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THE EXTENSIVE MARGIN OF AGGREGATE CONSUMPTION DEMAND

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Abstract

About half of the aggregate change in US non-durable consumption expenditure is due to changes in the products entering households' consumption basket (the extensive margin). Changes in the basket are driven by fluctuations in the rate at which households add new products; removals fluctuate little. These patterns are largely explained by the fact that households respond to income increases by adopting products already available on the market in their consumption basket. Fluctuations in household adoption cause a bias in the measurement of inflation, drive the aggregate demand for new products, and amplify the effects of aggregate shocks.

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The Extensive Margin of Aggregate Consumption Demand

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Abstract

About half of the aggregate change in US non-durable consumption expenditure is due to changes in the products entering households' consumption basket (the extensive margin). Changes in the basket are driven by fluctuations in the rate at which households add new products; removals fluctuate little. These patterns are largely explained by the fact that households respond to income increases by adopting products already available on the market in their consumption basket. Fluctuations in household adoption cause a bias in the measurement of inflation, drive the aggregate demand for new products, and amplify the effects of aggregate shocks.

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1 Introduction

At least since Dixit and Stiglitz (1977), Krugman (1980), and Romer (1990), it is well known that the introduction of new product varieties in the market changes the consumption basket of households along the *extensive margin*, increasing welfare. In practice, an average household consumes just a tiny fraction of the varieties in the market and most changes in the consumption basket along the extensive margin are due to varieties already in the market.[1] The conventional view, well formalized by Anderson, de Palma, and Thisse (1992), is that households consider for consumption *all* varieties in the market and the observed heterogeneity in consumption baskets is just noise, irrelevant for the aggregate implications of love-of-variety models and consistent with a representative household's preferences.[2] In this paper we show that, in response to transitory income shocks, households do persistently change their consumption basket: they start to buy varieties never purchased before even if they were available all along. We show that the micro-evidence is better consistent with the idea that households search for the varieties they like to consume, which induces persistent heterogeneity in the consumption baskets of households. This *search-for-love* formulation has novel implications for measuring inflation and the effects of shocks.

We incorporate a random utility model of discrete product choice à la McFadden (1973, 1974) in a standard household dynamic optimization problem à la Ramsey (1928). As in the conventional view, the household has a set of varieties she considers for consumption (her "consideration set"); varieties in the set are subject to preference shocks, which induce noisy changes in the consumption basket; owing to the preference shocks, a larger set reduces the welfare-relevant household price index, which provides a micro-foundation for love of variety. Differently from the conventional view, the consideration set is endogenous and heterogeneous across households due to search-for-love: a household decides how many new varieties in the market to sample (adoption expenditure) and some of the newly sampled varieties are randomly brought into the consideration set.[3] In response to a transitory income shock, the household adopts more varieties: first, there is a *scale effect*, typical

[1] For example under our preferred definition of variety in the Kilts-Nielsen Consumer Panel (KNCP), in a typical year there are about 70,000 different varieties on sale in the market and a household consumes just half a percentage point of them. In a year, the expenditure of the household on varieties that were not purchased in the previous year is 33 percent of total expenditure. The expenditure on varieties new to the US market is just around 1.3 percent of total expenditure (see also Table 4 in Broda and Weinstein 2010), which increase to just around 4 percent when availability is defined at the local market (DMA) level.

[2] Formally, Anderson et al. (1992) show that the CES utility of the representative household is the expected utility of (ex ante identical) households facing a discrete choice problem over all varieties in the market subject to idiosyncratic preference shocks with an extreme value distribution of type I.

[3] It is these differences in consideration sets for identical households (in terms of observable characteristics such as income, education or geographic location) that make the model different from other standard variety choice models, e.g. Hottman, Redding, and Weinstein (2016).

of love-of-variety models, which makes varieties more valuable when spending is higher; secondly, adoption is a form of investment which persistently reduces the welfare-relevant household price index and serves to *smooth consumption*.

Over time consumption expenditure can change along the intensive and the extensive margin. The extensive margin reflects *net* additions of varieties to the consumption basket, which is the difference between gross *additions* (expenditure on varieties not previously purchased) and *removals* of varieties (previous-period expenditure on varieties no longer purchased). Some gross additions are just noise due to preference shocks, others reflect household adoption of varieties continuously available in the market, the remaining ones are due to new varieties in the market. We calibrate the model by drawing detailed statistics from the Kilts-Nielsen Consumer Panel (KNCP) and reproduce the level of net and gross additions in the data. The model matches fairly closely the effects of the federal government's Economic Stimulus Payment (ESP) to households in 2008, which we take as an example of a transitory income shock. As in Parker, Souleles, Johnson, and McClelland (2013) and Broda and Parker (2014) we compare households who receive the payment randomly over time and interpret the estimated responses as characterizing household behavior in partial equilibrium (at constant aggregate supply of varieties). The marginal propensity to consume out of the ESP is the sum of a marginal propensity to consume along the intensive and one along the extensive margin, the latter the resultant of additions less removals. The extensive margin accounts for more than a third of the overall propensity, almost entirely driven by additions. Around a third of the increase in additions is due to varieties that the household had never purchased in the previous years and will repurchase again at least once in the year after receipt of ESP. A model with an exogenous consideration set (determined just by the aggregate supply of varieties), which we take as a formalization of the conventional view, fails to match this evidence.

We estimate the time series of adoption expenditure by full information methods using data on net additions and expenditure. We allow the return to adoption to vary over time, in order to control for changes in the number of varieties available in the market (Perla 2017), advertising by firms (Goeree 2008) or search intensity by households (Kaplan and Menzio 2016). In the data about half of the cyclical dynamics of aggregate consumption expenditure is accounted for by net additions, driven mostly by the pro-cyclicality of the rate at which households add new varieties, while removals are comparatively acyclical. The model fits well these cyclical patterns. Household's adoption expenditure is pro-cyclical and two-and-a-half times as volatile as total expenditure.

We endogenize the number of varieties in the market as in Romer (1990) and Bilbiie, Ghironi, and Melitz (2012) and discuss implications of search-for-love for inflation measurement. We relate household level inflation in our model to the inflation implied by the CES unified price index (CUPI) of Redding and Weinstein (2019).[4] CUPI is based on a representative household—either of the aggregate population or of one of its subgroups (for example defined in terms of income, education or geographic location). CUPI differs from the US Consumer Price Index (CPI) because of two terms. The first is the correction term proposed by Feenstra (1994) to measure how new varieties in the market affect welfare under love of variety. The second reflects the dispersion of aggregate consumption shares intended to measure the welfare effects of a mean preserving spread in preferences: since varieties are substitute, higher dispersion improves welfare and reduces inflation. There are two main reasons why CUPI fails to accurately measure true household level inflation when households search for the varieties they like to consume. First, household level inflation depends on the number of varieties in the consideration set of households, while the representative household is assumed to have a consideration set equal to the *union* of the consideration sets of all households in the economy. This difference widens when household adoption falls. Second, the dispersion of aggregate consumption shares reflects not only households' preferences for varieties but also the speed at which newly introduced varieties accumulate their customer base. When adoption falls, accumulating a customer base requires more time and consumption shares become more dispersed. When adoption expenditure falls, both effects make CUPI underestimate true household level inflation. The bias is (mainly) due to the assumption that households share the same consideration set: CUPI calculated at the household level measures accurately household level inflation.

Search-for-love also matters for the response to shocks. We analyze the effects of fiscal transfers during the US Great Recession and its recovery.[5] We consider an economy in a liquidity trap with intertemporal spill-overs in innovation, as in Romer (1990). During the period 2010-2019, fiscal transfers have increased consumption by little less than a percentage point on average. Adoption expenditure amplifies the effects of transfers (roughly by 40 percent) relative to a model with exogenous adoption. The reason is twofold. One is due to *household-level inflation*: fiscal transfers stimulate adoption that pushes down the welfare relevant household price index today, generating expectations of higher future household level inflation, which reduces the real interest rate and stimulates aggregate demand—an effect particularly valuable for an economy in a liquidity trap. The other is due to the *demand for innovation*: more household adoption pushes up the value of a new product, because new firms find easier to accumulate a customer base, causing a larger increase in

[4] CUPI extends the price index by Sato (1976) and Vartia (1976) to allow for love of variety, as in Feenstra (1994), as well as for time varying preference shocks.

[5] Fiscal transfers represented almost 80% of the increase in government expenditure over the period (Oh and Reis 2012).

innovation. Quantitatively, the two effects account roughly equally for the amplification.

Other authors have shown that households' shopping behavior responds to shocks by documenting changes in product quality (Jaimovich, Rebelo, and Wong 2019, Argente and Lee 2017 and Faber and Fally 2017) and in how intensively households search for lower prices on the products they usually purchase (Coibion, Gorodnichenko, and Hong 2015 and Campos and Reggio 2019). The focus on the extensive margin and household adoption of varieties *within* quality groups of products is novel. We also show that search intensity alone cannot explain the pro-cyclicality of gross additions and household adoption of varieties. A key distinction is that search is intensive in time, which is more abundant in recessions, whereas adoption entails the purchase of new products, a form of pro-cyclical investment.

Broda and Weinstein (2010) and Argente, Lee, and Moreira (2018) document that the launch of new products is pro-cyclical. Here we show that households' propensity to adopt new varieties matters for this cyclical pattern, since acquiring a stable customer base is a primary determinant of the profitability of a new product. Bilbiie et al. (2012) study how the introduction of new varieties in the market affects business cycles; see Bilbiie, Ghironi, and Melitz (2007), Bilbiie, Fujiwara, and Ghironi (2014), and Chugh and Ghironi (2011) for an analysis of the implications for monetary and fiscal policy. Our focus on the household, which should invest actively in adopting new consumption varieties, is novel and complementary to theirs. Household's adoption influences the aggregate demand for new products and amplifies the effects of shocks on firms' innovation.

The thesis that households' consideration set is only a subset of the products on the market is shared with Perla (2017), who studies the implications for firm growth and industry dynamics. Here we focus on the determinants of household adoption of new varieties, emphasizing the implications for inflation and business cycle analysis.

There is an abundant literature on measuring the marginal propensity to consume out of income shocks (Blundell, Pistaferri, and Preston 2008, Broda and Parker 2014, Johnson, Parker, Souleles, and McClelland 2006, Parker et al. 2013) as well as on its theoretical determinants; see for example Kaplan and Violante (2014), Kueng (2018), and Campbell and Hercowitz (2019). We decompose the overall marginal propensity to consume into propensity along the intensive margin and propensity along the extensive margin, showing that the latter's response partly reflects the adoption of additional varieties.

Section 2 decomposes the cyclical fluctuations in expenditure into the intensive and extensive margin. Section 3 studies the 2008 tax rebate. Section 4 presents the household's model, Section 5 parameterizes it and analyzes the effects of an income shock. Section 6 analyzes its business cycle properties. Section 7 discusses implications of the extensive margin. Section 8 concludes. The Appendix contains further details on data and model.

2 Decomposing household consumption expenditure

We characterize how household's consumption expenditure changes along the intensive and the extensive margin over time (Section 2.3) and in response to an income shock (Section 3). We later use this evidence to identify and validate the model of Section 4. We first introduce some definitions, then discuss the data and finally present empirical results.

