Credit Shocks and Equilibrium Dynamics in Consumer Durable Goods Markets

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Abstract

This paper studies the equilibrium dynamics arising in consumer durable goods markets in response to aggregate credit supply shocks. To this end, we develop a general-equilibrium model of durable consumption with heterogeneous households facing idiosyncratic income risk and borrowing constraints. Two novel features of our framework are that: 1) used durable goods trade on secondary markets at market-clearing prices; and 2) households endogenously choose when to scrap them. The model successfully matches several empirical patterns of U.S. car markets around the Great Recession that we document using a rich dataset on the prices of new and used vehicles as well as CEX data on households' vehicle replacement activity. After a negative credit shock (i.e., a tightening of the borrowing limit), debt-constrained households postpone the decision to scrap and upgrade their cars. The economy experiences a period of low resale prices for used cars, which reduces wealthy households' incentives to replace their cars, thereby decreasing new-car sales. We also use our framework to study the effects of aggregate income shocks, the role of cars as collateral, and to evaluate targeted fiscal stimulus policies such as the Car Allowance Rebate System in 2009 ("Cash for clunkers").

PRELIMINARY AND INCOMPLETE

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1 Introduction

This paper studies the equilibrium dynamics arising in consumer durable goods markets when households are hit by aggregate credit supply shocks. Expenditures on durable goods are a highly volatile and procyclical component of GDP. For instance, during the Great Recession, new car sales in the U.S. dropped from approximately 16 millions in 2007 to 11 millions in 2009, as Figure 1 displays. In this paper, we use micro data on vehicle prices and on households' vehicle replacement decisions, as well as a quantitative model of an economy with heterogeneous households, borrowing constraints, and equilibrium in durable goods markets, to propose a novel mechanism that links aggregate credit conditions to durable goods purchases. A tightening of credit supply induces borrowing-constrained, lower-income households to postpone their purchases of used cars, thereby decreasing used-car prices; in turn, the decline in used-car prices makes it more expensive for higher-income households to replace their used cars with new ones, thereby decreasing new-car sales.

The purchase of a car is a large financial commitment for most households and, thus, vehicle purchases are a large component of personal consumption expenditures on durable goods (around 40%). Moreover, secondary markets for cars are typically larger than the market for new cars: Gavazza, Lizzeri, and Roketskiy (2014) reports that in the U.S. there are approximately three used-car transactions for each new-car sale. Hence, households' decisions on when to sell (or to scrap) and upgrade their cars bear potentially important consequences for the aggregate economy. Furthermore, specific policy interventions such as the 2009 Cars Allowance Rebate System (commonly known as "Cash for clunkers") in the U.S. and a similar "Scrappage Scheme" in the U.K. suggest that understanding how these household decisions affect aggregate outcomes would be valuable from a policy perspective.

To analyze the behavior of U.S. car markets during the Great Recession, we combine data on new and used car prices obtained from the National Automobile Dealers Association (NADA), with household data from the Consumer Expenditure Survey (CEX). These datasets report several interesting patterns; specifically, we document that: 1) replacement accounts for at least 50 percent of new-vehicle sales; 2) the cost of replacing a used car with a new one increased dramatically during the Great Recession; 3) the cost of replacement increased during the Great Recession because used-car prices declined (and, thus,

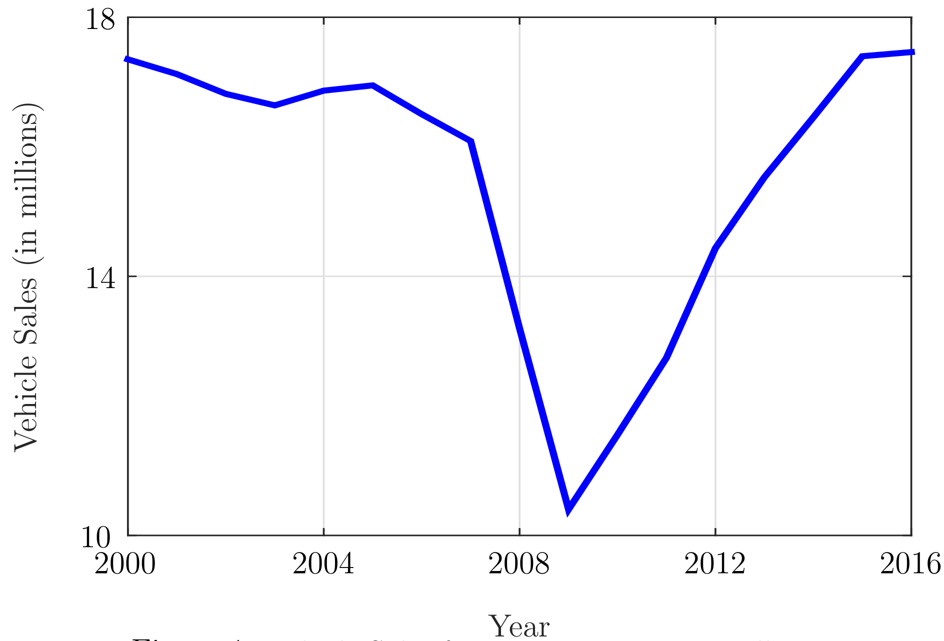

Figure 1: Vehicle Sales from 2000 to 2016, in millions.

not because new-car prices increased); 4) the fraction of households who replaced a used vehicle with a new one declined during the Great Recession; 5) the fraction of households purchasing a used vehicle declined during the Great Recession, thereby suggesting that the decline in used-car prices was more largely due to a decline in their demand, rather than to an increase in their supply; and 6) the number of vehicles scrapped declined sharply during the Great Recession.

These empirical patterns further motivate us to understand whether a general equilibrium model of durable consumption can account for these facts. Our model builds on an incomplete-markets framework with uninsurable income shocks and durable adjustment (e.g., Berger and Vavra, 2015; Guerrieri and Lorenzoni, 2017) by introducing two novel features: 1) durable goods differ in their quality, because of depreciation, and trade at equilibrium prices on secondary markets; and 2) households endogenously choose when to replace their depreciated durable goods and/or whether to scrap them.

We calibrate the model to replicate several key features of car markets and car ownership in the U.S., as well as empirical targets about household income and wealth. Our economy features a strong negative correlation between wealth and car age, consistent with empirical evidence that Gavazza, Lizzeri, and Roketskiy (2014) report. Wealthier households tend to always own relatively new cars; when their cars depreciate, they sell them and replace them with newer ones. Low-wealth households tend to own older cars, scrapping them when they become really old and replacing them with intermediate-age used cars. Thus, secondary markets play the fundamental role of reallocating used cars from higher-income households to lower-income ones.

We consider a shock that permanently tightens credit limits. Several papers propose this shock as a plausible exogenous source of macroeconomic dynamics consistent with the experience of the Great Recession (e.g., Guerrieri and Lorenzoni, 2017; Huo and Ríos-Rull, 2016). A tighter borrowing constraint leads to additional precautionary savings. If bonds and durables are good substitutes, as is typically the case in models that do not account for equilibrium prices of durables, households respond to the credit shock by accumulating both liquid wealth and durables, leading to a counterfactual increase in new durable purchases. A decrease in real interest rates due to precautionary savings makes it particularly attractive for wealthier households to substitute away from bonds towards durables in their saving decisions.

In contrast, in our model the timing of replacement and equilibrium dynamics in secondary markets are crucial to understand the propagation of the credit shock and to trigger a decrease in durable purchases after a credit tightening. Low-wealth households, for whom the borrowing constraints becomes tighter, decide to postpone the scrappage of their old vehicles. As they are natural buyers of moderately-used cars, low-wealth households' decision leads to a decrease in the demand of moderately-used cars, thereby lowering their price. Hence, high-wealth households, who normally supply moderately-used cars as they replace them with new ones, suffer an increase in the replacement cost of their vehicles; thus, they decide to postpone their purchases of new vehicles. Hence, the equilibrium features low used-car prices and low new-car sales following the credit shock. Even though the change in the borrowing limits does not directly affect wealthy households, they are indirectly induced to postpone their new-car purchases by equilibrium dynamics on secondary markets.

Our rich framework allows us to study several interest interactions between car markets and the macroeconomy. We first consider the effects of aggregate income shocks, finding that they reinforce our mechanism. Next, we extend our model to analyze the role of vehicles as collateral. Finally, we evaluate the effects of targeted fiscal stimulus, in the form of car replacement subsidies. We find that this type of policy depresses trading in secondary markets, leading to a dampening of its overall effect on demand for new durables.

The rest of the paper is organized as follows. Section 2 highlights our contribution to the literature. Section 3 documents the key empirical patterns on vehicle prices and households' vehicle replacement during the Great Recession. Section 4 introduces our model, which we calibrate and we use to perform numerical simulations in Section 5. Section 6 concludes.

2 Related Literature

This paper contributes to several strands of literature. First, since at least Mankiw (1982) and Bernanke (1985), understanding the dynamics of expenditures on durable goods has been a key question in macroeconomics, as they represent a large and highly volatile component of consumption. Starting from Caballero (1993) and Eberly (1994), the literature has focused on models of durables adjustment in the presence of frictions, such as fixed adjustment costs, that lead to inaction and lumpy adjustment. Recently, Kaplan and Violante (2014), Berger and Vavra (2015) and Guerrieri and Lorenzoni (2017) embed households' adjustment/trading costs into a Bewley (1986)-Aiyagari (1994) general-equilibrium framework with uninsurable idiosyncratic risk.[1] Caplin and Leahy (2006) emphasize the importance of imposing equilibrium in durable goods markets with fixed adjustment costs in order to explain the dynamic behavior of durable purchases following aggregate shocks. We build on this theoretical insight by developing a rich quantitative general equilibrium framework to study the role of equilibrium dynamics in durable goods markets for the propagation of credit shocks. Our framework contributes to the literature on adjustment of durable goods by enriching the standard incomplete-markets framework with a vintage structure for durables, imposing equilibrium in secondary markets and explicitly modeling households' scrappage decisions. These novel features matter for the aggregate dynamics

[1] Relatedly, Huo and Ríos-Rull (2016) and Favilukis, Ludvigson, and Van Nieuwerburgh (2017) study the effects of financial shocks in a model of housing with incomplete markets.

of durable good markets, in particular after a shock that affects the availability of credit.

