household liquidity constraints interacted with policy's effectiveness.

We now introduce CfC in our life-cycle model. The short duration of the program, July 1, 2009, to August 24, 2009, makes our annual model unsuitable for examining this policy. Instead, we simulate a bimonthly parametrization of the model. The policy is modeled as a two- state Markov process, where switching to the policy is a zero probability event, but households understand that once the policy is introduced, it is a time limited state. During CfC, a fraction π of households receive a $\varpi\%$ subsidy on car purchases subject to car spending not exceeding $\overline{D}$ (see Section S6 of the Appendix for details). We calibrate the policy to have an expected duration of two periods, as the program was initially scheduled to end in November. The size of the subsidy, ϖ, is chosen to target a 10% subsidy on the value of a purchase, in line with the data. $\overline{D}$ is set so that eligible households make car

TABLE VII

BIMONTHLY CASH FOR CLUNKERS CALIBRATION.

	Value	Source
Parameters		
Percentage of households eligible for Cash for Clunkers	12.7	
Discount on car stock (ϖ)	0.036	
Max car threshold (2-month perm. income) ($\overline{D}$)	6.3	
Probability of Cash for Clunkers continuing	0.5	Duration: July–Nov
Targets		
Policy cost as a share of 2008 car expenditure	1.0	$3bn prog. cost
Effective discount on a new car purchase	10.0	max discount:max price
Decline in value of purchase of eligible households	6.8	Hoekstra, Puller, and West (2017)



(a) share of hh purchasing car (c) log. value|purchase

FIGURE 21.—Cash for Clunkers: Extensive and Intensive Car Margins. Notes: Top row shows the results of the bimonthly model, the bottom row is the bimonthly model aggregated on a household basis to yearly averages. *No shocks* is a model without aggregate shocks, *Shocks* is the aggregate shocks from the data averaged across the year. The dashed line is without the policy intervention, the solid thick line is with the policy, calculated on a post subsidy household expenditure basis. The thin line is with the policy and includes the value of the subsidy. The light shaded area is the Great Recession, the dark shaded area is the duration of the Cash for Clunkers policy. Lines are colored online.

purchases that are 6.8% lower than similar control households during a 1-year window, which matches the quasiexperimental results of Hoekstra, Puller, and West (2017). The eligibility fraction is chosen to match the total size of the government subsidy relative to total car expenditure in 2008, which on new and used cars, was $2.9 billion, corresponding to a target of approximately 1%. Table VII summarizes the parametrization.

We simulate the bimonthly model with the CfC policy taking place in July 2009 for one period. As can be seen from Figure 21, panel (a), the policy results in a substantial increase in car purchases of around 2 percentage points during July 2009 and a fall in the value of cars purchased (panel (a)). Consistent with the empirical studies cited above, the increase in car spending during the subsidy period depresses subsequent car purchases so that a significant fraction of the purchases can be classified as a change in timing rather than additional purchases.

In the bottom row of Figure 21, we reaggregate the bimonthly data into annual variables. At the annual frequency, the effects of the CfC program are fairly modest, with a small increase in share of household adjusting and a small decline in the value of cars purchased relative to the decline due to aggregate shocks. Thus, while program is not neutral, quantitatively it matters little for our results.[27]

6. CONCLUSION

In this paper, we have shown how household choices can be used to draw inference on the shocks and beliefs of economic agents. Our approach focuses on spending on a large ticket durable good, cars, and shows that movements in its extensive and intensive margins may contain valuable information about what drives households' choices. We

[27]Appendix Figure A.21 presents the results for total car expenditure and the aggregate car stock. Table A.12 reports the additional car expenditure of the program under alternative policy designs.

build a mapping from observed consumption and savings choices to shocks and beliefs using a rich life-cycle model. We gain insights from the dynamics of aggregate spending patterns in the economy and from cohort-level patterns. This variability enables us to isolate shocks that are reflected not only in aggregate moments, but also in differences across generations and age groups.

We applied this methodology to unpack the shocks and beliefs of U.S. households during the GR. We document a rich set of empirical facts about consumption and savings patterns during this episode including the novel insight that the intensive car spending margin contracted significantly during the GR unlike in previous downturns. We argue that noncurrent-income shocks are important empirically and that cohort-level adjustment patterns indicate differential impact of the recession across generations. Through the lens of our model, we show that the empirical regularities can be explained by the combination of four different types of shocks: a large aggregate income shock, a decline in household wealth affecting mainly the middle-aged, higher costs of car loans, and a lower expected future life-cycle income growth.

This methodology can be used more generally in settings where information about choices at a disaggregated level and involving nontrivial nonconvex adjustment costs is available. For example, it would be of great interest to use it to look at housing choices. This framework can also be adopted to firm investment and labor hiring choices, which share important aspects with the consumer choice problem we have examined. It would equally be interesting to extend the methodology to a general equilibrium framework where pecuniary externalities through the price system would be present. Other interesting extensions could consider richer modeling of income processes, introducing features such as cross-agent differences in skills and education or frictional labor markets. We leave these for future research.

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