2.1 Methodology

The consumption expenditure of household $h \in \mathcal{H}$ at time t is equal to the sum of the expenditures on all the varieties consumed

$$e_{ht} \equiv \sum_{\nu \in \mathcal{V}} e_{\nu ht}, \tag{1}$$

where e_{hvt} denotes the expenditure of the household on variety $\nu \in \mathcal{V}$. Here, by convention, all expenditures are per household (total expenditure divided by the total number of households). $\mathcal{H}$ and $\mathcal{V}$ denote the set of all households and of all varieties in the economy at *some* time t, respectively. Given (1), aggregate expenditure per household is equal to

$$E_t = \sum_{h \in \mathcal{H}} e_{ht},$$

whose growth rate can be expressed as:

$$\frac{\Delta E_t}{E_{t-1}} \equiv \frac{E_t - E_{t-1}}{E_{t-1}} = \sum_{h \in \mathcal{H}} \frac{e_{ht} - e_{ht-1}}{e_{ht-1}} \times \frac{e_{ht-1}}{E_{t-1}}. \tag{2}$$

The overall change in household h's expenditure stems partly from changes in expenditure on products already purchased in the previous period—the *intensive margin*—and partly from net additions of products to the consumption basket—the *extensive margin*. Net additions are the difference between the household's current expenditure on products newly added and previous-period expenditure on products now removed from the basket. In brief, we have that

$$\frac{e_{ht} - e_{ht-1}}{e_{ht-1}} = i_{ht} + a_{ht} - r_{ht} \tag{3}$$

where

$$i_{ht} = \sum_{\nu \in \mathcal{V}} \frac{e_{\nu ht} - e_{\nu ht-1}}{e_{ht-1}} \times \mathbb{I}(e_{\nu ht-1} > 0) \times \mathbb{I}(e_{\nu ht} > 0) \tag{4}$$

$$a_{ht} = \sum_{\nu \in \mathcal{V}} \frac{e_{\nu ht}}{e_{ht-1}} \times \mathbb{I}(e_{\nu ht-1} = 0) \times \mathbb{I}(e_{\nu ht} > 0) \tag{5}$$

$$r_{ht} = \sum_{\nu \in \mathcal{V}} \frac{e_{\nu ht-1}}{e_{ht-1}} \times \mathbb{I}(e_{\nu ht-1} > 0) \times \mathbb{I}(e_{\nu ht} = 0) \tag{6}$$

with $\mathbb{I}(\cdot)$ denoting the indicator function. Changes in the expenditure of household h can be due to the intensive margin i_{ht} in (4), to (gross) additions of products to the basket a_{ht} in (5), or to removals from the basket r_{ht} in (6). Combining (2) with (3), we obtain

$$\frac{\Delta E_t}{E_{t-1}} = I_t + N_t \tag{7}$$

where I_t and N_t denote the changes in aggregate expenditure due to the intensive margin and net additions, respectively. The contribution of the intensive margin is the weighted sum of the terms i_{ht} in (4)

$$I_t = \sum_{h \in \mathcal{H}} i_{ht} \times \frac{e_{ht-1}}{E_{t-1}}, \tag{8}$$

while net additions are defined as

$$N_t = A_t - R_t, \tag{9}$$

which is the difference between the weighted sum of the expenditures on products added,

$$A_t = \sum_{h \in \mathcal{H}} a_{ht} \times \frac{e_{ht-1}}{E_{t-1}}, \tag{10}$$

and the weighted sum of previous-period expenditures on products now removed,

$$R_t = \sum_{h \in \mathcal{H}} r_{ht} \times \frac{e_{ht-1}}{E_{t-1}}. \tag{11}$$

2.2 The data

Our analysis relies on the Kilts-Nielsen Consumer Panel (KNCP). Here we discuss the data briefly, leaving further details to Appendix A. KNCP is a rotating panel of an average of 60,000 households per year, with the median household remaining in the sample for three consecutive years. Households report the prices and quantities of all the products purchased in stores, using a scanning device provided by Nielsen.[6] The sample is representative of the US population, and expenditures in KNCP track the corresponding categories in the Consumer Expenditure Survey (CEX) quite well. Products are identified by their Universal Product Code (UPC). Since versions of the same product packaged differently have a different UPC, identifying a variety with the UPC would force us to classify a change along the extensive margin also when the household still consumes exactly the

[6]The product categories in KNCP survey are dry groceries, frozen foods, dairy, deli, packaged meat, fresh foods, non-food groceries, alcohol, general merchandise, and health and beauty aids, which account for 13% of total consumption expenditure (durables and non-durables) as calculated by the Consumer Expenditure Survey (CEX). The stores covered by KNCP are traditional grocery shops, drugstores, supermarkets, superstores and club stores.

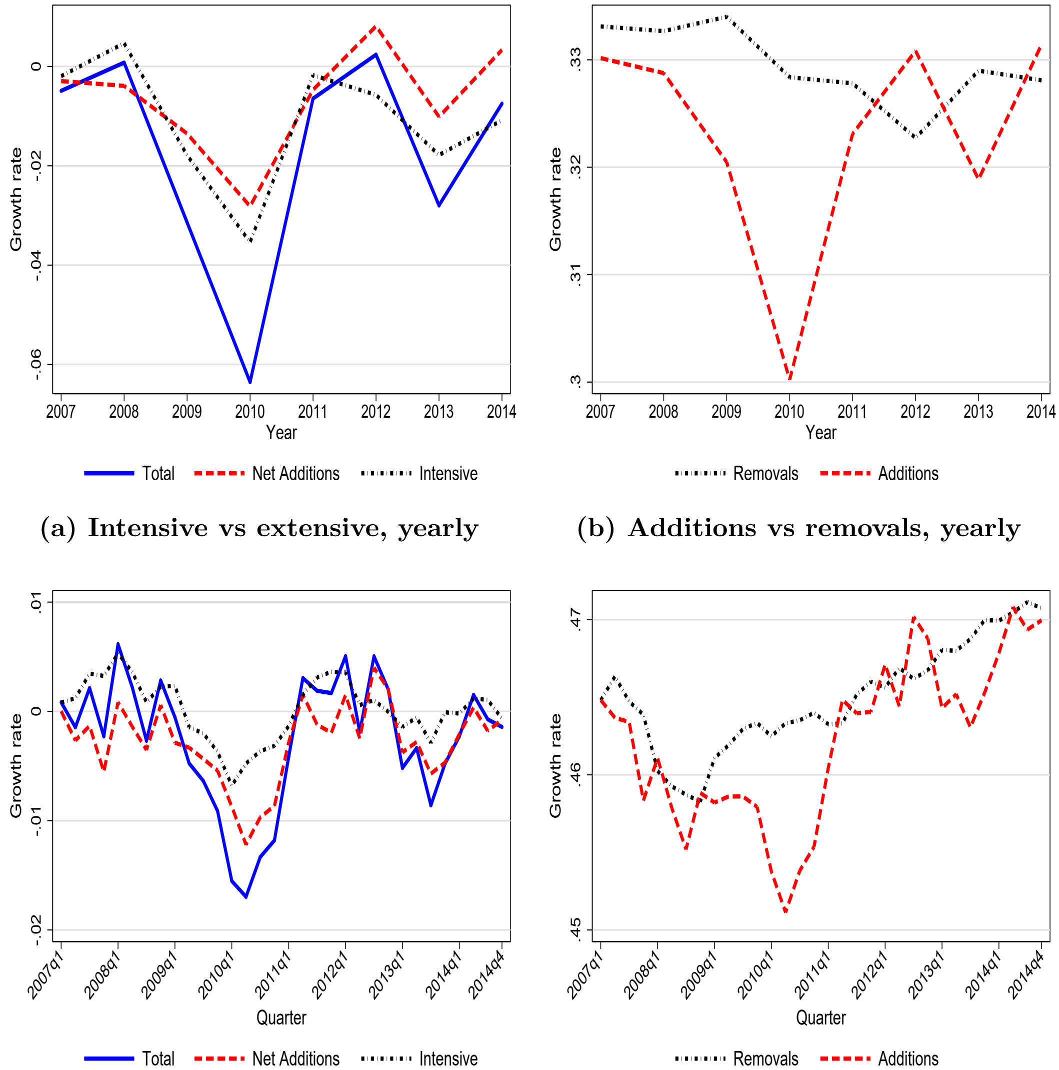
same product. The University of Chicago has addressed this problem by grouping all UPCs with the same characterizing name or logo into a single *brand* variable. Examples of brands in the "Ice cream, Novelties" category are "Häagen Dazs" and "Häagen Dazs Extra". Of course, the same brand could be used for different products (Häagen Dazs could refer to ice cream as well as frozen desserts or yogurt). Nielsen groups the 1.4 million UPCs present in KNCP into 735 homogeneous product modules. Examples of product modules are "carbonated beverages," "laundry supplies," "ice cream in bulk" and "frozen yogurt." Similarly to Handbury (2013), we identify a variety as the combination of brand and product module (that is, Häagen Dazs in the ice cream module is a different variety from Häagen Dazs in the frozen yogurt module). With this definition, there are about 70,000 different varieties sold in the market in a year, with the average household buying 350.[7] We also try the alternative of identifying varieties directly by UPCs. We exclude the category "general merchandise", which is quite heterogeneous, contains some durable goods (such as electronics), and is only spottily reported by households, as well as all products with no UPC (such as fresh food products and bakery goods), which are reported only by a small subsample of KNPC households. We take only households with expenditures in every month of a year, to make sure that their consumption behavior is measured accurately (the results are robust to selecting households with expenditures in at least ten months). Our baseline analysis is yearly, which automatically controls for seasonal changes in consumption baskets, but we also report results quarterly, the standard frequency for business cycle analysis. Since the focus is on changes, households in the sample in year t should also be present in year $t-1$. As discussed in Appendix A, the growth rate of expenditure in this subsample is lower than the growth rate of aggregate expenditure in the full sample, but the correlation between the two series is high (close to 90 percent). All statistics are aggregated using Nielsen's sampling weights. Since the weight of a household could change over time, we use the average weight in year $t-1$ and t. We cover the period 2007-2014, because KNCP was redesigned in 2006, increasing sample size and product coverage, and the data for 2015 were not available to us.

2.3 Findings

Panel (a) of Figure 1 plots the growth rate of aggregate expenditure $\Delta E_t/E_{t-1}$ (solid blue line) and the contribution of the intensive margin I_t (dotted black line) and net additions N_t (dashed red line). Panel (b) further decomposes net additions N_t into additions A_t (dashed red line) and removals R_t (dotted black line). The series are at yearly frequency,

[7] All white labels (also called private labels) within a product module have the same brand code and are identified as the same variety.

Figure 1: Flows in aggregate expenditure



(a) Intensive vs extensive, yearly **(b) Additions vs removals, yearly**

(c) Intensive vs extensive, quarterly **(d) Additions vs removals, quarterly**

Panel (a) and (c) plot the growth rate of expenditure, $\Delta E_t/E_{t-1}$, together with the contribution of the intensive margin I_t and net additions N_t. Panel (b) and (d) plot additions A_t and removals R_t. In the first row, the analysis is at yearly frequency, in the second quarterly. The quarterly series are 4-quarters moving averages. A variety is defined as a brand/product-module pair.

and there is substantial turnover in consumption baskets, additions accounting for about 30 percent of expenditure. Net additions and the intensive margin have roughly the same volatility and co-move positively with expenditure growth, with a correlation of over 90 percent (Table 1). Removals are relatively acyclical, while additions co-move strongly with expenditure. The "β-decomposition" row in Table 1 reports the estimated coefficient β_X from an OLS regression where the independent variable is expenditure growth, $\Delta E_t/E_{t-1}$, and the dependent variable X is reported by column. Formally:

$$X_t = \alpha_X + \beta_X \frac{\Delta E_t}{E_{t-1}} + \text{error}$$

where $X_t = I_t, N_t, A_t, R_t$. OLS is a linear operator, which implies that the coefficients for the intensive margin and net additions sum to 1 ($\beta_I + \beta_N = 1$) and that the coefficient for net additions, β_N, equals the difference between that for additions and that for removals ($\beta_N = \beta_A - \beta_R$). In this sense β_X can be interpreted as a measure of the contribution of X_t to the cyclical fluctuation in $\Delta E_t/E_{t-1}$. Using this metric, Table 1 shows that net additions N_t account for almost half of the variation in expenditure growth $\Delta E_t/E_{t-1}$, with additions A_t accounting for practically all of the fluctuation in N_t.

Panels (c) and (d) of Figure 1 are analogous to panels (a) and (b), but now the flows are quarterly. For seasonal adjustment, the quarterly series are computed as 4-quarter moving averages. Additions and removals are now larger in absolute terms, but the cyclical properties of the series change very little in that A_t still explains a large share of the fluctuation in E_t and R_t only a small share (Table 1). Compared with the yearly frequency, the contribution of net additions is now somewhat greater and additions and removals tend to co-move slightly more strongly. The quarterly series also indicate that at the end of

Table 1: Descriptive statistics

	ΔE_t	I_t	N_t	A_t	R_t
a) Yearly frequency					
Standard deviation (%)	2.20	1.30	1.10	1.00	0.40
Correlation with ΔE_t	1.00	0.95	0.93	0.95	-0.12
β-Decomposition, β_X	1.00	0.54	0.46	0.44	-0.02
b) Quarterly frequency					
Standard deviation (%)	0.60	0.30	0.40	0.50	0.40
Correlation with ΔE_t	1.00	0.91	0.94	0.65	0.02
β-Decomposition, β_X	1.00	0.43	0.57	0.58	0.01

The row labeled "β-Decomposition" reports the OLS coefficient β_X from regressing the variable by column, $X_t = I_t, N_t, A_t, R_t$, against the percentage change in expenditure, $X_t = \alpha_X + \beta_X \Delta E_t/E_{t-1} + \text{error}$. The properties of OLS imply $\beta_I + \beta_N = 1$ and $\beta_N = \beta_A - \beta_R$. A variety is identified as a brand/product-module pair.

the sample period the value of additions and removals was greater. This increase is not reflected in the yearly series, which jibes with the idea that households reduced the number of shopping trips during the recovery. When flows are calculated at high frequencies, this change in behavior results in an artificial increase in additions and removals.