Specifically, a novel contribution of this paper is to show that market clearing in used-car markets implies that the degree of irreversibility (or adjustment costs) when trading durables is an equilibrium outcome that varies with the aggregate state of the economy, as opposed to an exogenous parameter. This feature of our model is essential to explain the increase in the replacement cost of cars that we document in micro data around the Great Recession. Our focus on shocks to credit supply in the context of our model is consistent with the empirical analysis of Benmelech, Meisenzahl, and Ramcharan (Forthcoming), according to which a decrease in supply of car loans explains a large fraction of the reduction in car purchases during the Great Recession.[2]

Second, the mechanism that we highlight in this paper shares some features with those in other papers in which agents are simultaneously buying and selling assets. Stein (1995) develops an equilibrium model of the housing market in which small shocks to house prices get amplified through households' down payment constraints that reduce housing demand and, thus, further depress prices. Anenberg and Bayer (2013) shows that the cost of simultaneously holding two homes varies endogenously over the cycle and is the main driver of fluctuations in transaction volume. Hence, we contribute to this literature by showing that a similar mechanism applies to other durable good markets, such as car markets, where the main motive for trade is the depreciation of the the asset, rather than the changing preferences of the asset owners (as in housing markets).

Third, the theoretical literature on consumer durable goods has investigated the role of secondary markets in allocating new and used goods (see, among others, Rust, 1985; Anderson and Ginsburgh, 1994; Waldman, 1997; Hendel and Lizzeri, 1999). Particularly related are the empirical/quantitative contributions of Adda and Cooper (2000), which studies government subsidies to the replacement of old cars with new ones in France, finding that they stimulate new-vehicle sales in the short run, but reduce them in the medium-run trough

[2]Our paper is also related to: Adda and Cooper (2006), which studies the aggregate dynamics of car purchases in a partial-equilibrium model of replacement and develops a version of the model with secondary markets; Oh (2017), which studies durable replacement and second-hand markets in a representative-agent business-cycle model; Rampini (2016), which analyzes the role of durability in determining how easy it is to finance purchases of durable goods in a model with collateral constraints; Chafwehé (2017), which considers equilibrium in secondary markets for durables in a stationary partial-equilibrium model with incomplete markets.

changes in the cross-sectional distribution of car ages; Stolyarov (2002), which investigates resale rates across different car vintages; and Gavazza, Lizzeri, and Roketskiy (2014), which provides a quantitative analysis of the allocative and welfare role of secondary markets. We contribute to this literature by introducing idiosyncratic income risk and trading in non-contingent bonds. This allows us to study the role of borrowing constraints for durable upgrading decisions and to highlight the real-option aspects of durable purchases: when buying a car, households take into account the correlation between their income opportunities and the possibility to resell their cars on the secondary market. Moreover, we consider aggregate shocks, including an aggregate contraction in the availability of credit, and study the equilibrium interactions between markets for durables and the rest of the economy.

Finally, the paper contributes to the literature that studies capital replacement and, more generally, markets for capital goods. Among other papers, Cooper and Haltiwanger (1993) shows that the process of costly replacement of depreciated machines can create endogenous fluctuations in productivity and output of a single producer; Cooper, Haltiwanger, and Power (1999) explores aggregate investment fluctuations due to plants' discrete replacement of their capital stock; and Cho and Rust (2008) studies the car replacement policy of auto rental companies. However, none of these papers consider equilibrium in the market for used capital in presence of aggregate dynamics and, thus, fluctuations due to endogenous changes in the resale price of capital. Hence, our paper complements the recent work of Lanteri (2017), which focuses on capital reallocation in an equilibrium model of partially irreversible investment with endogenous resale price of capital, whereas we focus on consumer durables.

3 Data and Empirical Patterns

The goal of this section is to document the key empirical fact of this paper on the cost of replacement during the Great Recession, as well as some complementary patterns on the importance of replacement sales for primary car markets and on household adjustment of their vehicle stock.

3.1 Data sources

We use two main data sources. The first one is a rich dataset on new and used car prices obtained from the National Automobile Dealers Association. The second one is the Consumer Expenditure Survey. We now describe these datasets in more detail.

NADA Prices. This dataset is an unbalanced panel, reporting historic values of different vintages of vehicle models. It includes two price series—retail and trade-in—for 10 U.S. geographic regions—California, Central Desert, Eastern, Midwest, Mountain, New England, Northwest, Southeast, and Southwest.[3] Retail prices represent "the typical selling price" of a transaction between a dealer (as a seller) and a user (as a buyer) for a used vehicle, based on clean conditions; trade-in prices represent "the typical price for a vehicle at trade-in"—i.e., a transaction in which a buyer sells an older model to a dealer, using the proceeds as partial payment on a new purchase. NADA prices are updated monthly, based on transaction records at dealerships. We obtained these price data for the month of July for every year from 2003 to 2012.

CEX. This is a quarterly survey of U.S. households that, among other things, reports detailed information about households' vehicles at the time of the interview, such as: the model; the age; whether it is owned or leased; the acquisition date (although it is often missing); and whether it was acquired new or used.

We use these data from 2003 to 2012 (for comparability of our NADA prices mentioned above) to compute some aggregate statistics on households' vehicle holdings and transactions. More specifically, the CEX surveys are quarterly, with most households interviewed for four quarters. We define a vehicle replacement when we observe that a household disposes of a vehicle that the household previously possessed (either owned or leased) and the same household acquires another vehicle, even if these two events happen in different quarters. This definition mechanically implies that households surveyed for fewer quarter are less likely to replace a vehicle than households surveyed for all four quarters. Hence, we restrict our analysis to households surveyed for at least three quarters, computing our statistics at the annual level.

[3] The States included in each region are available at the following link: http://www.nada.com/b2b/Portals/0/assets/pdf/NADA_Regions%20Datasheet_2013.pdf.

While the CEX data are useful to understand households' decisions regarding their vehicles, we should point out that their use poses some challenges. Most importantly, the sample size of each CEX survey is not large—on average, approximately 7,000 households per quarterly survey; since we further restrict our analysis to households surveyed for at least three quarters, we have approximately 5,600 households per year. Moreover, households trade their vehicles infrequently, which implies that the aggregate statistics that we construct based on these CEX data will be noisy.[4]

We also complement these two main datasets with aggregate data on the U.S. car stock obtained from the Bureau of Transportation Statistics.

3.2 Empirical patterns

These datasets reveal interesting patterns on the role of replacement for new-car sales, and how replacement varied during the Great Recession relative to the previous years.

1) Replacement sales account for a large share of new car sales.

The CEX data are well-suited for understanding the role of replacement sales for primary markets. Figure 2 displays the fraction of households who replaced used vehicles with new ones as a fraction of all households who acquired new vehicles. It shows that replacement accounts for approximately 50 percent of households' purchases of new vehicles and that this fraction declined slightly during 2008-2009. Hence, this large cross-sectional share (which, for the reasons that we recounted above, should be an underestimate of the true share) suggests that a decline of replacement can have a first-order effect on new-car sales.

2) The cost of replacement spiked during the Great Recession.

Figure 3 displays perhaps the most striking among the empirical patterns that we report in this Section. Specifically, we use NADA prices to compute the replacement cost of new vehicles, calculated as the difference between the retail price of a new (i.e., age-0) vehicle model and the four-year-old trade-in price of the same vehicle model. The four panels of Figure 3 display these replacement costs for some of the most popular vehicles in the U.S.:

[4]Households' vehicle sales most likely follow vehicle purchases, rather than vice versa. Hence, our procedure could miss households' replacement when households purchase a vehicle in the last quarter in which they are surveyed (since the subsequent sales are not recorded).

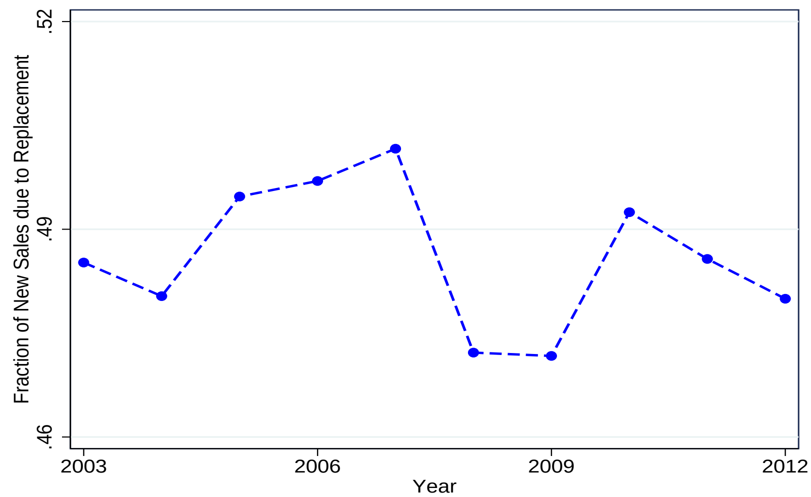

Figure 2: Fraction of households with cars who replaced at least one used vehicle with a new one during 2003-2012.

the Honda Civic (top-left panel), the Ford Taurus (top-right panel), the Toyota Camry (bottom-left panel), and the Honda Accord (bottom-right panel).[5] All these panels show that the cost of replacing a used car with a new one increased during the Great Recession, spiking up in 2009 by approximately 20 percent relative to the previous few years.