Fluctuations in the extensive margin may reflect changes in the sectoral or quality composition of the consumption basket or in the varieties available in the market. To study these issues we break the extensive margin down into *within* and *between* group components, defining the groups differently depending on the point at issue. Formally, let $\mathcal{V}_t$ be the set of varieties available in the market at time t and $\mathcal{V}_t^g$, $g = 1, 2...\mathcal{G}$ denote a partition of $\mathcal{V}_t$: $\bigcup_{g=1}^{\mathcal{G}} \mathcal{V}_t^g = \mathcal{V}_t$ and $\mathcal{V}_t^g \bigcap \mathcal{V}_t^{g'} = \emptyset$, $\forall g \neq g'$. The time-t expenditure of household h in varieties of group g are equal to

$$e_{ht}^g = \sum_{\nu \in \mathcal{V}_t^g} e_{\nu ht}.$$

Given the partition $\mathcal{G}$, the *between-group* component of additions A_t^b is equal to the sum of all additions in groups where households had zero expenditure at $t-1$, while the between-group component of removals R_t^b is equal to the sum of all removals in groups where households have zero expenditure at t, so that

$$A_t^b = \sum_{g=1}^{\mathcal{G}} A_t^g, \tag{12}$$

$$R_t^b = \sum_{g=1}^{\mathcal{G}} R_t^g, \tag{13}$$

where A_t^g is the contribution of group g to the between-group component of additions

$$A_t^g = \frac{\sum_{h \in \mathcal{H}} e_{ht}^g \times \mathbb{I}(e_{ht-1}^g = 0) \times \mathbb{I}(e_{ht}^g > 0)}{E_{t-1}},$$

while R_t^g is its contribution to the between-group component of removals

$$R_t^g = \frac{\sum_{h \in \mathcal{H}} e_{ht-1}^g \times \mathbb{I}(e_{ht-1}^g > 0) \times \mathbb{I}(e_{ht}^g = 0)}{E_{t-1}}.$$

The within-group component of additions A_t^w and of removals R_t^w are equal to the sum of all additions and removals in groups where households spent a strictly positive amount both in $t-1$ and in t; these components are obtained as a residual:

$$A_t^w = A_t - A_t^b, \tag{14}$$

$$R_t^w = R_t - R_t^b. \tag{15}$$

Table 2 reports β-decompositions analogous to those in Table 1 for different partitions of the set of available varieties. We focus on the yearly analysis, with brief discussion of the quarterly results where significant differences emerge. We start by partitioning the varieties into Nielsen's 735 product modules. Panel (a) of Table 2 documents that even with this very fine sectoral breakdown additions fluctuate substantially in sectors where households were already actively buying varieties in the previous year. The within-group component of additions accounts for more than half the overall cyclical contribution of net additions to the growth in expenditure. At quarterly frequency, the contribution of the between-sector component of gross and net additions increases, presumably reflecting seasonal patterns in the composition of the consumption basket.

Argente and Lee (2017) have observed that over the cycle households substitute products of different quality. Of course, quality substitution may be intensive or extensive. Substitution of products along the extensive margin would counterfactually predict that additions and removals should comove positively, which is prima facie evidence that substitution (across sectors or quality categories) is unlikely to drive our results. To analyze the issue more formally, we construct a measure of the quality of variety $\nu \in \mathcal{V}$ based on its average per unit price over time. In calculating the average unit price, we control for a full set of time dummies interacted with the 95 product group dummies (for additional detail, see Appendix A). Within each product group, we assign varieties to ten different quality bins corresponding to the deciles of the quality distribution within the group, thus partitioning the variety space into 950 groups, $\mathcal{G}$ =950. Panel (b) of Table 2 shows that quality substitution affects the cyclical properties of net and gross additions, but it does not fully account for them. At the yearly frequency, the contribution to expenditure growth of the within-quality component of net additions is as large as that of the between-quality component.[8] Changes between product groups account for no more than 5 percent of the total contribution of net and gross additions, and for removals they are almost negligible.

As shown by Broda and Weinstein (2010), the net entry of new varieties into the market is strongly pro-cyclical. It is important to determine whether the cyclicality of additions and removals depends on the net entry of new varieties into the market, or whether it arises also within the set of continuously available varieties. We accordingly partition the space of varieties at time t according to whether they are newly introduced, withdrawn, or continuously available both at $t-1$ and at t.[9] Panel (c) of Table 2 shows that, at the yearly frequency, fluctuations in net and gross additions occur mainly in continuously

[8]The between-quality component is also not fully consistent with quality substitution along the extensive margin that would imply a positive comovement between additions and removals.

[9]The introduction and withdrawal date of a variety is at the Designated Market Area (DMA) level and is identified combining household level (KNCP) and store level (KNRS) data; see Appendix A for details.

Table 2: Within/Between components, β-decompositions

Frequency:	**Yearly**			**Quarterly**		
Variable X_t:	N_t	A_t	R_t	N_t	A_t	R_t
Total contribution of X, $\beta^w_X + \beta^b_X$	0.46	0.44	-0.02	0.57	0.58	0.01
a) Changes in sectoral composition						
Within, β^w_X	0.27	0.27	0.00	0.20	0.22	0.02
Between, β^b_X	0.19	0.17	-0.02	0.37	0.36	-0.01
b) Quality substitution						
Within, β^w_X	0.20	0.20	0.00	0.15	0.13	-0.02
Between quality within product group, β^b_X	0.21	0.20	-0.01	0.25	0.29	0.04
Between product group, β^b_X	0.05	0.04	-0.01	0.18	0.17	-0.01
c) Varieties available in the market						
Within, β^w_X	0.41	0.40	-0.02	0.55	0.56	0.01
Between, β^b_X, due to new varieties	0.05	0.04	0.00	0.02	0.03	0.01

Each entry is the estimated OLS coefficient β^s_X from regressing the between component $s = b$ or the within component $s = w$ of the variable $X_t = N_t, A_t, R_t$ in column against expenditure growth: $X^s_t = \alpha^s_X + \beta^s_X \Delta E_t/E_{t-1} +$ error. The first row reports the total contribution of variable X_t (the sum of its between and within components) to the fluctuation in $\Delta E_t/E_{t-1}$. A variety is identified by a brand/product-module pair. The sectors in panel (a) correspond to the 735 product modules defined by Nielsen. In panel (b), there are 950 groups corresponding to 95 product-groups defined by Nielsen, each partitioned into 10 quality bins corresponding to deciles of average prices within the product-group. In panel (c) β^w_X corresponds to varieties available in the market also at $t-1$, while β^b_X corresponds to varieties first introduced in the market at t.

present varieties. For example, additions in continuously available varieties contribute about 39 percent of the fluctuation in expenditure growth, $\beta^w_A = 0.40$, while the analogous contribution of additions in new varieties is around 4 percent, $\beta^b_A = 0.04$. Overall, these findings are consistent with the thesis that firms' product innovation is pro-cyclical, but changes in the net supply of varieties do not fully explain the observed changes in the consumption basket along the extensive margin. In Appendix A we further relate these findings to those in Broda and Weinstein (2010).[10]

Appendix A reports on several additional exercises, which generally confirm the robustness of the previous results. In particular we show that the previous patterns hold across households with different permanent income (as measured by their level of expenditure),

[10]When we identify a variety by UPC alone, the contribution of newly introduced varieties to fluctuations in additions increases by 20 to 25 percentage points over the contribution of 4 percent reported in Table 2, which is in line with the estimates in Table 7 of Broda and Weinstein (2010). This indicates that during booms firms use new UPCs of the same brand to attract new customers—a form of strategic marketing.

for product varieties of different durability, across different US regions, and also when measuring expenditures at constant rather than at current prices or when identifying additions to and removals from the household consumption basket using a longer reference period (two years); see Appendix A for the full details.

3 Responses to an income shock

Rather than reflecting genuine changes in household demand behavior, the foregoing findings could be driven by general equilibrium effects or changes in marketing and pricing strategies. To analyse this issue, we examine the effects of the 2008 federal Economic Stimulus Payment (ESP) to households. Roughly, the ESP amounted to a transfer of $300 to single-person households and $600 to couples, which was reduced by 5 percent of the amount by which household's gross income exceeded the threshold of $75,000 for singles and $150,000 for couples; see Parker et al. (2013) and Broda and Parker (2014) for details. On average, ESP was equal to 3.1% of households' personal consumption expenditure in the second quarter of 2008. As in Parker et al. (2013) and Broda and Parker (2014), we combined data from KNCP survey with additional information on the week when the household received the ESP, at some time between April and July 2008. The timing of transfer of the ESP was randomized by social security number. The response of consumption to its receipt is gauged by comparing households that received the payment at randomly different points in time. For each household h and week t in 2008, we calculate the percentage difference between expenditure in that week, denoted by e_{ht}, and its average weekly expenditure in the reference period 2004-2007, denoted by $\overline{e}_h \equiv \sum_{\nu \in \mathcal{V}} \overline{e}_{\nu h}$, where $\overline{e}_{\nu h}$ is the average weekly expenditure of household h in variety ν in 2004-2007:

$$\widetilde{g}_{ht} = \frac{e_{ht} - \overline{e}_h}{\overline{e}_h} = \widetilde{i}_{ht} + \widetilde{a}_{ht} - \widetilde{r}_{ht}.$$

$\widetilde{g}_{ht}$ is decomposed into a term due to the intensive margin $\widetilde{i}_{ht}$, one due to gross additions, $\widetilde{a}_{ht}$, and one due to removals $\widetilde{r}_{ht}$, which are defined similarly as before:

$$\widetilde{i}_{ht} = \sum_{\nu \in \mathcal{V}} \frac{e_{\nu ht} - \overline{e}_{\nu h}}{\overline{e}_{\nu h}} \times \mathbb{I}(\overline{e}_{\nu h} > 0) \times \mathbb{I}(e_{\nu ht} > 0), \tag{16}$$

$$\widetilde{a}_{ht} = \sum_{\nu \in \mathcal{V}} \frac{e_{\nu ht}}{\overline{e}_{\nu h}} \times \mathbb{I}(\overline{e}_{\nu h} = 0) \times \mathbb{I}(e_{\nu ht} > 0), \tag{17}$$

$$\widetilde{r}_{ht} = \sum_{\nu \in \mathcal{V}} \frac{e_{\nu ht-1}}{\overline{e}_{\nu h}} \times \mathbb{I}(\overline{e}_{\nu h} > 0) \times \mathbb{I}(e_{\nu ht} = 0). \tag{18}$$

The contribution of net additions is then measured by

$$\widetilde{n}_{ht} = \widetilde{a}_{ht} - \widetilde{r}_{ht}. \tag{19}$$

Notice that a product added to the consumption basket in a week of 2008 contributes to $\widetilde{a}_{ht}$ only if the household had never purchased it during the entire period 2004-2007, which implies that additions are identified at least four times more restrictively than in Section 2, where the reference period was at most one year.[11] To measure persistent changes in the household consumption basket, we also construct a measure of *persistent additions*, $\widetilde{a}^{per}_{ht}$, equal to the subset of the additions in (17) which happen in products that the household will buy again at least once in one of the 52 weeks after t. We then run the following regressions

$$\widetilde{x}_{ht} = \alpha + \beta_{-1} LEAD_{ht} + \beta_0 CURRENT_{ht} + \sum_{\tau=1}^{8} \beta_\tau LAG_{h\tau t} + \psi_t + \epsilon_{ht}, \qquad (20)$$

where the dependent variable is $\widetilde{x} = \widetilde{g}, \widetilde{i}, \widetilde{n}, \widetilde{a}, \widetilde{a}^{per}$, $LEAD$ is a dummy variable equal to 1 in the four weeks before receipt of ESP, $CURRENT$ is equal to 1 in the week of receipt and the three following weeks, $LAG_{h\tau t}$ is equal to one if the household has received ESP τ months before t and ψ_t are time dummies. In running (20) we weight households using their KNCP weights. Table 3 reports the results from estimating (20), where the dependent variable $\widetilde{x}$ appears in column. The table reports three coefficients corresponding to the anticipated response to receipt of ESP, β_{-1}, the response on receipt, β_0, and the four-week lagged response, β_1. We call these coefficients marginal propensities to consume out of ESP. The estimates for different $\widetilde{x}$ decompose the overall marginal propensity to consume estimated by Broda and Parker (2014), MPC_{E}, into the sum of one marginal propensity to consume along the intensive margin, MPC_{I}, and another due to net additions, MPC_{N}, which can be further broken down into a component due to removals and one due to additions, MPC_{A}. Finally the additions can be temporary or persistent, the latter marginal propensity denoted by $\text{MPC}_{\text{A-Per}}$. The overall marginal propensity to consume upon receipt of ESP is around 6 percent, which is in line with the estimates of Broda and Parker (2014). There is some evidence that expenditure increases in the four weeks before the receipt of ESP, by around 2.5 percent. Net additions account for 30-40 percent of the total marginal propensity to consume upon receipt of ESP. Net additions correspond almost perfectly to gross additions.

Table 4 shows that persistent additions $\widetilde{a}^{per}$ account for roughly a third of the response of additions $\widetilde{a}$: expenditures increase by roughly one percent in varieties that the household had never purchased in the previous 4 years and will repurchase again at least once in the year after receipt of ESP, indicating that households respond to temporary income changes by adding new products, which then remain persistently in their consumption basket for several weeks after the income boost.

[11]Likewise, varieties sometimes purchased by the household in the period 2004-2007 contribute to $\widetilde{r}_{ht}$ if they are not purchased in the specific week t of 2008.

Table 3: Decomposing the Marginal Propensity to Consume to ESP

Response to ESP (%)	**Total** MPC_E	**Intensive** MPC_I	**Net** MPC_N	**Gross** MPC_A	**Removals** MPC_R
Month before, β_{-1}	2.69*	1.50	1.19*	1.57**	0.38*
	(1.47)	(1.04)	(0.65)	(0.64)	(0.21)
Month of receipt, β_0	6.08***	3.96***	2.11***	2.63***	0.52
	(1.84)	(1.34)	(0.82)	(0.82)	(0.33)
Month after, β_1	5.40**	2.94*	2.47**	3.33***	0.87*
	(2.40)	(1.74)	(1.05)	(1.07)	(0.47)
Number of observations	324324	324324	324324	324324	324324
Number of households	6237	6237	6237	6237	6237

Results from estimating (20) for $\widetilde{x} = \widetilde{g}, \widetilde{i}, \widetilde{n}, \widetilde{a}, \widetilde{r}$. Data are weekly. ESP stands for Economic Stimulus Payment in 2008. MPC stands for Marginal Propensity to Consume in total expenditure (column 1), intensive margin (column 2), net additions (column 3), gross additions (column 4), and removals (column 5). Additions and removals are calculated using 2004-2007 as a reference period.

As in Section 2.3, we also decompose the response of additions $\widetilde{a}$ into a component within sectors and quality groups where the household had purchased some varieties in the previous four years and a component due to purchase of varieties in sectors or quality groups that had never entered the household's consumption basket before. We partition the space of available varieties at time t into 950 different groups, corresponding to 10 quality bins within each of Nielsen's 95 product groups. Table 4 indicates that the within-quality within-product-group component accounts for more than 90 percent of the response of additions, MPC_A, implying that quality substitution does not drive the response of the extensive margin to the ESP. This evidence is in line with the observed lack of comovement between additions and removals: under substitution of products along the extensive margin additions and removals would comove positively.

The survey administered by Broda and Parker (2014) over the period April-June 2008 also asks the following question to Nielsen households: "*About how often do you or other household members make purchases that you later regret?*" The possible answers are: "*Never*"; "*Rarely*"; "*Occasionally*"; "*Often*". We study whether more additions are associated with greater regret. In the first half of 2008 we averaged the additions $\widetilde{a}_{ht}$ in (17). For the three terciles of the resulting distribution of average $\widetilde{a}_{ht}$'s we calculated the fraction of households selecting each of the previous four options. We find that the households

Table 4: Components of the marginal propensity to consume in additions

Response to ESP (MPC_A, %)	**Persistent Additions** $\text{MPC}_{\text{A-Per}}$	**Within quality & Within product groups**	**Between quality & Within product groups**	**Between product groups**
Month before, β_{-1}	0.65**	1.25**	0.08	0.24*
	(0.29)	(0.50)	(0.25)	(0.14)
Month of receipt, β_0	0.93**	2.33***	0.17	0.13
	(0.37)	(0.65)	(0.31)	(0.15)
Month after, β_1	1.42***	3.01***	0.12	0.20
	(0.52)	(0.86)	(0.39)	(0.18)
Number of observations	324324	324324	324324	324324
Number of households	6237	6237	6237	6237

In column 1 the dependent variable is additions in products repurchased at least once in one of the 52 weeks after t, $\widetilde{a}^{per}$. Columns 2, 3 and 4 decompose MPC_A in Table 3 as the sum of the three components indicated by column, once varieties are partitioned into 10 quality bins and 95 product groups.

spending more on additions (top tercile) are 7 percent more likely to occasionally regret their purchases than those spending less in additions (bottom tercile), see Appendix A for further details. To better characterize how households adopt new varieties, in the Appendix we also studied the time profile of expenditure in varieties newly added by the household to her consumption basket and find that (i) the first purchase of the household in a newly added variety is on average small in value, (ii) the probability of repurchasing the variety in the future is relatively low, but (iii) conditional on repurchasing the household spends in the newly added variety as much as she spends in other varieties she regularly buys. Overall, this evidence suggests that at first the household is uncertain whether it will like the new variety and therefore spends little on it. If it turns out to like the new variety, it then treats it like the others it typically buys. If not, it stops buying it, with some regret for the initial purchase.

4 Household's problem: McFadden meets Ramsey

We build on a conventional random utility model of discrete choice of products à la McFadden (1973, 1974) to match the high level of additions observed in the data. Time t is discrete. In each period the household has a set of varieties she considers for consumption: the *consideration set*. Varieties in the consideration set are subject to preference shocks that produce turnover in the consumption basket. We embed the discrete choice model in a standard dynamic optimization problem à la Ramsey (1928) where the household decides saving and *adoption expenditure*, i.e. how many varieties to sample so as to enlarge the consideration set. We first characterize the economy, then solve for the static maximization problem of allocating expenditures to varieties in the consideration set. Finally we turn to dynamic optimization. Section 7 studies the economy in general equilibrium.

4.1 The economy

The household is infinitely lived and maximizes the expected present value of the utility from consumption $u(c_t)$, with $u' > 0$ and $u'' < 0$. The subjective discount factor is $\rho \in (0,1)$. In the economy there are $\mathcal{V}_t = [0,1] \times [0, v_t]$ varieties corresponding to a measure 1 of sectors, each containing v_t distinct varieties, see Figure 2. In sector $j \in [0,1]$ at time t, the household considers buying a *discrete* number of varieties $n_{jt} \geq 0$ that are in her consideration set for the sector $\Omega_{jt} \subseteq [0, v_t]$, see Figure 2. We denote by $q_{\nu j}$ the amount of variety $\nu \in \Omega_{jt}$ in sector $j \in [0,1]$ consumed. Consumption is equal to

$$c_t = \left[\int_0^1 \left(\sum_{\nu \in \Omega_{jt}} z_{\nu jt} q_{\nu j} \right)^{\frac{\sigma-1}{\sigma}} dj \right]^{\frac{\sigma}{\sigma-1}}, \tag{21}$$

which means that varieties are differentiated across sectors with a constant elasticity of substitution $\sigma > 1$; within each sector, they are perfectly substitutable. As in standard random utility models of discrete choice, the unit value of a variety $\nu \in \Omega_{jt}$ is subject to preference shocks $z_{\nu jt}$ which are iid drawings from a Fréchet distribution with shape parameter $\kappa > \sigma - 1$ and scale parameter equal to 1.[12]

All varieties are sold at the same price, equal to P_t in monetary terms. Hereafter, we set a variety in $\mathcal{V}_t$ as the numeraire. At t, the household obtains (gross) capital income $\iota_t \, a_{t-1}$ and other income y_t (endogenized in Section 7.2) and decides her *total expenditure* e_t and savings a_t subject to the constraint:

$$e_t + a_t \leq \iota_t \, a_{t-1} + y_t. \tag{22}$$

Household's total expenditure e_t is the sum of expenditures for consumption

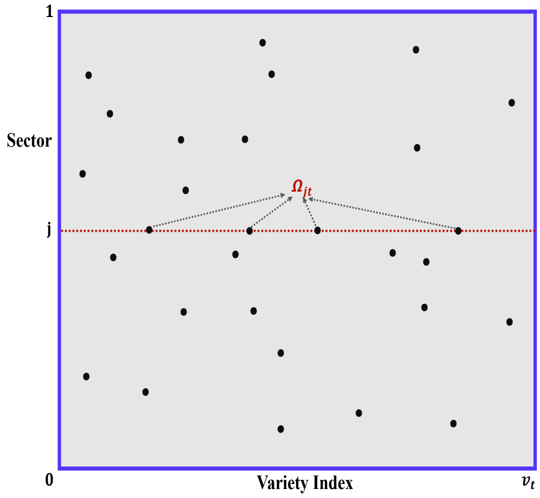
$$s_t = \int_0^1 \sum_{\nu \in \Omega_{jt}} q_{\nu j} dj \tag{23}$$

[12]The CDF of a Fréchet distribution is equal to $\Pr(X \leq x) = e^{-\left(\frac{x}{s}\right)^{-\kappa}}$ with support $x > 0$, where κ and s are the shape and scale parameter, respectively. Its expected value is equal to

$$E(X) = \begin{cases} s\Gamma\left(1 - \frac{1}{\kappa}\right) & \text{if } \kappa > 1 \\ \infty & \text{if } \kappa \leq 1 \end{cases}.$$

The Fréchet distribution is max-stable, which we use extensively to achieve analytical tractability.

Figure 2: The space of varieties and the household's consideration set



Each bullet point represents a variety in the household's consideration set. The union of all the points has the cardinality of the continuum.

and expenditures on experimenting with new varieties to be added to her time-t consideration sets, $x_t \in R^2_+$, so that

$$e_t \equiv s_t + x_t. \tag{24}$$

We refer to x_t as *adoption expenditure*. Experimentation is fully random over the space of varieties $\mathcal{V}_t$.[13] With adoption expenditure x, the household finds varieties to be added to her time-t consideration sets according to a Poisson process over the space $\mathcal{V}_t$ with intensity

$$\Lambda_t(x) = e^{\lambda_t}\Lambda(x), \tag{25}$$

where $\Lambda(x)$ is increasing and concave in x, $\Lambda'(x) > 0$ and $\Lambda''(x) < 0$.[14] Changes in the search technology λ_t may be due to firms' advertising, the availability of varieties in the market v_t or household's search effort. Newly found varieties in sector j are added to the consideration set Ω_{jt}. From time $t-1$ to t, there is an iid probability $\delta \in (0,1)$ that the household drops a variety from the consideration set, either because she (permanently) changes habits (or forgets about the variety), which happens with probability δ_p, or because the variety is withdrawn from the market, which happens with probability δ_f. As a result, $1-\delta \equiv (1-\delta_p)(1-\delta_f)$. We assume that the initial number of varieties (at time zero) in

[13]Random experimentation also implies that there is no memory of varieties unsuccessfully tried in the past. The assumption is that a variety might have to be tried more than once before the household starts to appreciate it and brings it into the consideration set.