3) The cost of replacement spiked because used-vehicle prices collapsed.

Figure 4 highlights the key reason why the cost of replacement increased during the Great Recession. Its four panels display the (detrended) prices of a new and of a 4-year-old vehicle for the same models for which we calculated the cost of replacement of Figure 3. These panels show that, while new-car prices were quite stable throughout the 2003-2012 period, used-car prices were substantially more volatile and, most notably, dropped remarkably during the Great Recession, by approximately 15 percent.

4) Vehicle replacement declined.

How did households respond to this increase in the cost of replacement? The CEX can help us to provide some insights into these questions. More specifically, we use these data to calculate the fraction of households who replaced a used vehicle with a new one.

[5] We use prices in the Eastern region in the figures, but we obtained the same results when using prices from other regions, or we average prices across regions.

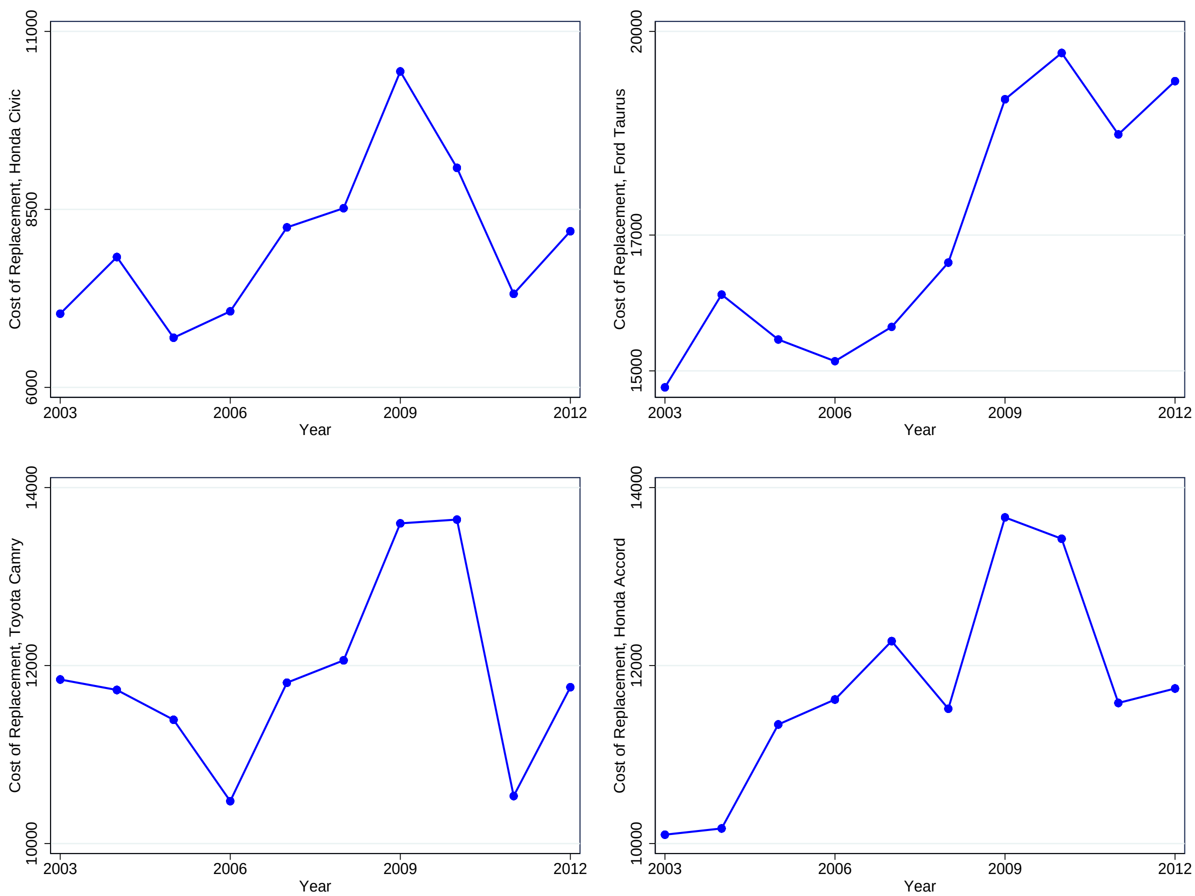

Figure 3: The figure displays the cost of replacing a 4-year old vehicle with a new one of the same model during the period 2003-2012 for some popular models: the Honda Civic (top-left panel), the Ford Taurus (top-right panel), the Toyota Camry (bottom-left panel), and the Honda Accord (bottom-right panel).

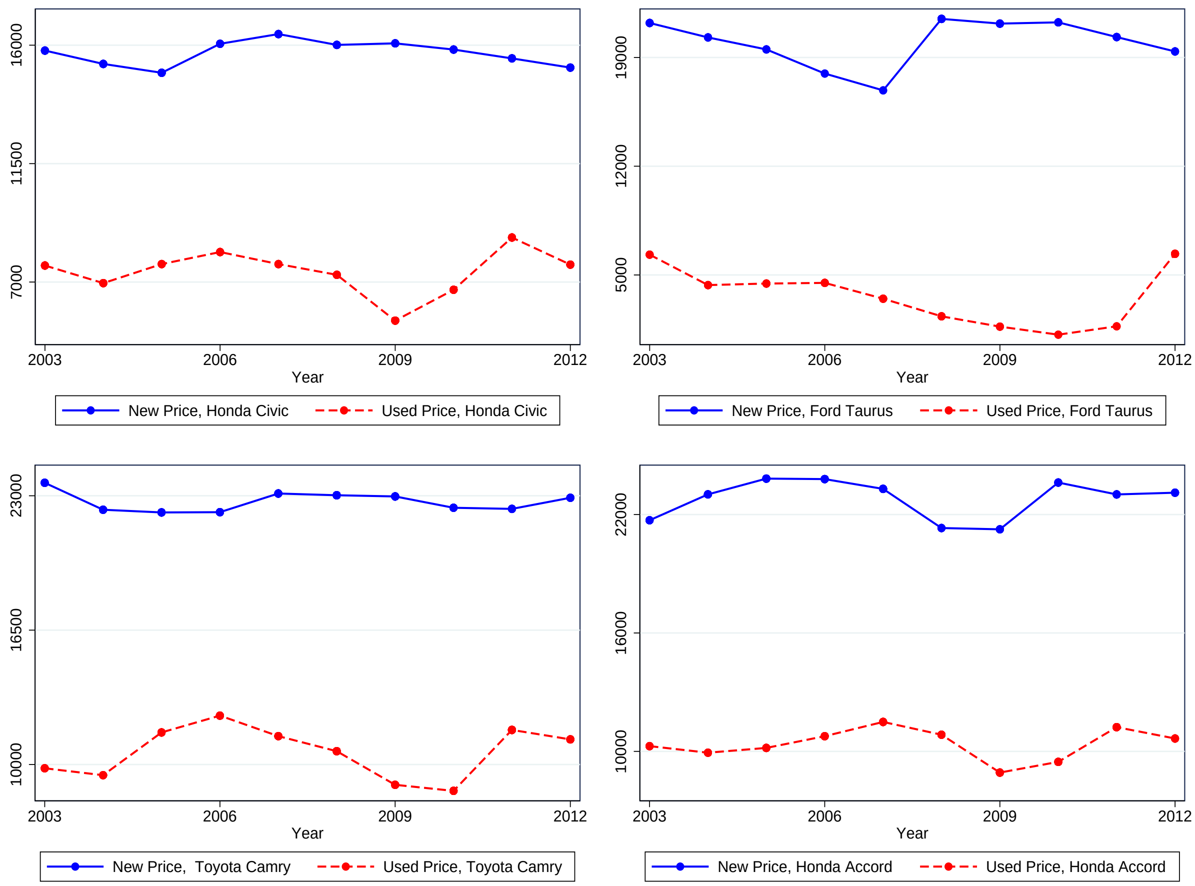

Figure 4: The figure displays the detrended prices of new and used (i.e., 4-year old) vehicles during the period 2003-2012 for some popular models: the Honda Civic (top-left panel), the Ford Taurus (top-right panel), the Toyota Camry (bottom-left panel), and the Honda Accord (bottom-right panel).

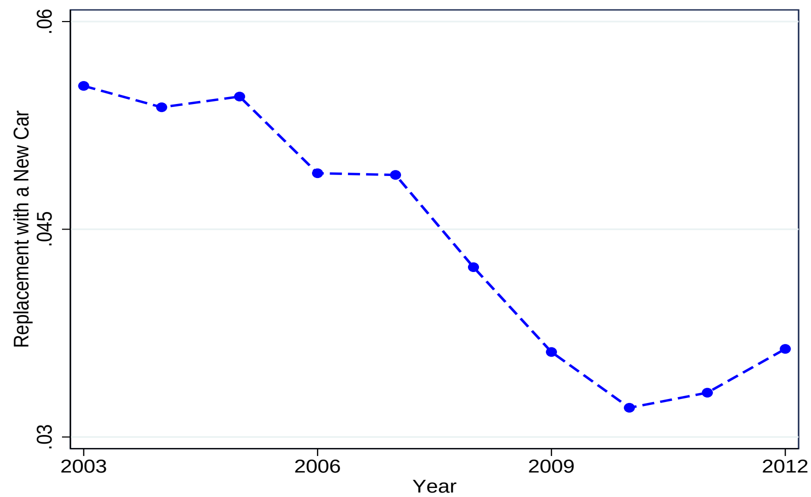

Figure 5: Fraction of households with cars who replaced at least one used vehicle with a new one during 2003-2012.

Figure 5 displays this fraction for each year during 2003-2012. It shows that the fraction of households who replaced their used vehicles with new ones bottomed during the Great Depression, thus exactly when the cost of replacement spiked.

5) The decline in used-car prices was due to a decline in their demand.

We can further use the CEX data to investigate the behavior of households in secondary car markets, which can shed some light on the decline of used-car prices documented in Figure 4. To this goal, we calculate the fraction of households who replaced a used, old car with another used, but younger, car. The left panel of Figure 6 shows that this fraction *declined* during the Great Recession, thereby suggesting that a decline in the demand for used cars was perhaps the main reason for the decline in used-car prices, rather than perhaps an increase in their supply.[6] The right panel of Figure 6 further reinforces the idea that the increase in the supply of used cars during the Great Recession was likely modest, by displaying the fraction of households who sold cars but did not simultaneously purchased another one. While this fraction increased during the Great Recession, the magnitude of the overall increase from 2007 to 2010 was modest (approximately .09 percent) and, thus,

[6]Figure 5 and the left panel of Figure 6 together suggest that the decline in used-car prices did not trigger a substitution from new cars to lightly-used (i.e., pre-owned, in the language of car markets) vehicles.

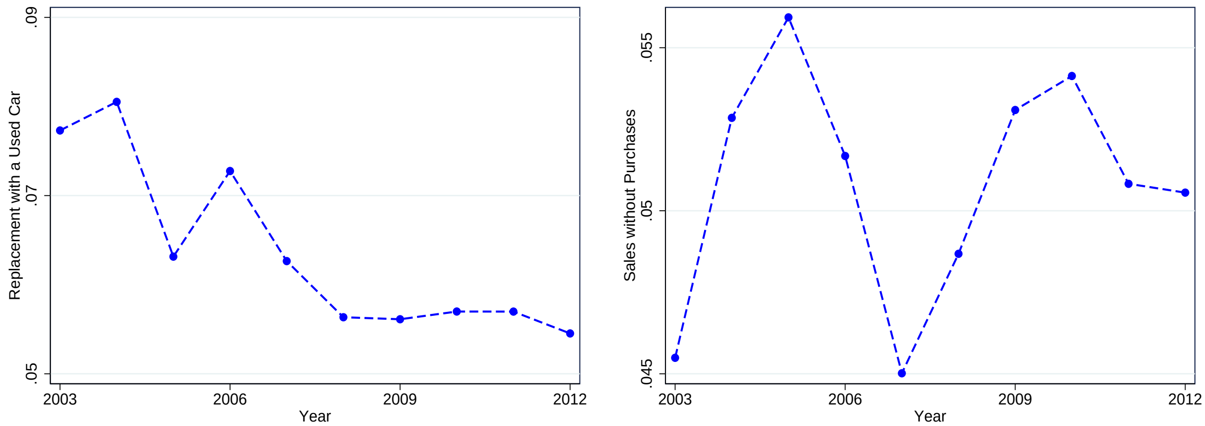

Figure 6: The left panel displays the fraction of households with cars who replaced at least one used vehicle with another used one during 2003-2012. The right panel displays the fraction of households with cars who disposed of a used vehicle without acquiring another one during 2003-2012.

it is smaller than the decline in replacement purchases documented in the left panel of Figure 6; more generally, the level that it reached during those years was lower than the level that it reached pre-2008, while replacement purchases clearly bottomed during the Great Recession.

6) Vehicle scrappage declined.

Finally, Figure 7 displays the total number of vehicles scrapped in the U.S., as reported by the Bureau of Transportation Statistics. Consistent with all the previous patterns, the figure shows that vehicle scrappage bottomed during the Great Recession, declining by approximately 12 percent in 2010 relative to 2008-2009. Thus, this sharp decline suggests that low-income households held on longer to their vehicles during the Great Recession relative to previous years, thereby delaying their replacement and depressing used-car demand.

Overall, these empirical patterns seem to suggest a novel narrative for the decline in new-vehicle sales during the Great Recession. Specifically, used-car prices declined because the demand for used cars declined. In turn, the decline of used car prices increased the cost of replacing used cars with new ones, thereby reducing the demand for new cars. Thus, in the next Section we formalize this idea in an Bewley (1986) economy in which households can

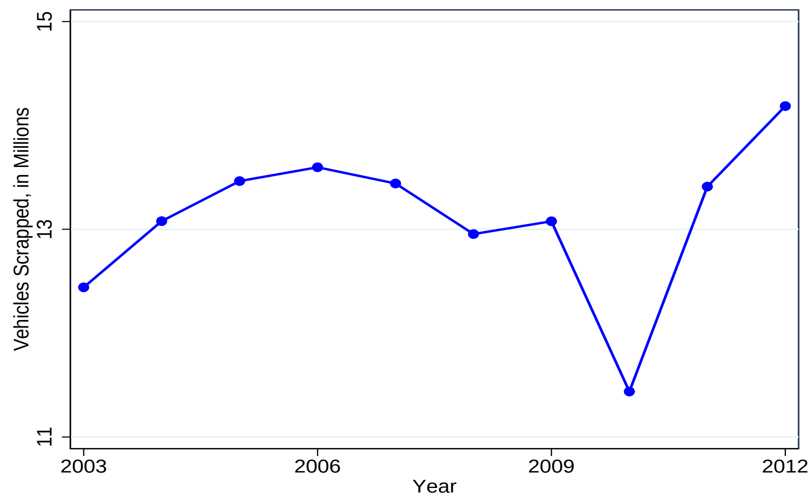

Figure 7: Number of vehicles scrapped during 2003-2012.

acquire durable goods of different vintages, subject to a borrowing constraint. We show that a tightening of the borrowing limit induces a larger fraction of constrained, lower-income households to decrease their demand for used cars, thereby triggering the decrease in secondary-market prices that makes it more expensive for higher-income households to replace their used cars with new ones and, thus, decreases new-car sales.

4 Model

In this section, we build a framework to study households' durable adjustment when their durables depreciate over time and they face idiosyncratic income risk. Households consume both a non-durable consumption good and a durable good (i.e., a car). The key features of our framework are that depreciation of the durables implies that different vintages are imperfect substitutes, with newer goods yielding higher utility; households can trade these vintages in secondary markets, or scrap them. We first describe the stationary equilibrium of the model, in which all aggregates and prices are constant over time. In the next section, we will consider the effects of aggregate shocks on the dynamics of our model economy.

4.1 Environment

Preferences. A continuum of unit-mass of infinitely-lived households, indexed by i, has preferences represented by a utility function defined over infinite sequences of non-durable consumption c_{it} and durable consumption (i.e., car services) d_{it}:

$$\mathrm{E}_0 \sum_{t=0}^{\infty} \beta^t u(c_{it}, d_{it}), \tag{1}$$

where E_0 is the expectation operator, $\beta \in (0, 1)$ is the discount factor, and $u(c_{it}, d_{it})$ is the per-period utility function.

Durable Goods. We consider a finite number N of different car qualities q_n, with $q_1 > q_2 > ... > q_N$. New cars are of quality q_1 and cars depreciate stochastically over time. Specifically, a car of quality $n = 1, ..., N-1$ becomes a car of quality $n+1$ in the following period with probability π_n.

Agents own at most one car.[7] Hence, there are $N + 1$ possible car ownership statuses, the first N corresponding to the N car qualities, and the $N + 1$th corresponding to the no-car ownership status. Households' utilities from durables d_{it} equal q_n if they own a car of quality n, and θ_i if they do not own a car; θ_i is a household-specific type, constant over time, drawn from a distribution $F_\theta(\theta)$, determining household i's relative preference for living without a car. Hence, we allow for ex-ante heterogeneity in the necessity of a car, for example because of heterogeneous distance of households' residence from their workplaces or heterogeneous quality of public transport in the cities where they live, which we take as exogenous.

Technology. In every period, each household receives an idiosyncratic stochastic income w_{it} (denominated in units of the non-durable good), which evolves over time according to a Markov process with transition $F_w(w_{it}, w_{i,t+1})$.

New cars are produced by perfectly-competitive firms using a linear technology that takes the non-durable good as the only input. Let p_{q_1} be the constant marginal cost of

[7] Computational simplicity prompts us to abstract from the possibility of owning multiple vehicles. While several U.S. households own more than one vehicle, multiple vehicles do not seem to affect the main mechanism that we focus on —i.e., delayed replacement.

new cars in terms of non-durables. Perfectly-competitive firms operate a linear scrappage technology that gives p_{q_N} units of output good for each scrapped car, regardless of its age. A car of quality q_N must be exogenously scrapped in the following period.

Markets. The timing of the model is as follows. At the beginning of each period, households receive their income and observe the depreciation shock to their durables. After that, they make trading, production, consumption and saving decisions. We take the non-durable good as the numeraire of our economy.

Households can trade their cars at equilibrium prices, subject to transaction costs. While we recount above that technology determines p_{q_1} and p_{q_N}, cars of qualities $n = 2, ..., N-1$ trade at their market-clearing prices p_{q_n}. For notational convenience, $p_{q_{N+1}} = 0$.

Households can borrow and save by trading one-period non-contingent bonds $b_{i,t+1}$, priced at p_b, subject to a borrowing constraint

$$b_{i,t+1} \geq \phi, \tag{2}$$

where $\phi \leq 0$ is the debt limit.

Government. The government issues a constant level of non-contingent bonds b_G and imposes lump-sum taxes T on all households to finance interest payments on its debt. Hence, the budget constraint of the government is

$$b_G(1 - p_b) = T. \tag{3}$$

In Section 5, we will also study a deficit-financed stimulus policy that subsidizes households replacement of their cars.