[14]This means that if the household spends $\widehat{\delta} \in R_+$ units on $\widehat{\delta}$ different varieties, the probability of finding one is $\Lambda_t(x)\widehat{\delta}$, the probability of finding none is $1-\Lambda_t(x)\widehat{\delta}$, and the probability of finding more than one is of an order smaller than $\widehat{\delta}$. Notice that if $x \in R^2_+$ the mass of varieties found belongs to R_+, while if $x \in R_+$ the number of varieties found is a (random) natural number. Finally notice that, since the amount spent on varieties added to the consideration set is infinitesimal, these expenditures yields no consumption utility in (21).

the household's consideration set for a sector is distributed as a Poisson distribution with expected value μ_{-1}. In Appendix B we show that the Poisson property is preserved over time so that:

Lemma 1. *Let $f_t(n)$ denote the fraction of sectors whose consideration set contains $n \geq 0$ varieties at time $t \geq 0$. If $f_0(n)$ is a Poisson distribution with mean μ_0, then $f_t(n)$ is also a Poisson distribution, $f_t(n) \equiv \frac{\mu_t^n e^{-\mu_t}}{n!}$, with mean μ_t which evolves as follows:*

$$\mu_t = (1 - \delta)\, \mu_{t-1} + \Lambda_t(x_t). \tag{26}$$

4.2 Static maximization

For given consumption expenditure s_t in (23), consumption c_t is obtained by maximizing (21) with respect to $q_{\nu j} \geq 0$ $\forall \nu \in \Omega_{jt}$ and $\forall j \in [0, 1]$. The solution to the problem is characterized by the following proposition proved in Appendix B:

Proposition 1. *Consumption in (21) satisfies $c_t = \frac{s_t}{p_t}$ where p_t is the welfare-relevant household price index equal to*

$$p_t = p(\mu_t) = \left[\Gamma\left(1 - \frac{\sigma - 1}{\kappa}\right) \sum_{n=0}^{\infty} n^{\frac{\sigma-1}{\kappa}}\, f_t(n) \right]^{-\frac{1}{\sigma-1}}. \tag{27}$$

Household consumption expenditure satisfies $s_t = \sum_0^\infty s_{nt} f_t(n)$, where

$$s_{nt} = \frac{n^{\frac{\sigma-1}{\kappa}}}{\sum_{m=0}^{\infty} m^{\frac{\sigma-1}{\kappa}}\, f_t(m)}\, s_t \tag{28}$$

denotes average consumption expenditure in a sector with a consideration set of n varieties.

From Lemma 1, the welfare-relevant household price index p_t in (27) is a function of only the average number of varieties in the consideration set μ_t. p_t has a constant elasticity, $1/(\sigma - 1)$, with respect to the mass of sectors with a non-empty consideration set, equal to $1 - f_t(0)$. This reflects the *love-of-variety* motive built into the CES aggregator in (21). Given a non-empty consideration set in a sector, the size of the set still matters for the price index, because a greater number of varieties n_{jt} in Ω_{jt} increases the value of the variety consumed by the household: formally, $E\left(\max_{\nu \in \Omega_{jt}} z_{\nu jt}\right) = \Gamma\left(1 - 1/\kappa\right) n_{jt}^{1/\kappa}$ is increasing in $n_{jt} > 0$ with elasticity $1/\kappa$. The marginal value of one more variety in the consideration set is greater when κ or σ is smaller: smaller κ implies that a specific variety is more likely to have little value, while smaller σ implies that varieties in a sector can be less easily replaced by varieties in other sectors. Both effects make a larger consideration set more valuable.

4.3 Optimal adoption expenditure

Given the law of motion of μ_t in (26), the budget constraint in (22), and the income process y_t, the household chooses total expenditure, $e_t \geq 0$, adoption expenditure $x_t \geq 0$, and savings a_t to maximize

$$\mathbb{E}_t \left[\sum_{j=t}^{\infty} \rho^{j-t} u\left(\frac{e_j - x_j}{p(\mu_j)} \right) \right]. \tag{29}$$

The following Proposition proved in Appendix B characterizes the solution to the problem:

Proposition 2. *Adoption expenditure x_t satisfies the following Euler condition $\forall t$*

$$1 = \frac{\Lambda_t'(x_t)\, \eta(\mu_t)}{\mu_t} (e_t - x_t) + (1-\delta)\, \mathbb{E}_t \left[\rho_{t,t+1} \frac{\Lambda_t'(x_t)}{\Lambda_{t+1}'(x_{t+1})} \right], \tag{30}$$

where

$$\rho_{t,t+j} \equiv \rho \frac{p_t}{p_{t+j}} \frac{u'\left(c_{t+j}\right)}{u'\left(c_t\right)} \tag{31}$$

is the household discount factor at t for income in period $t+j$, and

$$\eta(\mu_t) \equiv -\frac{d \ln p(\mu_t)}{d \ln \mu_t} = \frac{1}{\sigma - 1} \left[\frac{\sum_{n=0}^{\infty} n^{\frac{\sigma-1}{\kappa}+1} f(n;\mu_t)}{\sum_{n=0}^{\infty} n^{\frac{\sigma-1}{\kappa}} f(n;\mu_t)} - \mu_t \right] \tag{32}$$

is the elasticity of the household price index with respect to μ_t, which satisfies $\eta(\mu_t) \in [0, 1/(\sigma-1)]$. Total expenditure e_t solves the following standard Euler condition $\forall t$

$$1 = \mathbb{E}_t \left(\rho_{t,t+1}\, \iota_{t+1} \right). \tag{33}$$

The Euler condition in (30) implies that x_t maximizes (29) taking as given the optimal path of total expenditure e_t: conditional on e_t, the choice of x_t is independent of the sources of the fluctuations in e_t (say whether they are due to changes in income or financial returns). The left-hand-side of (30) is the marginal cost of sampling the space of existing varieties. The right-hand-side is the sum of the instantaneous gain plus its continuation value. The instantaneous gain comes from the reduction in the price index following an increase of $\Lambda_t'(x)$ in μ, which increases consumption c, for given total expenditure e. The continuation value is determined by noticing that, from tomorrow's standpoint, the household is indifferent between spending 1 unit on adoption today and $1-\delta$ tomorrow, since a fraction δ of today's investment gets lost. The instantaneous gain is greater, when total expenditure e_t is higher, because a given reduction in the price index is more beneficial. This is a *scale* effect typically present in models with love of variety. The continuation value is greater when today's consumption is temporarily higher, which increases $\rho_{t,t+1}$ in (31). As a result, the household spends more on adoption, which persistently lowers the household price index. Essentially, the adoption of more varieties is a form of investment which persistently reduces the welfare-relevant household price index and helps the household in achieving better *consumption smoothing.* The Euler condition for total expenditure in (33) can be extended to allow for more financial assets and adjustment costs in portfolio rebalancing, as in Kaplan and Violante (2014). This would generate empirically plausible values for the marginal propensity to consume, still leaving (30) unchanged (provided $x_t > 0$).

4.4 Additions, removals and the intensive margin

As in (7), the growth rate of total expenditure can be expressed as equal to

$$\frac{e_t - e_{t-1}}{e_{t-1}} = N_{rt} + I_{rt} = A_{rt} - R_{rt} + I_{rt}, \tag{34}$$

where net additions N_{rt}, additions A_{rt}, removals R_{rt} and the intensive margin I_{rt} are defined as in Section (2.1), with $N_{rt} = A_{rt} - R_{rt}$. In Appendix B we derive analytical expressions for these variables. Here we briefly discuss their key features, emphasizing the distinction between flows into and out of the consumption basket, which we observe, and flows due to changes in the consideration set, which we can only infer indirectly and which we refer to as *true* additions and removals. Additions are the sum of the following three terms:

$$A_{rt} = \frac{x_t}{e_{t-1}} + \frac{\Lambda_t(x_t)}{\mu_t}\frac{s_t}{e_{t-1}} + \left[\frac{(1-\delta)^2\mu_{t-2}}{\mu_t}\frac{s_t}{e_{t-1}} - \tilde{e}_t^1\right]. \tag{35}$$

The first term on the right-hand side of (35) stands for adoption expenditure x_t, which by definition involves new varieties. The second term is the contribution of *true additions* to the household's consideration set: expenditure on newly added varieties to the consideration set whose preference draw is the highest among the varieties in the consideration set, an event which happens with probability $\Lambda_t(x_t)/\mu_t$. Finally, the third term in square brackets measures additions to the consumption basket that do not reflect a change in the consideration set. These *noisy* additions are due to preference shocks that make the household purchase a variety that was already in her consideration set at time $t-1$ but was discarded in favor of another variety. Noisy additions are calculated as the difference between the expenditure at time t (as a share of e_{t-1}) in varieties already in the consideration set at $t-2$, which happens with probability $(1-\delta)^2\mu_{t-2}/\mu_t$, and the portion of this share on varieties that were also purchased at $t-1$, which is equal to $\tilde{e}_t^1$ (for the analytical expression of this, see Appendix B).[15]

[15] Notice that the expenditure at time t on varieties added to the consideration set at time $t-1$ always contributes to the intensive margin, since the variety was consumed for sure at $t-1$ as part of the household's adoption expenditure.

Analogously, removals can be expressed as

$$R_{rt} = \frac{x_{t-1}}{e_{t-1}} + \frac{\delta s_{t-1}}{e_{t-1}} + \left[\frac{(1-\delta)s_{t-1}}{e_{t-1}} - \tilde{e}^0_{t-1}\right]. \tag{36}$$

The first term on the right-hand side of (36) is the contribution of past adoption expenditure x_{t-1}, which necessarily leads to removals because the portion of x_{t-1} spent on varieties newly added to the consideration set at $t-1$ has zero measure. The second term corresponds to *true* removals from the consideration set, which happens with probability δ. Finally the third term measures removals due to preference shocks that make the household opt for a variety different from that consumed at $t-1$ even if the latter is still in the consideration set at t. These *noisy* removals are expressed as the difference between the share of $t-1$ expenditure on varieties still in the consideration set at t (probability $1-\delta$) minus the portion of this share on varieties purchased also at t, which is equal to $\tilde{e}^0_{t-1}$ (for an analytical expression, see Appendix B). Finally the intensive margin is obtained as a residual using (34), which yields

$$I_{rt} = \frac{(1-\delta)\Lambda_{t-1}(x_{t-1})}{\mu_t}\frac{s_t}{e_{t-1}} + \tilde{e}^1_t - \tilde{e}^0_{t-1}. \tag{37}$$

Finally notice that the flows N_t, A_t, R_t, and I_t in Section (2.1) are nominal while the flows in (34)-(37) are real—we use a variety as the numeraire. Given the monetary price of a variety P_t, we use the following simple identities to go from real to nominal flows:

$$\frac{\Delta E_t}{E_{t-1}} = \frac{\frac{P_t}{P_{t-1}}e_t - e_{t-1}}{e_{t-1}}, \quad A_t = \frac{P_t}{P_{t-1}}A_{rt}, \quad R_t = R_{rt}, \quad N_t = A_t - R_t, \quad I_t = \frac{\Delta E_t}{E_{t-1}} - N_t. \tag{38}$$

5 Calibration and response to the ESP

We calibrate the model by targeting detailed statistics from KNCP. Then we analyze how well the model matches the effects of the 2008 ESP, as estimated in Section 3.

5.1 Calibration

The model is specified at the quarterly frequency and calibrated in a steady state with total expenditure $\bar{e}$ normalized to one and zero inflation, $P_t = P_{t-1}$. The consumption-utility is $u(c) = \left(c^{1-\gamma} - 1\right)/(1-\gamma)$ and the Poisson arrival rate in (25) is $e^{\bar{\lambda}}\Lambda(\bar{x})$ with

$$\Lambda(x) = x\left[1 - \frac{1}{1+\alpha}\left(\frac{x}{\chi}\right)^{\alpha}\right], \tag{39}$$

where $\bar{\lambda}$ measures steady state search efficiency, $\alpha \geq 0$ determines decreasing returns to adoption expenditure and $\chi \geq 0$ is the maximum efficient level of adoption expenditure. Table 5 reports the calibrated parameter values with the associated calibration targets.

The curvature parameter of the utility function γ and the subjective discount factor ρ are set to the standard values of $\gamma = 1$ (log-preferences) and $\rho = 0.99$. To calibrate the exit rate of varieties from the consideration set δ, we notice that, in steady state, the share of expenditure at $t + \tau$ on varieties that the household has first purchased at t is equal to

$$A^F(\tau) = (1-\delta)^\tau \frac{\delta(\bar{e} - \bar{x})}{\bar{e}}, \quad \tau \geq 1 \tag{40}$$

which uses the steady state identity $\Lambda(\bar{x})/\mu = \delta$. At t, the household adds $\Lambda(\bar{x})$ new varieties to her consideration set. Since varieties exit the consideration set at rate δ, the share of expenditure at $t+\tau$ on varieties added to the consideration set at t, as given by (40), falls at rate δ as τ increases. Solving for δ in (40), we obtain $\delta = 1 - [A^F(7)/A^F(3)]^{1/4}$, where we focus on an interval 4 quarters apart to control for seasonal effects in shopping behavior. To evaluate $A^F(3)$ and $A^F(7)$, we consider a panel of about 20,000 households continuously present in KNCP from 2004 though 2008, thereby excluding the Great Recession that in KNCP first materializes in 2009. We identify all varieties purchased in I:07 (first quarter of 2007), that were never purchased by the household in any of the previous ℓ quarters for $\ell = 1, 2...12$. In IV:07, $\tau = 3$, and IV:08, $\tau = 7$, we calculate the average quarterly share of expenditure on the varieties purchased in I:07 but not purchased in any of the ℓ quarters before I:07. For both $\tau = 3$ and $\tau = 7$, the data are decreasing in ℓ and we fit an exponential regression model over ℓ—containing a constant and three terms in $\exp(-\tilde{\beta}_i \ell)$ $i = 1, 2, 3$. We take the horizontal asymptote of the regression model (the constant) as measuring $A^F(\tau)$. We find $A^F(3) = 0.0220$ and $A^F(7) = 0.0165$, which imply a δ of roughly 7 percent.