4.2 Household Problem

Households maximize their utility function (1), subject to the borrowing limit (2) and the following budget constraint:

$$c_{it} + p_{\tilde{q}_{it}} + p_b b_{i,t+1} + T = w_{it} + p_{q_{it}} - \lambda\left(p_{q_{it}}\right)\mathcal{I}\left(\tilde{q}_{it} \neq q_{it}\right) + b_{it}, \tag{4}$$

where $\tilde{q}_{it}$ is the car chosen for period t; and $\lambda(\cdot)$ is the vintage-specific transaction cost, which households pay if they trade their cars; and $\mathcal{I}(\tilde{q}_{it} \neq q_{it})$ is an indicator function equal to one when household i trades its car, and zero otherwise. The left-hand side of the budget (4) reports household expenditures: non-durable expenditures c_{it}, durable expenditures $p_{\tilde{q}_{it}}$ on car $\tilde{q}_{it}$, bond purchases $p_b b_{i,t+1}$, and lump-sum taxes T. The right-hand side reports household resources: income w_{it}, the proceeds $p_{q_{it}}$ of the sale of car q_{it}, net of transaction costs $\lambda(p_{q_{it}})$, and bond holdings b_{it}.

We now describe households' problem in recursive form. Let $V(b, w, q; \theta)$ be the value function of a household of type θ with bond holdings b, income w, and car of quality q. This function satisfies the following Bellman equation:

$$V(b, w, q; \theta) = \max_{c, b', \tilde{q}} u(c, d(\tilde{q}, \theta)) + \beta \mathrm{E}\left[V(b', w', q'; \theta) | \tilde{q}, w\right], \tag{5}$$

where the maximization is subject to the borrowing constraint (2), the budget constraint (4), as well as the stochastic transitions for income and car quality. The Bellman equation (5) makes it explicit that household preferences for durables depend on their type θ. Similarly, our notation highlights that households' chosen car quality $\tilde{q}$ could differ from the car quality q' that they own at the beginning of the following period because of depreciation.

The policy functions $b' = g_b(b, w, q; \theta)$ and $\tilde{q} = g_q(b, w, q; \theta)$ for future bond holdings and for car choice, respectively, solve the dynamic program (5).

4.3 Competitive Equilibrium

We now define the stationary competitive equilibrium of this economy. Let $m(b, w, q; \theta)$ be the beginning-of-period stationary cumulative distribution of households over individual states (i.e., bond holdings b, income w, and car quality q) and type θ.

Clearing in the bonds market requires:

$$\int g_b(b, w, q; \theta) dm(b, w, q; \theta) = b_G, \tag{6}$$

that is, the aggregate net supply of assets from households equals the level of government debt.

Clearing in the market for cars of quality q_1 requires:

$$\int \mathcal{I}(g_q(b,w,q;\theta)=q_1)dm(b,w,q;\theta)=\int dm(b,w,q_1;\theta)+x, \tag{7}$$

where x is aggregate production of new cars. The left-hand side is the aggregate demand for cars of quality q_1, which comes from all households who hold a car of quality q at the beginning of the period and whose policy function is to hold a car of quality equal to q_1 at the end of the period (thus, the indicator function $\mathcal{I}$ for their choices). The right-hand side is the aggregate supply of cars of quality $q=q_1$, which comes from new production and from existing cars of quality q_1 which did not depreciate from the previous period.

Clearing in the market for cars of a given quality $\bar{q}=2,..N-1$ requires:

$$\int \mathcal{I}(g_s(b,w,q;\theta)=\bar{q})dm(b,w,q;\theta)\leq\int dm(b,w,\bar{q};\theta). \tag{8}$$

The left-hand side is the aggregate demand for cars of a given quality $\bar{q}$, which comes from all households who hold a car of quality q at the beginning of the period and whose policy function is to hold a car of quality $\bar{q}$ at the end of the period (thus, the indicator function $\mathcal{I}$ for their choices). The right-hand side is the aggregate supply of cars of quality $\bar{q}$. If no cars of quality $\bar{q}$ are scrapped in equilibrium, then inequality (8) holds with the equal sign; if some cars cars of quality $\bar{q}$ are scrapped in equilibrium, then (8) holds with strict inequality, and $p_{\bar{q}}=p_{q_N}$, that is, they trade at the scrappage value.

Definition 1 *A* ***Recursive Stationary Competitive Equilibrium*** *is: (i) A value function V and associated policy functions g_b and g_q; (ii) A stationary distribution m; and (iii) a vector of prices $(p_b,p_{q_2},...,p_{q_{N-1}})$; such that:*

1. *V satisfies the Bellman equation (5);*

2. *The stationary distribution m is consistent with the type distribution F_θ, the exogenous income and car depreciation shocks, as well as with household policy functions g_b and g_q; and*

3. The bond market and car markets clear, that is, equations (6), (7) and (8) hold.

5 Quantitative Analyses

In this section we discuss the calibration of our model and we describe some key properties of the stationary equilibrium. Moreover, we use the parametrized model to study the effects of credit shocks—i.e., a tightening of the borrowing limit—as well as aggregate income shocks. We also consider cars as collateral and we use our model to evaluate a replacement stimulus policy.

5.1 Calibration

We now describe our choices of functional forms and parameter values for: preferences, income process, credit market, car production and trading. Table 1 reports the numerical values of the parameters.

Preferences. We follow Berger and Vavra (2015) and choose the following per-period utility function: $u(c_{it}, d_{it}) = \frac{\left(c_{it}^{\alpha} d_{it}^{1-\alpha}\right)^{1-\gamma}}{1-\gamma}$.

We set $\alpha = 0.95$ to match the expenditure share on vehicles, which is approximately five percent, according to Personal Consumption Expenditure data from the U.S. Bureau of Economic Analysis. We set the curvature of the per-period utility $\gamma = 2$, which is within the range of those that Aiyagari (1994) considers.

A period in the model coincides with a year, consistently with the frequency of our data. Hence, we set $\beta = 0.94$, which, jointly with the calibrated degree of idiosyncratic risk, discussed below, delivers a real interest rate of approximately three percent.

Income Process. We choose a parsimonious parametrization of the income shock, specifically an AR(1) process in logs: $\log(w_{i,t+1}) = \rho \log(w_{i,t}) + \epsilon_{i,t+1}$. We set the persistence of the process to $\rho = 0.9$; the innovations $\epsilon_{i,t+1}$ are i.i.d. across households and over time, normally distributed with mean $-0.5\sigma_w^2$ and standard deviation $\sigma_\epsilon = 0.2$, following the estimates by Flodén and Lindé (2001) using PSID data. Thus, the mean income equals one—i.e., a normalization—and the cross-sectional standard deviation equals $\sigma_w = \frac{\sigma_\epsilon}{\sqrt{1-\rho^2}}$.

We further discretize this process with a three-valued Markov chain, using the method developed by Rouwenhorst (1995).

Credit Market. Following the procedure proposed by Guerrieri and Lorenzoni (2017), we set the borrowing constraint ϕ and the level of the government debt to match two moments from Flow of Funds data before the financial crisis, namely the ratio of consumer credit to GDP (.18) and the ratio of liquid assets to GDP (1.78).

Cars. A large number of vintages (and, thus, a large number of endogenous prices) makes computation cumbersome, in the context of a model with rich heterogeneity and aggregate dynamics. Hence, we choose a parsimonious structure for car qualities by imposing $N = 4$, and we refer to quality-q_1 cars as high-quality cars; to quality-q_2 cars as medium-quality ones; to quality-q_3 as low-quality ones; and to quality-q_4 cars as scrap cars. Moreover, we choose the numerical values of the depreciation probabilities and of the car qualities to match key features of car markets, such as the average car lifetime and the average price depreciation.

Specifically, we set the depreciation probabilities as follows: $\pi_1 = 1/3$, which implies that, on average, high-quality cars depreciate after three years, thereby triggering an increase in their volume of trade, consistent with that observed in the data Stolyarov (2002); $\pi_2 = 1/10$, which implies that, on average, cars are of medium quality for 10 years; and $\pi_3 = 1/2$. These depreciation parameters allow our model to closely match the average lifetime of cars, approximately equal to 15 years, as well as the average scrappage rate of 15-year-old cars, equal to approximately 10 percent, both of which Jacobsen and van Benthem (2015) reports.

We normalize $q_1 = 1$; we set $q_2 = 0.3$, $q_3 = 0.1$, and $q_4 = 0$. This quality levels, along with the aforementioned depreciation probabilities, allow the model to match closely the price decline of a three-year old car reported in Jacobsen and van Benthem (2015).

Moreover, we parametrize the type distribution determining the utility of not owning any car to a two-type distribution, with values $\theta_i \in \{0, 1\}$, with probabilities 0.9 and 0.1, respectively. These values imply that households with $\theta_i = 1$ choose not to own a car, whereas households with $\theta_i = 0$ choose to own one, and their frequencies allow the model to match the fraction of households with no car, which is approximately ten percent in the

Table 1: Calibration

Parameter	Value	Parameter	Value
α	0.95	π_3	1/2
β	0.94	δ_1	0
γ	2	δ_2	0.7
ρ	0.9	δ_3	0.67
σ_ϵ	0.2	θ	$\in \{0,1\}$
ϕ	-1	p_{q_1}	0.45
b_G	1.5	p_{q_4}	0.036
π_1	1/3	λ_0	0.03
π_2	1/10	λ_1	0.15

2000-2010 American Community Survey.

We further set the marginal cost of producing new cars to 0.45 in order to match the ratio of average new car prices to household income. We set the scrappage value p_{q_N} to 0.036 to match the value of cars older than 15 years that Jacobsen and van Benthem (2015) report. We verify in our numerical solutions that, at this scrappage value, there is excess supply of quality-q_3 cars. Hence, quality-q_3 cars trade at p_{q_N}, implying that we only need to endogenously solve for p_{q_2}.

Finally, we parametrize the transaction cost function to feature a fixed cost and a cost proportional to the car value—i.e., $\lambda_0 + \lambda_1 p_{q_n}$. We use the NADA prices to measure these transaction costs as the difference between retail and trade-in prices and estimate $\lambda_0 = 0.03$ and $\lambda_1 = 0.15$.

5.2 Car Replacement in Stationary Equilibrium

We now describe some key properties of the stationary equilibrium of our model. The majority of households, around 65%, own a used car of quality q_2. Furthermore, because of complementarity between non-durable consumption level and car quality in utility, the ergodic distribution of the model features a negative correlation between wealth and car quality (or age). Rich households upgrade their cars fast: as soon as their new cars depreciate, they trade them to purchase new ones. On the other hand, poor households tend to own cars of lower quality. As a consequence, households close to the borrowing limit are often close to the scrappage margin, typically replacing cars of quality q_3 or q_4 with cars of quality q_2.

In Figure 8, we illustrate this property of the model by plotting the thresholds for upgrading from q_3 to q_2 (blue line with circles) and from q_2 to q_1 (red line with crosses). These thresholds represent the minimum level of liquid wealth (on the y axis), such that agents with a certain level of income (x axis) decide to upgrade their car. For instance, above the red line, owners of used cars upgrade to a new car; below the red line, they keep their used car for at least one more period.

Notice that the threshold for upgrading from q_3 to q_2 coincides with the borrowing limit (black dashed line) for households with middle and high income. Hence, as soon as these cars depreciate to quality q_3, households endogenously scrap them and replace them with cars of quality q_2. However, households with low income and high debt (close to or at the borrowing limit) do not scrap their low-quality cars: the threshold for scrapping and upgrading to q_2 is higher than the borrowing limit. These low-income, borrowing-constrained households try to first deleverage to move away from the constraint and only then upgrade their car.

To gain further insight on the rich households dynamics implied by the model, we simulate a single household's decisions and illustrate the obtained path in Figure 9. Going from top to bottom, the panels in this figure show income, liquid wealth, car quality (a red cross indicates beginning-of-period car quality q_{it}, whenever this is different from the choice $\tilde{q}_{it}$) and non-durable consumption. When this agent goes through a long spell of high income realizations, she accumulates wealth and upgrades her car to new as soon as a depreciation shock occurs. In contrast, spells of low income are associated with positive debt and ownership of cars of lower quality. In particular, when the agent is against the borrowing limit, she often faces the decision of when to scrap a car of quality q_3 to purchase a car of quality q_2. Lumpiness in durable upgrading induces extra volatility in

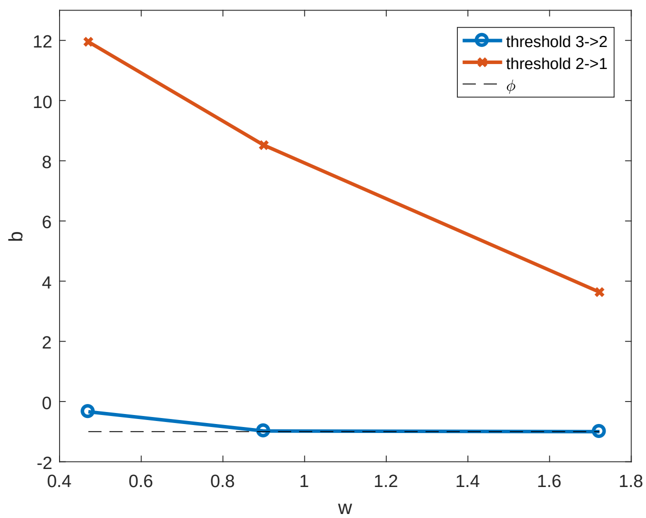

Figure 8: Thresholds for car replacement. x-axis: income;y-axis: liquid wealth. The blue line with circles represents the threshold for upgrading from quality q_3 to quality q_2. The red line with crosses represents the threshold for upgrading from quality q_2 to q_1. The black dashed line corresponds to the borrowing limit.

non-durable consumption (bottom panel), relative to a model without adjustment frictions. This simulation highlights the two reasons for trade in our model, namely depreciation and income shocks. At a given level of income an wealth, households tend to trade their car when it depreciates to a lower quality. However, even in absence of a depreciation shock, households upgrade their cars when positive income shocks lead to sufficiently large increases in liquid wealth.

5.3 Credit Shock

We now turn to the analysis of aggregate dynamics following an aggregate credit shock that makes the borrowing limit gradually and permanently tighter. It is plausible to assume that the financial crisis was an unexpected event for most households. Hence, we choose to model the credit tightening as an unexpected event that hits the economy in its stationary equilibrium, and focus on the transitional dynamics that arise after agents learn about the new credit conditions. Along the transition path, we assume that households have perfect

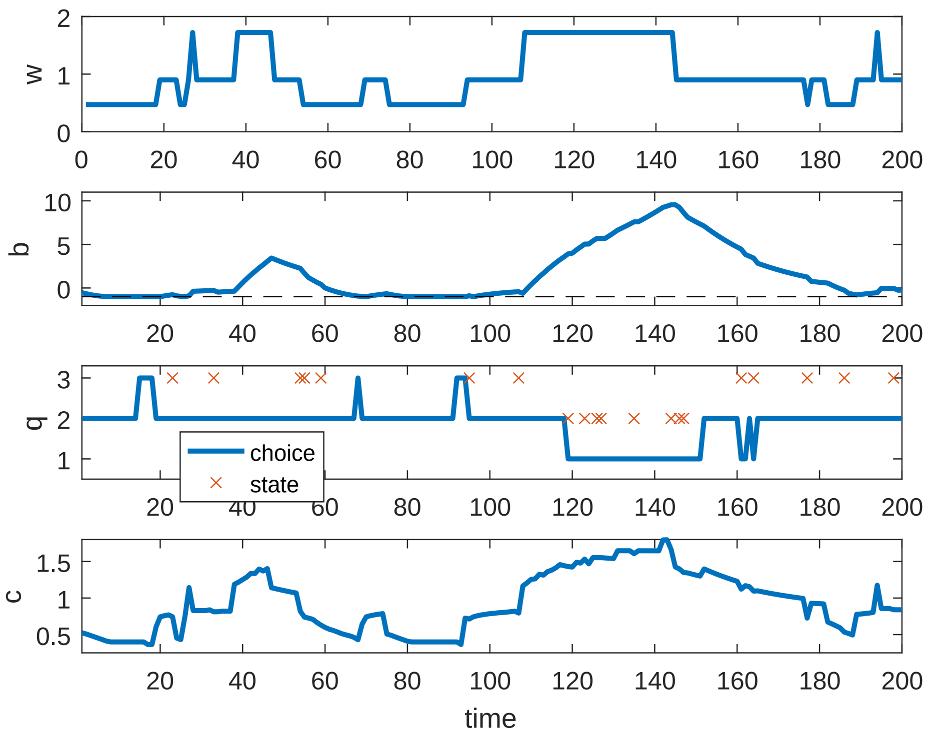

Figure 9: Simulation of individual household dynamics. Time (years) on the x-axis. Top panel: income; second panel: bond holdings; third panel: car quality (red cross indicates the beginning-of-period car quality, if different from the choice); bottom panel: non-durable consumption.

foresight.[8]

More specifically, we consider a shock that gradually reduces the credit limit from $\phi = -0.1$ to $\phi = -0.05$ over a two-year horizon. After the shock, the credit limit stays permanently at its new, tighter level. As in Guerrieri and Lorenzoni (2017), the shock forces households close or at the constraint to deleverage. Richer households also increase their precautionary savings, understanding that they will face tighter credit conditions, should their income decrease in the future. As all households try to increase their savings, general equilibrium forces induce a fall in the real interest rate to clear the credit market. Quantitatively, the size and the timing of the shock that we consider induces real interest rate dynamics that are close to those observed in the U.S. between 2007 and 2010.

In our model, the credit shock also has novel, important consequences on equilibrium prices and quantities on durable markets. In particular, poor agents who need to deleverage are the typical buyers of used cars. After the shock, they cannot easily finance the car replacement cost. Hence, they postpone the scrappage of their low-quality cars, giving priority to escaping the region close to the borrowing limit. As a consequence, demand for cars of quality q_2 falls. In turn, richer households, close to the replacement thresholds between quality q_2 and q_1, see their replacement cost increase, because of lower demand for used cars. Hence, even though they are not directly affected by the borrowing limit in their car purchase, they are indirectly induced to postpone replacing used cars with new ones, because of equilibrium price changes on the secondary market.

In Figure 10, we illustrate these dynamic responses of equilibrium prices and quantities following the credit tightening. Top left, we plot the exogenous dynamics of the borrowing limit. The shock leads to a decrease in the real interest rate (or, equivalently, an increase in the bond price, illustrated in the top-right panel) and a decrease in used prices (middle-

[8] Alternatively, one could assume that the borrowing limit is a random variable with distribution known by the agents. In order to solve for the model under this assumption, one could in principle implement the method proposed by Krusell and Smith (1998) and approximate the joint distribution of income, wealth and car quality with some informative moments that agents could use to form expectations about future equilibrium prices. However, the multiple dimensions of this distribution, as well as the multiple equilibrium prices, make it particularly hard to summarize the relevant information with few statistics in our model, in contrast with what is typically the case in simpler models of consumer behavior with incomplete markets. Furthermore, unlike standard business-cycle fluctuations, as argued by Huo and Ríos-Rull (2016), it does not seem too inappropriate to assume that households did not foresee the credit shock associated with the Great Recession.