To calibrate the 5 remaining parameters $[\bar{\lambda}, \alpha, \chi, \kappa, \theta]$, we target a steady state quarterly addition rate of 0.492, corresponding to its average level in 2007, which implicitly identifies search efficiency $\bar{\lambda}$. We also target the fraction of household's expenditure in a quarter on varieties that the household has never purchased before. In the model it corresponds to the share of expenditure in adoption and true additions, which after using the steady state identity $\Lambda(\bar{x})/\mu = \delta$, can be written as

$$A^R_\infty = \frac{\bar{x} + \delta(\bar{e} - \bar{x})}{\bar{e}}. \tag{41}$$

To estimate A^R_∞, we again rely on our sample of 20,000 households continuously present in KNCP before the Great Recession. In each quarter of 2007 we calculate the fraction of household's expenditure on varieties that the household has not purchased in any of the previous $\ell = 1, 2...12$ quarters and fit the same exponential regression model over ℓ as before. The horizontal asymptote yields $A^R_\infty = .179$, which together with the calibrated value of δ, implies $\bar{x} = 11.74\%$. We repeat the same exercise for households with different (average) expenditures in 2007. We take these statistics as representative of how adoption

Table 5: **Baseline calibration**

Model		Data	
Parameter	Value	Moment	Value
$\bar{e}$	1	Steady state expenditure	1
ρ	0.99	Quarterly real interest rate	.01
γ	1	Elasticity of inter-temporal substitution	1
δ	0.071	Attrition rate on new varieties, $A^F(7)/A^F(3)$	.069
κ	11.4	Quarterly additions	.490
$\bar{\lambda}$	0.89	Expenditure share on new varieties if $e = 1$	.179
σ	5.1	Expenditure share on new varieties if $e = .398$	.204
α	9.0	Expenditure share on new varieties if $e = .893$	.180
χ	0.19	Expenditure share on new varieties if $e = 1.858$	.150

expenditure x and the adoption rate $\Lambda(x)$ would vary across steady states with different total expenditure e. This variation identifies the curvature of the function Λ (determined by α and χ) and the marginal value of adding varieties to the consideration set—the elasticity η in (32)—, which depends on the Fréchet parameter κ and the parameter governing the elasticity of substitution across sectors θ. We consider households with expenditures (i) in the bottom quintile of the distribution of expenditures $e = .40$ (average expenditure in the group equal to 40% of average expenditure in the population); (ii) in the median quintile $e = .89$; and (iii) in the top quintile $e = 1.86$. As predicted by the model, wealthier households devote a smaller share of their expenditure to adoption: A^R_∞ is decreasing in total expenditures e. The value of A^R_∞ for $e = .398$, $e = .893$ and $e = 1.858$ is equal to .204, .180, and .150, respectively. Given the five targets, we solve a system of non-linear equations in the unknowns $[\bar{\lambda}, \alpha, \chi, \kappa, \theta]$. In a sector, our household with $\bar{e} = 1$ has an average number of varieties in her consideration set equal to $\bar{\mu} = 1.5$. The elasticity of $\Lambda(x)$ with respect to x at $\bar{x}$ is close to 1 (99 percent).

5.2 Response to the ESP

As discussed in Section 4.3, (30) determines optimal adoption expenditure x_t given the (expected) path of total expenditure e_t, which is sufficient to characterize the dynamics of additions, removals, and the intensive margin, see (35), (36), and (37). We rely on these properties to evaluate the effects of the 2008 ESP in the model. We take the response of total expenditure, e_t, to the ESP as given and solve for the optimal response of x_t implied by (30) using global (non-linear) methods with the parameter values of Table 5. ESP is assumed to (unexpectedly) increase e_t by 4.72% in one quarter only, equivalent to the simple average of β_{-1}, β_0 and β_1 in column 1 of Table 3. We simulate the consumption histories of 10,000 households, initially in a steady state with constant expenditure $\bar{e}$, over six years (24 quarters) and compare the model responses of net, gross and persistent additions to the increase in total expenditure by 4.72% with the estimates reported in Tables 3 and 4. As in Section 3, net and gross additions are calculated using a four-year reference period, while persistent additions correspond to additions of varieties purchased again at least once in the following 4 quarters. Table 6 reports the impact response to the ESP shock of logged total expenditure (column 1), the intensive margin (column 2), net additions (column 3), additions (column 4) and persistent additions (column 5). The first row corresponds to the data, the second to the model, and the third to a counterfactual model where adoption expenditure is assumed to remain constant at its steady state value. We take the counterfactual as a representation of the conventional view discussed in the

Table 6: Response of expenditure to the 2008 tax rebate

Dollars spent on ESP (%)	**Total** MPC_E	**Intensive** MPC_I	**Net** MPC_N	**Gross** MPC_A	**Persistent** $MPC_{A^{pers}}$
Data (3-month average)	4.72	2.80	1.92	2.51	1.00
Baseline model	4.72	2.60	2.12	2.79	0.88
Counterfactual model, constant x_t	4.72	4.39	0.33	0.33	0.26

MPC stands for Marginal Propensity to Consume in total expenditure (column 1), intensive margin (column 2), net additions (column 3), additions (column 4) and persistent additions (column 5). The first row reports the average of the coefficients β_{-1}, β_0 and β_1 of Table 3. The second row reports the model responses to a (one-quarter only) shock in logged expenditure $\ln e_t$ of 0.0472. The third row reports the response in the counterfactual model where adoption expenditure remains constant at its steady-state value. Additions and removals are calculated using a four-year reference period. Persistent additions are additions of varieties repurchased at least once in the following 4 quarters. The model is at the quarterly frequency with the parameter values of Table 5.

introduction, where the household's consideration set is (exogenously) determined just by the aggregate supply of varieties, which given the source of identification in the data can be assumed to be unchanged. The data indicate that net and gross additions account for more than a third of the overall response of total expenditure with more than a third of the increase in additions due to persistent additions. The model response of net, gross, and persistent additions is roughly in line with the data. The increase in adoption expenditure x_t is important for the result: x_t increases (by roughly 10 percent) first because varieties are generally more valuable, due to the scale effect, and secondly because the increase in x_t persistently reduces the household price index p_t, which enables the household to better smooth consumption over time. The rise in x_t makes the number of varieties in the consideration set of the household go up, which drives the increase in gross and persistent additions. The counterfactual model with constant adoption expenditure fails in replicating the data: the intensive margin accounts for more than 90 percent of the response of total expenditure, gross additions increase by 0.33 compared with 2.51 in the data, and persistent additions moves little (0.26 in the counterfactual model against 1.00 in the data).[16]

6 Time series evidence

We rely on the Kalman filter to estimate the time series of adoption expenditure and evaluate the cyclical properties of the model.

6.1 The time series of adoption expenditure

We estimate the in-sample profile of adoption expenditure x_t by full information maximum likelihood. Since we take the time series of total expenditure e_t as given, results are robust to the nature of the aggregate shocks that drive e_t. The household's adoption rate satisfies (25) with Λ given in (39) and search efficiency which follows the AR(1) process

$$\lambda_t = \bar{\lambda} + \varrho_\lambda \left(\lambda_{t-1} - \bar{\lambda} \right) + \epsilon_t^\lambda. \tag{42}$$

Logged total expenditure evolves as an autoregressive integrated moving average process, $B^e(L) \ln(e_t) = G^e(L) \epsilon_t^e$, where $B^e(L)$ and $G^e(L)$ are polynomials in the lag operator L. Based on an Akaike information criterion, we eventually choose an AR(1) process with serial correlation ϱ_e. The innovations ϵ_t^λ and ϵ_t^e are both iid normal with zero mean and standard deviation equal to ϑ_λ and ϑ_e, respectively. Since households adjust their total expenditure

[16] In the counterfactual model, persistent additions increase just because, upon receipt of ESP, the household spends more on all varieties and some of them will be repurchased again in the next 4 quarters due to random variation in the varieties that the household chooses to consume in a period.

endogenously, ϵ_t^e and ϵ_t^λ have correlation $\vartheta_{e\,\lambda}$ possibly different from zero. We log-linearize (26), (30), (35) and (36) and use the Kalman filter to evaluate the likelihood function of the series of quarterly net additions N_{rt} and logged total expenditure $\ln e_t$ of Section 2, converted into real value using (38) with P_t equal to the household's personal consumption price deflator from the Bureau of Economic Analysis (Mnemonic DFXARG3Q086SBEA).[17] In writing the likelihood function we acknowledge that net additions are four-quarters moving averages (see Appendix C). Given the parameter values of Table 5, we maximize the likelihood function with respect to the vector of parameters $[\varrho_e, \varrho_\lambda, \vartheta_e, \vartheta_\lambda, \vartheta_{e\,\lambda}]$ and the initial unobserved states of the system, i.e. the values of μ_t, λ_t, and e_t in the pre-sample period. Table 7 reports the estimated parameters with the associated standard errors.[18] The point estimate of the correlation between total expenditure and search efficiency, $\vartheta_{e\,\lambda}$, is negative in line with the thesis that households' search intensity is counter-cyclical.

Table 7: Parameter estimates

	ϱ_e	ϑ_e	ϱ_λ	ϑ_λ	$\vartheta_{e\,\lambda}$
ML estimates	0.82	0.013	0.20	0.006	-0.25
Standard errors	0.07	0.001	0.21	0.001	0.19

Maximum Likelihood estimates and standard errors of the parameters $[\varrho_e, \vartheta_e, \varrho_\lambda, \vartheta_\lambda, \vartheta_{e\,\lambda}]$. The likelihood function is calculated using the Kalman filter. The sample period is I:07-IV:14. Observables are net additions, N_{rt}, and logged expenditure, $\ln e_t$, both in real value.

We apply the Kalman smoothing algorithm to recover the in-sample profile of search efficiency λ_t, adoption expenditure x_t, consumption c_t, the price index p_t, the average number of varieties in the consideration set μ_t, and the adoption rate $\Lambda_t(x_t)$, all in logs. The time series for x_t corresponds to the dashed red line in panel (a) of Figure 3, which also plots total expenditure e_t (solid blue line). Since x_t falls during the recession, the consideration set shrinks (μ_t falls) and over the period 2008-2012 the welfare-relevant household price index p_t increases by around 60 basis points relative to its steady state value (see the solid blue line in panel (b) of Figure 3). p_t increases because the average number of varieties purchased by the household and the average value of each purchase both fall. The dotted

[17] We also correct for the negative bias in the trend of expenditure in KNCP by rescaling its average growth rate by a constant factor so as to match the overall increase of personal consumption expenditure from BEA (Mnemonic DFXARC1Q027SBEA) over the period 2007-2014. Attanasio, Battistin, and Leicester 2006 and Bee, Meyer, and Sullivan 2015 analyze the reasons for the negative bias in the trend of expenditure from household surveys (such as CEX and KNCP) relative to expenditure from BEA.