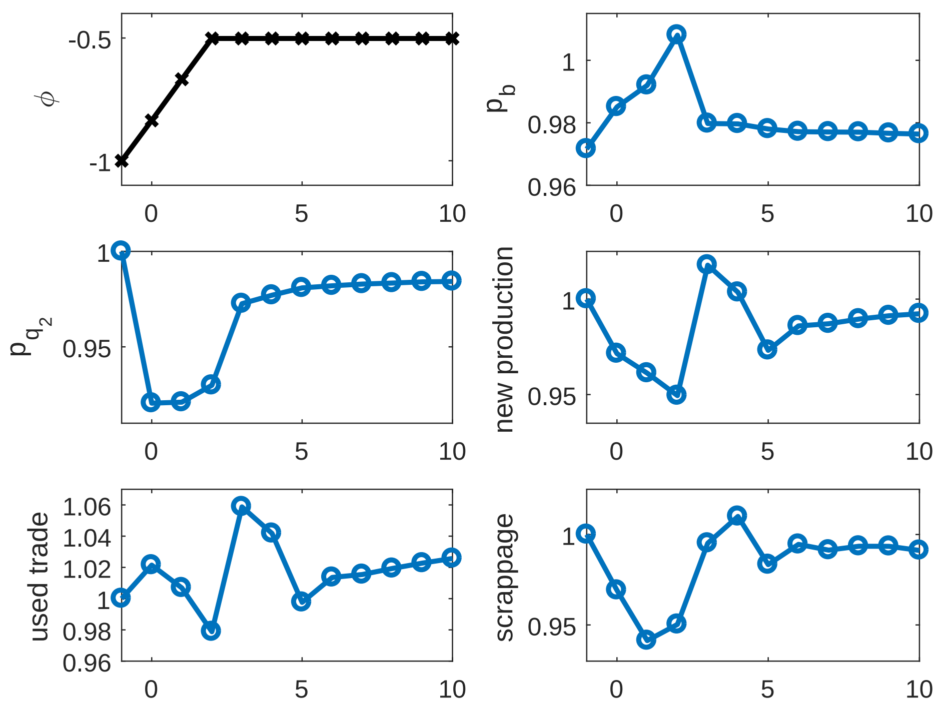

Figure 10: Credit Shock. The economy is in the initial stationary equilibrium in period -1 and agents learn about the new path of the borrowing limit in period 0. Top-left: borrowing limit; top-right: bond price; middle-left: price of used cars (quality q_2); middle-right: production of new cars; bottom-left: fraction of households trading a car of quality q_2; bottom-right: fraction of households scrapping a car.

left panel). Households optimally choose to postpone the car replacement activities, as illustrated in the remaining panels, which show the production of new cars (middle-right), trade in cars of quality q_2 (bottom-left) and scrappage (bottom-right). The fall in scrappage and upgrading leads to a prolonged ageing of the existing stock of cars, consistently with the empirical evidence in the US during the Great Recession.

5.4 The Role of Equilibrium in Secondary Markets

In order to highlight the role of secondary markets, we compare the response to the credit shock in general equilibrium with the outcome that would arise in absence of market clearing in the used-car market. Specifically, we assume that cars can be traded with the rest of the world at the prices prevailing in the initial stationary equilibrium. Hence, while the bond price respond to the shock to clear the bond market, the price of used cars p_{q_2} does not adjust. In Figure 11, the blue line with circles shows the path of new car sales in this Partial Equilibrium scenario. The red line with crosses shows the path of car scrappage. In absence of the endogenous response of used car prices, the economy features a strong negative comovement between scrappage and new car purchases. This result arises because borrowing-constrained agents decide to postpone scrappage of low-quality cars. Their demand for used cars falls, but this does not translate into a low price of used cars. Hence, there is no change in the replacement cost of used cars for wealthier households. In contrast, the low real interest rates stimulates their car replacement activity, inducing a large increase in new car sales, of approximately 50% relative to the initial stationary equilibrium. Hence, this experiment highlights the contribution of our mechanism in generating empirically plausible responses in new car sales, as well as car scrappage, after a credit tightening.

5.5 Aggregate Income Shock

We now consider the joint effect of a credit supply tightening and a negative aggregate income shock. This exercise allows us to study the equilibrium dynamics during an event similar to the Great Recession, in which both credit conditions and household incomes are negatively affected. Specifically, we assume that all households are hit by a 2% income loss for three years. The credit shock is parametrized as in our previous exercise. In Figure 12 we plot the transitional dynamics of our variables of interest. The aggregate income shock (displayed in the top right panel) amplifies the effects of the credit shock on car markets. In particular, it leads to a significantly larger decline in replacement activity and, ultimately, new car purchases, which decline by approximately 20% relative to the initial stationary equilibrium. Hence, following a combination of aggregate credit and income shocks, our mechanism accounts for a large fall in durable purchases, specifically over half of the empirical decrease in car sales during the Great Recession, illustrated in Figure 1.

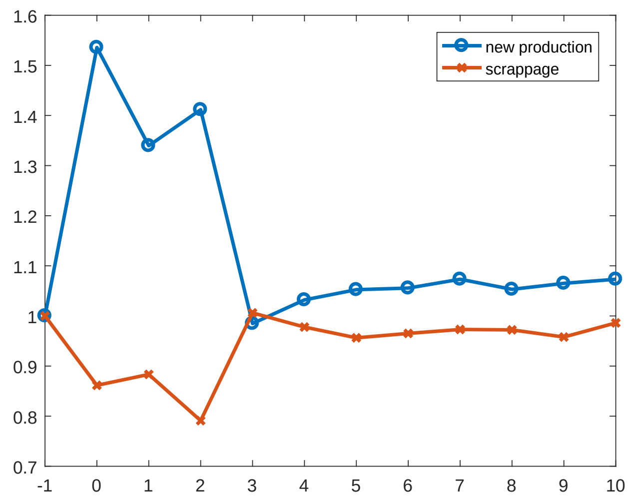

Figure 11: Credit Shock in Partial Equilibrium: new car purchases and scrappage. The economy is hit by the same credit shock as in Figure 10. The bond market clears. However, the market for used cars does not clear (i.e., cars can be traded with the rest of the world at the prices prevailing in the initial stationary equilibrium). Blue line with circles: new car purchases; red line with crosses: scrappage.

5.6 Collateral Constraint

In our baseline formulation of the model, we have considered a constant credit limit ϕ, independent of car values. We now explore a specification of the model with collateral constraints, in which a households' borrowing limits depend on the expected resale value of their cars. Specifically, we replace equation (2) with the following constraint:

$$b_{i,t+1} \geq \phi \left(\chi_0 + \chi_1 \mathrm{E}_t \left[p_{q_{i,t+1}} | \tilde{q_{it}} \right] \right), \tag{9}$$

which allows for both uncollateralized debt and collateralized car loans. Equation (9) highlights that the expected collateral value depends on the chosen car quality. Higher quality implies a higher expected equilibrium resale value, and thus a larger borrowing capacity. To match our empirical targets with this specification, we set $\chi_0 = .5$, $\chi_1 = .85$ and consider a shock that, as in our baseline formulation, brings ϕ from -0.1 to -.05.

Figure 13 illustrates the transitional dynamics of our variables of interest. Qualitatively,

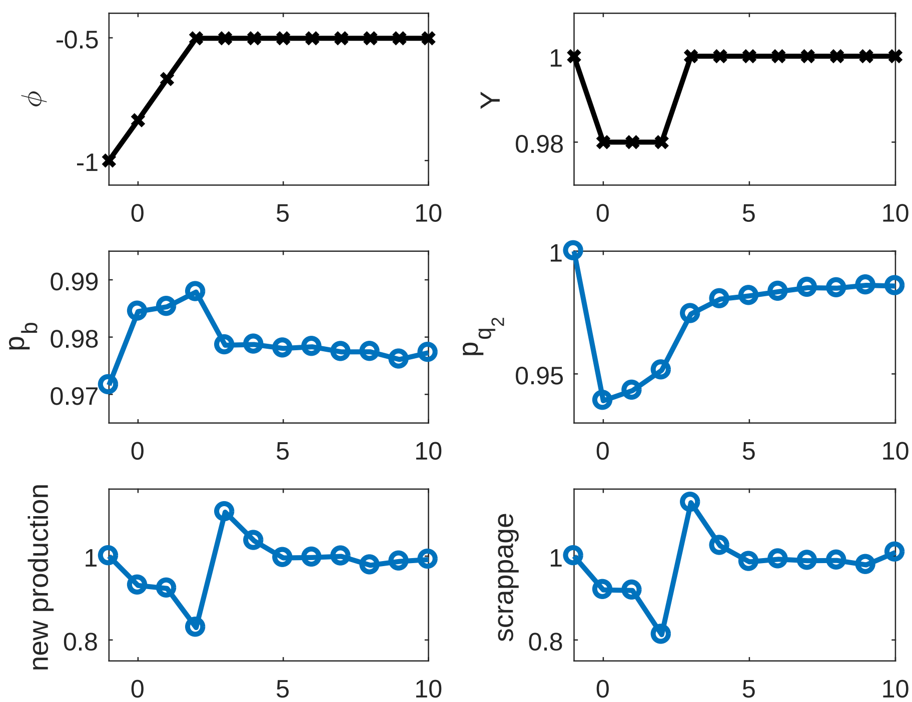

Figure 12: Credit and income shock. The economy is in the initial stationary equilibrium in period -1 and agents learn about the new path of the borrowing limit in period 0. Top-left: borrowing limit; top-right: income shock, hitting all households; middle-left: bonds price; middle-right: price of used cars (quality q_2); bottom-left: production of new cars; bottom-right: fraction of households scrapping a car.