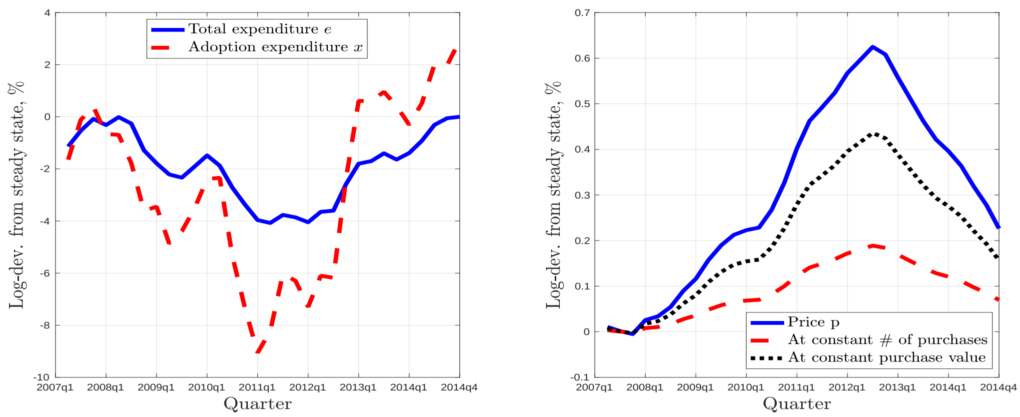
[18] The initial unobserved states of the system are not statistically different from their steady state value; for brevity, they are not reported here.

black line in panel (b) shows the contribution of the first effect, the dashed red line of the second. They correspond to the second and third term on the right hand side of

$$\ln p_t = -\frac{1}{\sigma-1}\ln\Gamma\left(1-\frac{\sigma\text{-}1}{\kappa}\right) - \frac{1}{\sigma-1}\ln\left(1-f(0;\mu_t)\right) - \frac{1}{\sigma-1}\ln\left(E_t\left[n^{\frac{\sigma-1}{\kappa}}|n>0\right]\right),$$

which is obtained by taking logs in (27). The first effect (second term) accounts for roughly two-thirds of the in-sample increase in p_t.

Figure 3: Adoption expenditure and the household price index



(a) Adoption vs total expenditure **(b) Household price index, $\ln p_t$**

6.2 Business cycle properties

Table 8 reports standard deviations and correlations with total expenditure e_t of the variables λ_t, x_t, c_t, p_t, μ_t, $\Lambda_t(x_t)$, all in logs. Adoption expenditure x_t is around two and a half times as volatile as e_t and the two series have a positive correlation of 88 percent. Since households use adoption expenditure to smooth consumption, c_t is less volatile than e_t. Search efficiency λ_t is counter-cyclical, but its volatility contributes little to the cyclical volatility of variables: shocks to search efficiency attenuate just marginally the volatility of variables. This can be seen by looking at the third row of Table 8 which reports statistics after setting all shocks in (42) to zero, $\epsilon_t^\lambda = 0$, $\forall t$.

We use (35)-(37), the identity in (38) and the price deflator P_t to calculate the intensive margin I_t, net additions N_t, and additions A_t, all in nominal terms and expressed as 4-quarters moving averages as in Section 2. Table 9 reports their standard deviations and β-coefficients on (nominal) expenditure growth $\Delta E_t/E_{t-1}$, which are the model's counterparts of the estimates in panel (b) of Table 1. The model matches the empirical properties of net and gross additions reasonably well: their contributions to changes in expenditure growth, as measured by the β-coefficients, are 56 and 51 percent in the model, compared with 57 and 58 percent in the data. In columns 3-6 of Table 9, we report the standard deviations

Table 8: Business cycle statistics

	e_t	λ_t	x_t	c_t	p_t	μ_t	$\Lambda_t(x_t)$
Standard Deviation	1.37	0.21	3.39	1.32	0.19	1.22	3.31
Correlation with e_t	1.00	-0.32	0.88	0.97	-0.66	0.66	0.87
Standard Deviation if $\lambda_t = \bar{\lambda}$	1.37	0.00	3.52	1.42	0.24	1.56	3.48

In-sample estimates using the Kalman smoothing algorithm (period I:07-IV:14). All variables are in logs, expressed in real value, and calculated as 4-quarters moving averages. Standard deviations are expressed in percentage units.

and β-coefficients of the three terms that represent additions in (35): adoption expenditure, true additions, and noisy additions (all evaluated in nominal terms). The sum of adoption expenditure and true additions accounts for roughly a half of the overall contribution of additions to the volatility of expenditure growth $\Delta E_t/E_{t-1}$.

Table 9: Cyclical contribution of additions and removals

	I_t	N_t	A_t	$A_t^{adoption}$	A_t^{true}	A_t^{noisy}
Standard deviation (%)	0.28	0.37	0.47	0.39	0.20	0.27
β-decomposition, β_X	0.43	0.57	0.54	0.17	0.13	0.24

In-sample estimates over the period I:07-IV:14. They are 4-quarter moving averages converted into nominal value using (38) and the index P_t (Mnemonic DFXARG3Q086SBEA). "β-Decomposition" is the OLS estimated coefficient β_X from regressing the variable in column, $X_t = I_t, N_t, A_t, A_t^{adoption}, A_t^{true}, A_t^{noisy}$, against the percentage change in (nominal) expenditure growth $\Delta E_t/E_{t-1}$: $X_t = \alpha_X + \beta_X \, \Delta E_t/E_{t-1} + \epsilon$.

We now evaluate whether the model matches the contribution of additions in new varieties on the market to the volatility of $\Delta E_t/E_{t-1}$, equal to 3 percent (panel (c) of Table 2). In the model, additions in new varieties are equal to:

$$A_t^n = \frac{P_t}{P_{t-1}} \left[\frac{x_t}{e_{t-1}} + \frac{\Lambda_t(x_t)}{\mu_t} \frac{s_t}{e_{t-1}} \right] \frac{v_t - (1 - \delta_f) v_{t-1}}{v_t}, \tag{43}$$

which uses the fact that, due to random search, a share $1 - (1 - \delta_f)v_{t-1}/v_t$ of adoption expenditure and true additions are on varieties new to the market. The flow of new varieties is determined by equating the cost of discovering a new variety $\xi > 0$ to its value D_t:

$$\xi = D_t. \tag{44}$$

We assume that a variety discovered at t is first on sale at $t + 1$ and, due to the existence of a competitive fringe of producers, firms set a limit price equal to a constant markup $1/\varphi$

over the marginal cost of production $\varphi \in (0,1)$. As a result:

$$D_t = (1-\varphi)\,\mathbb{E}_t\left[\sum_{j=1}^{\infty}(1-\delta_f)^{j-1}\rho_{t,t+j}\left(\frac{e_{t+j}-x_{t+j}}{\mu_{t+j}}m_{t,t+j}+\frac{x_{t+j}}{v_{t+j}}\right)\right], \tag{45}$$

which is equal to the profits per unit of the variety sold, $1-\varphi$, times the present value of income from the variety. The discount factor is $\rho_{t,t+j}$ in (31) times the surviving probability of the variety $(1-\delta_f)^{j-1}$. Income at $t+j$ is the sum of two terms. First, there are $m_{t,t+j}$ *customers* of the variety— that is households with the variety in their consideration set— who (in expected value) spend $(e_{t+j}-x_{t+j})/\mu_{t+j}$ on it. Second, the variety earns x_{t+j}/v_{t+j} as the result of household's experimentation. The customers at $t+j$ are equal to

$$m_{t,t+j} = \sum_{i=1}^{j}(1-\delta_p)^{j-i}\frac{\Lambda_{t+i}(x_{t+i})}{v_{t+i}}, \quad \forall j \geq 1 \tag{46}$$

since at each time $t+i$, $\forall i \leq j$, the firm obtains $\Lambda_{t+i}(x_{t+i})/v_{t+i}$ new customers, increasing the number of customers at $t+j$ in proportion $(1-\delta_p)^{j-i}$. In Appendix D.2, we use (44) to express $\ln v_{t+1}$ as a function of the past and future expected history of $\ln e_t$, $\ln c_t$, $\ln x_t$, and λ_t, given the information available at t. For each t over the period I:07-IV:14 these histories are calculated using the state space representation of the household's problem previously estimated. We set $\delta_f = 0.05$ (corresponding to the average attrition rate of varieties in the KNPC) and $\delta_p = 1-(1-\delta)/(1-\delta_f)$. The cost of a new variety ξ matches a ratio of R&D expenditure to total consumption expenditure of 5 percent (in line with the data), while φ is such that (44) is satisfied in steady state with $v=1$. All other parameters values are as in Table 5. Table 10 reports the standard deviation, the correlation with expenditure $\ln e_t$ and the OLS β-coefficient obtained by regressing A_t^n in (43) on expenditure growth $\Delta E_t/E_{t-1}$ in the data, baseline model, and counterfactual model with constant adoption

Table 10: Cyclical properties of the supply of varieties

Varieties in the market, v_t	St. Dev.	Correlation with e_t	A_t^n: β-coeff.
Data	0.03	0.70	0.03
Baseline model	0.03	0.81	0.03
Counterfactual model, constant x_t	0.01	0.78	0.02

Logged number of varieties on the market in model and data (linearly detrended) over the period I:07-IV:14. The last column reports the contribution of additions in new varieties A_t^n to expenditure growth $\Delta E_t/E_{t-1}$ using a β-decomposition.

expenditure. The model matches well the data. Again endogenous adoption matters for the good fit: in the model with constant adoption the standard deviation of $\ln v_t$ falls by two-thirds, and the β-coefficient on $\Delta E_t/E_{t-1}$ by one-third.

7 Implications of the extensive margin

We now discuss implications of the extensive margin for the measurement of inflation and the general equilibrium effects of fiscal transfers.

7.1 Measurement of inflation

The welfare relevant measure of inflation is $\Delta \ln (P_t p_t)$, where Δ is the first difference operator. Commonly available price indexes are based on a representative household (of the aggregate population or of one of its subgroups) and neglect differences in consideration sets across households, which introduces two types of biases when x_t is endogenous. The first is due to *aggregation*: p_t in (27) depends on the (average) number of varieties in the consideration set of each household, μ_t, while the representative household has a consideration equal to the *union* of the consideration sets of all households she represents, v_t. The second bias is due to *endogenous preferences*: the consumption utility from a variety is endogenous (increasing in μ_t) while price indexes typically assume a utility value with constant mean. To quantify the two biases, we now relate $\Delta \ln (P_t p_t)$ to the inflation measure based on the CES unified price index (CUPI) by Redding and Weinstein (2019), which extends the price index by Sato (1976) and Vartia (1976) to allow for love of variety, as in Feenstra (1994), as well as for time varying preference shocks. In the economy there is a measure 1 of households who have the same income, $\iota_t a_{t-1}$ and y_t, the same expected number of varieties in their consideration set, μ_t, and independently sample the space of varieties $\mathcal{V}_t$ $\forall t$. We use the estimated series of Section 6, to construct two versions of CUPI: one based on a hypothetical representative household, named ACUPI, and another one constructed at the household level, named HCUPI. By comparing ACUPI with HCUPI we measure the aggregation bias. By comparing $\Delta \ln (P_t p_t)$ with HCUPI we measure the bias introduced by endogenous preferences. Overall we find that only the aggregation bias is quantitatively important.

ACUPI As in Redding and Weinstein (2019) we could postulate the existence of a *representative household* with CES preferences over the set of available varieties $\mathcal{V}_t \in R^2_+$

$$C_t^A = \left(\int_0^1 C_{jt}^{\frac{\sigma_b - 1}{\sigma_b}} dj \right)^{\frac{\sigma_b}{\sigma_b - 1}} \quad \text{with} \quad C_{jt} = \left[\int_0^{v_t} (\varphi_{\nu jt} e_{\nu jt})^{\frac{\sigma_w - 1}{\sigma_w}} d\nu \right]^{\frac{\sigma_w}{\sigma_w - 1}}, \tag{47}$$

and $\sigma_b, \sigma_w > 1$, where $e_{\nu jt}$ denotes time-t aggregate expenditure in variety $\nu \in [0, v_t]$ in sector $j \in [0, 1]$, whose utility value is $\varphi_{\nu jt}$. Since all sectors are symmetric and varieties are sold at the same nominal price P_t, the exact price index implied by (47) is $P_t p_t^A$ where

$$p_t^A = \left(\int_0^{v_t} {\varphi_{\nu jt}}^{1-\sigma_w} d\nu \right)^{\frac{1}{\sigma_w - 1}}. \tag{48}$$