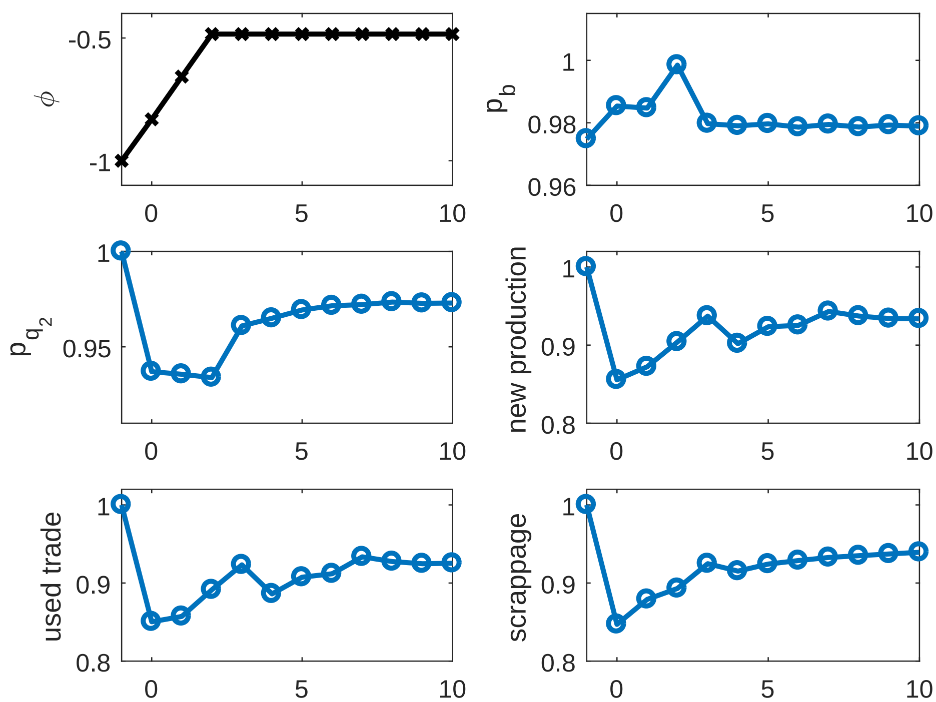

Figure 13: Shock to the collateral constraint. The economy is in the initial stationary equilibrium in period -1 and agents learn about the new path of the borrowing limit in period 0. Top-left: borrowing limit; top-right: bond price; middle-left: price of used cars (quality q_2); middle-right: production of new cars; bottom-left: fraction of households trading a car of quality q_2; bottom-right: fraction of households scrapping a car.

the results are unchanged relative to the baseline shock. Quantitatively, we observe a larger and more persistent response of car replacement activity, with an overall 15% decrease in new car purchases at the through relative to the initial stationary equilibrium.

5.7 The Effects of a Durable Replacement Subsidy

We now use our framework to study the effects of a fiscal intervention aimed at stimulating durable replacement during a credit crunch. Such countercyclical stimulus policies are common across countries and over time (e.g. Adda and Cooper (2000) consider two interventions in France in the 1990s). In particular, a car replacement stimulus was implemented in the US in 2009 (the Cars Allowance Rebate System, commonly referred to as "Cash for clunkers"). Existing structural analyses of such policies (e.g. Adda and Cooper (2000)) abstract from general equilibrium effects, and specifically from their effects on secondary market dynamics, which, in our framework, are key to determine the overall effect of the policy interventions on sales of new durables. By imposing equilibrium in car markets we uncover a novel mechanism that dampens the effect of the replacement stimulus. Namely, by diverting demand from used cars towards new ones, the policy depresses the secondary market, thereby reducing incentives to replace intermediate-age cars that do not qualify for the subsidy.

We introduce a durable replacement stimulus following the credit supply shock discussed in subsection 5.3. In the first year in which the credit shock hits, the government offers a subsidy to owners of cars of quality q_3 who choose to scrap their car and replace it with a new vehicles (quality q_1) during that year. We set the subsidy equal to 8% of the price of new cars and assume that this policy is initially financed by running a government deficit.[9] After ten years, the government raises lump-sum taxes in order to gradually reduce the debt to its initial steady-state value. Formally, taxes follow the following rule:

$$T_t = \begin{cases} T_t^* \text{ if } t < 10 \\ T_t^* + \psi(b_{Gt} - b_G^*) \text{ if } t \geq 10 \end{cases} \tag{10}$$

where T_t^* and b_G^* are taxes and government debt in the counterfactual no-policy scenario analyzed in subsection 5.3. Specifically, we set $\psi = 0.05$.

In Figure 14, we compare the path of the key variables of interest under the policy (red line with crosses) with their counterfactual no-policy dynamics (blue line with circles). The direct, quantitatively modest, effect of the policy is to attenuate the fall in scrappage and new car sales, as desired by policy makers. Our framework highlights a general equilibrium effect that dampens this stimulus effect. Notice that the policy induces a further decline in the price of used cars (quality q_2) and a larger fall in the volume of trade, relative

[9] The Car Allowance Rebate System offered subsidies between \$3,500 and \$4,500, depending on car models, i.e. over 10% of the average new car price. However, they were only available during the months of July and August 2009. Our yearly calibration does not allow us to exactly match this quantitative aspect of the policy. Hence, we limit ourselves to providing an illustration of the key mechanism.

to the counterfactual dynamics. This is because in the counterfactual no-policy scenario, most households who scrap their old cars would replace them with cars of intermediate quality. However, the stimulus leads to substitution away from intermediate-quality cars and towards new cars. As a result, demand for cars of quality q_2 falls, leading to lower price and quantity traded. In turn, a temporarily lower price of used cars creates an incentive for richer household who would - absent the policy - replace their q_2 car with a q_1 car to postpone this replacement. Hence, overall the policy is less effective than models that abstract from general-equilibrium effects would predict.

Furthermore, we find that the policy generates intertemporal substitution in scrappage and demand for new cars only from few years after the policy. This is consistent with the empirical findings of Mian and Sufi (2012). Finally, the size of the policy is not large enough to induce significant changes in the dynamics of equilibrium interest rates.

6 Conclusions

This paper proposes a novel general-equilibrium mechanism that links borrowing constraints to household durable upgrading decisions. Specifically, we focus on the dynamics of U.S. car markets around the Great Recession. Using micro data on prices of new and used cars, as well as on household car purchases, we document that an important fraction of new car purchases is due to replacement. During the Great Recession, a fall in prices of used cars lead to an increase in the replacement cost of used cars, inducing households to reduce and postpone their car upgrading decisions.

We introduce a quantitative model with household income risk, borrowing constraints and equilibrium in durable goods markets, and we show that our model can replicate these facts about prices and quantities on car markets. After a credit tightening, poor household decide to postpone the scrappage of old cars. This leads to a fall in demand on the secondary market, decreasing resale prices of used cars. As a consequence, the cost of replacement increases and richer household find it optimal to delay their car upgrades, inducing a fall in new car purchases.

By incorporating households' durable scrappage, trading and replacement in a general-

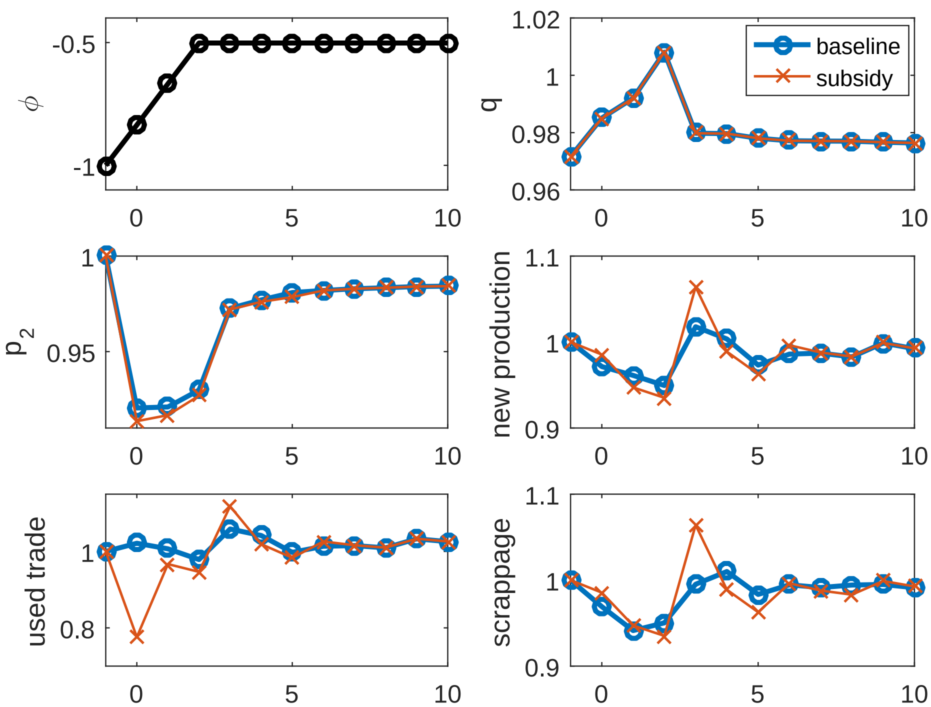

Figure 14: Credit shock and durable replacement subsidy. Blue line with circles: equilibrium dynamics in absence of the subsidy; red line with crosses: equilibrium dynamics in presence of a car replacement subsidy that applies in period 0 only. The economy is in the initial stationary equilibrium in period -1 and agents learn about the new path of the borrowing limit and about the policy intervention in period 0. Top-left: borrowing limit; top-right: bond price; middle-left: price of used cars (quality q_2); middle-right: production of new cars; bottom-left: fraction of households trading a car of quality q_2; bottom-right: fraction of households scrapping a car.

equilibrium model with incomplete markets, our framework allows us to study the implications of durable replacement subsidies such as the 2009 "Cash for clunkers" program. We find that this type of targeted fiscal stimulus induces substitution in demand away from used durables and towards new ones, thereby depressing secondary market trading. This effect dampens the overall effectiveness of the stimulus, by reducing replacement of intermediate-age cars that do not qualify for the subsidy.

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