We denote by Ω_{jt}^A the set of varieties in sector j consumed by the representative household at $t-1$ and at t: $e_{\nu jt-1} > 0$ and $e_{\nu jt} > 0$ $\forall \nu j \in \Omega_{jt}^A$. Since a variety exits the market with probability δ_f, the mass of varieties in Ω_{jt}^A is equal to $N_t^A \equiv (1 - \delta_f) v_{t-1}$. We also denote by λ_t^{AF} the expenditures at time t in varieties in Ω_{jt}^A as a share of total expenditures

$$\lambda_t^{AF} = \frac{\int_{\Omega_{jt}^A} e_{\nu jt} d\nu}{e_t}, \forall t$$

and by $s_{\nu jt}^A \equiv e_{\nu jt} / (e_t \lambda_t^{AF})$ the time-t expenditures on variety νj as a share of the expenditures on all varieties in Ω_{jt}^A. Redding and Weinstein (2019) normalize the preference shocks $\varphi_{\nu jt}$'s to be time invariant on average so that $\forall t$

$$\int_{\Omega_{jt}^A} \ln \varphi_{\nu jt} d\nu = \int_{\Omega_{jt}^A} \ln \varphi_{\nu jt-1} d\nu, \tag{49}$$

and use this normalization to rewrite $\Delta \ln P_t^A$ (see Appendix E for details) as follows

$$\Phi^{ACUPI} \equiv \Delta \ln \left(P_t p_t^A \right) = \frac{1}{\sigma_w - 1} \Delta \ln \lambda_t^{AF} + \Phi^{ACCV}, \tag{50}$$

where Φ^{ACCV} corresponds to the CES exact price index for common varieties

$$\Phi^{ACCV} = \Delta \ln P_t + \frac{1}{\sigma_w - 1} \frac{\int_{\Omega_{jt}^A} \Delta \ln s_{\nu jt}^A d\nu}{N_t^A}. \tag{51}$$

The term $\frac{1}{\sigma_w - 1} \Delta \ln \lambda_t^{AF}$ in (50) is the correction term proposed by Feenstra (1994) to measure how the net entry of varieties in the households' consumption basket affects welfare under love of variety. The first term in the right hand side of (51) is the (average) price of single varieties, which is the basis of the US Consumer Price Index (CPI), while the second is the change in the geometric mean of relative expenditures shares for common varieties. With $\sigma_w > 1$, this term falls when expenditure shares become more dispersed: since varieties are substitute in (47), an increase in the dispersion of preference shocks $\varphi_{\nu jt}$'s increases welfare (reduces the price index) because the household can substitute away from varieties with a low preference shock to varieties with a high preference shock. This term measures the effects of time varying preferences on inflation and it is novel relative to the price indexes by Sato (1976), Vartia (1976), and Feenstra (1994).

HCUPI One can proceed analogously and construct the CUPI by Redding and Weinstein (2019) at the household level. Let Ω_t^H denote the set of varieties that the household consumes at $t-1$ and at t: $q_{\nu jt-1} > 0$ and $q_{\nu jt} > 0$ in (23).[19] Let λ_t^{HF} denote the expenditures at time t on all varieties in Ω_t^H as a fraction of total expenditures e_t. Finally, let s_{jt}^H denote the expenditures at time t on the variety consumed by the household in sector j as a share of $e_t \lambda_t^{HF}$. In Appendix E, we show that

$$\Delta \ln \left(P_t p_t\right) = \Phi_t^{HCUPI} - \frac{\int_{\Omega_t^H} \Delta \ln \widehat{z}_{jt} dj}{N_t^H} + \frac{1}{\sigma - 1} \Delta \ln \left(\frac{e_t}{e_t - x_t} \right), \tag{52}$$

where $\hat{z}_{jt} \equiv \max_{i \in \Omega_{jt}} \{z_{\nu jt}\}$ is the consumption utility of the variety consumed in sector j and $N_t^H \in [0, 1]$ is the mass of varieties in Ω_t^H. The first term in the right hand side of (52) corresponds to the household level CUPI by Redding and Weinstein (2019):

$$\Phi_t^{HCUPI} \equiv \frac{1}{\sigma - 1} \Delta \ln \lambda_t^{HF} + \Phi_t^{HCCV} \tag{53}$$

where $\frac{1}{\sigma-1} \Delta \ln \lambda_t^{HF}$ is the household level variety correction term by Feenstra (1994) and Φ_t^{HCCV} is the analogue of (51) at the household level:

$$\Phi_t^{HCCV} \equiv \Delta \ln P_t + \frac{1}{\sigma - 1} \frac{\int_{\Omega_t^H} \Delta \ln s_{jt}^H dj}{N_t^H}. \tag{54}$$

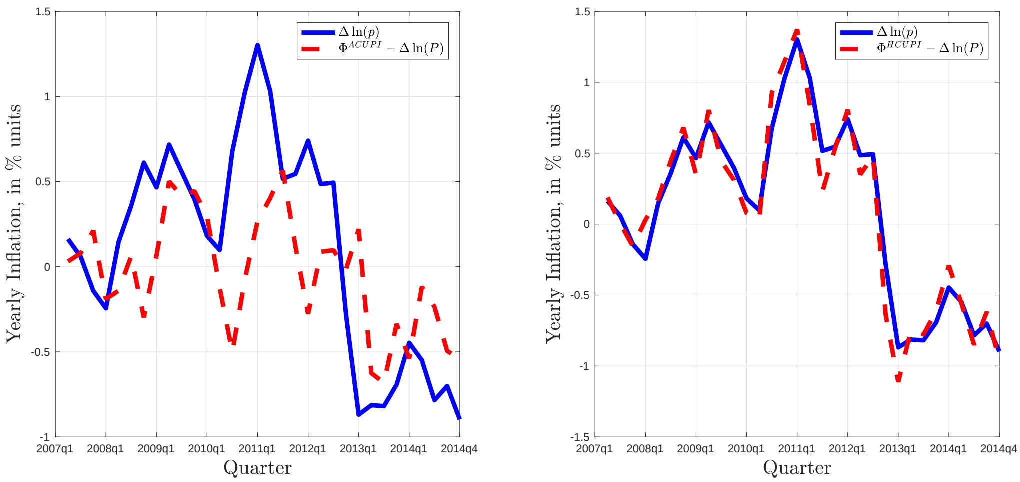
The first term in the right hand side of (54) is CPI inflation, the second is the geometric mean of relative expenditures shares for common varieties, which falls when expenditure shares become more dispersed: with $\sigma > 1$, more dispersed preferences increase welfare (reduce p_t) because the household substitutes away from varieties with low preferences to varieties with high preferences. The second and third term in the right hand side of (52) are novel relative to the CUPI by Redding and Weinstein (2019). The second term arises because the normalization in (49) does not hold: the consumption utility $\hat{z}_{jt}$ is increasing in the number of varieties in the consideration set in the sector, so its expected value is increasing in μ_t. The third term, increasing in x_t, arises because x_t is a form of investment which has no direct effects on the consumption utility of the household.

Inflation biases Panel (a) of Figure 4 plots $\Delta \ln p_t$ (solid blue line) and $\Phi^{ACUPI} - \Delta \ln P_t$ (dashed red line), calculated by setting $\sigma_w = \sigma$. Panel (b) plots $\Delta \ln p_t$ (solid blue line) and $\Phi^{HCUPI} - \Delta \ln P_t$ (dashed red line). Inflation is calculated year on year as 4-quarter changes in log price indexes. Φ^{HCUPI} tracks very closely $\Delta \ln (P_t p_t)$, while Φ^{ACUPI} tends to underestimate inflation by more than one percentage points over the years 2010-2011, when

[19] Notice that we focus on varieties with positive consumption expenditures, since the expenditure on a variety due to experimentation has mass zero on the real line, which would prevent from taking logs.

adoption expenditure x_t exhibits a pronounced fall (Figure 3). The reason why Φ^{ACUPI} underestimates inflation over this period is twofold. First the contribution of new varieties to welfare according to ACUPI, is given by λ_t^{AF}, which reflects the number of varieties in the market v_t, while λ_t^{HF} in HCUPI measures changes in the household consumption basket, which are at least partly driven by changes in the household consideration set μ_t. When x_t falls, the wedge between v_t and μ_t widens, and ACUPI tends to underestimate household level inflation. Second, the (average) dispersion of consumption shares at the household level, s_{jt}^H's, is different from the dispersion of consumption shares at the aggregate level, s_{jt}^A's. While the dispersion in s_{jt}^H's reflects household heterogeneity in consumption utility across varieties, the dispersion in s_{jt}^A's also reflects the speed at which newly introduced varieties accumulate their customer base. When x_t falls, accumulating a customer base requires more time. This increases the dispersion in s_{jt}^A's, causing Φ_t^{ACCV} to fall relative to Φ_t^{HCCV}, which also makes Φ^{ACUPI} underestimate true household level inflation. At the peak of the difference between $\Delta \ln(P_t p_t)$ and Φ_t^{ACUPI} (equal to 143 basis points), errors in the Feenstra correction term contribute by around 49 basis point, with the remaining 94 basis point almost entirely due to $\Phi_t^{HCCV} - \Phi_t^{ACCV}$.

Figure 4: Biases in household level inflation



(a) ACUPI **(b) HCUPI**

The difference between $\Delta \ln p_t$ and $\Phi_t^{HCUPI} - \Delta \ln P_t$ in panel (b) is generally small for two reasons. First, changes in μ_t, which drive changes in preferences, not only affect the mean number of varieties in the consideration set of households but also their variance (the mean and the variance of the Poisson distribution are indeed equal). As a result the welfare gains of the increase in μ_t are already well characterized by changes in the dispersion of household level consumption shares in (54), in line with the logic by Redding and Weinstein (2019). Moreover, the second and the third term in the right hand side of (52) (neglected in HCUPI) move in opposite directions in response to changes in x_t. As a result, the two additional terms in (52) not only are small in absolute value but also comove negatively.

7.2 Fiscal transfers over the Great Recession

We solve for the model's general equilibrium after characterizing the production technology, which allows for innovation spill-overs, and nominal rigidities, which leave a role for aggregate demand. We use the model to quantify the effects of federal fiscal transfers during the US Great Recession and its recovery. Fiscal transfers represented almost 80% of the increase in government expenditure over the period (Oh and Reis 2012).

Assumptions The technology to produce variety $(j, v) \in \mathcal{V}_t$ is

$$y_{\nu jt} = v_t^{\varpi}\, l_{\nu jt}, \tag{55}$$

where $l_{\nu jt}$ is labor input. Labor productivity in (55) increases with the number of varieties v_t, with $\varpi \in [0, 1]$, which builds on Romer (1990) where v_t enhances labor productivity by allowing greater division of labor.[20] Given our choice of the numeraire (the price of a variety is 1) and the constant markup over marginal cost we have that

$$w_t = \varphi v_t^{\varpi}. \tag{56}$$

As in Romer (1990) and Bilbiie et al. (2012), R&D is labor intensive: l_{dt} labor units in R&D yield $\frac{\varphi}{\xi}\, v_t^{\varpi}\, l_{dt}$ new varieties. Given (56), $\xi > 0$ is the cost of a new variety, which justifies the free-entry condition in (44). The number of varieties evolves according to

$$v_{t+1} = (1 - \delta_f)\, v_t + \frac{w_t\, l_{dt}}{\xi}, \tag{57}$$

where $w_t l_{dt}$ is R&D investment.

We extend the household's problem to allow for sticky wages modelled as in Erceg, Henderson, and Levin (2000) and Auclert and Mitman (2019) and for government bonds, b_t, which pay a gross return r_{t+1} at $t+1$. All households are identical, post a nominal wage W_t and supply any amount of labor demanded at the posted wage. Adjusting the wage W_t involves quadratic adjustment costs $\kappa_t \equiv \kappa\left(\Pi_t^W\right) w_t \ell_t$ where $w_t \equiv W_t/P_t$ is the real wage, $w_t \ell_t$ is (aggregate) labor income, $\Pi_t^W \equiv W_t/W_{t-1}$ is wage inflation, and $\kappa(1) = \kappa'(1) = 0$ with $\kappa'' > 0$. The time t household budget constraint is

$$e_t + a_t + b_t \leq \iota_t\, a_{t-1} + r_t b_{t-1} + w_t \ell_t + \kappa_t - \tau_t \tag{58}$$

[20] Greater product variety could also allow firms to offer a more specialized product to existing customers, which would increase quality adjusted output. Under this alternative interpretation, the quality adjusted unit price of a variety would also increase.

where τ_t are taxes net of government transfers. As in Krishnamurthy and Vissing-Jorgensen (2012) and Fisher (2015), government bonds provide some liquidity services, $h(b_t)$, which implies that government transfers financed by issuing government debt stimulate expenditure.[21] The household maximizes the expected present value of the utility from consumption $u(c_t)$ and liquidity services, $h(b_t)$, net of the disutility of working ℓ_t, $\varepsilon(\ell_t)$:

$$\mathbb{E}_t \left\{ \sum_{j=t}^{\infty} \rho^{j-t} \left[u\left(c_j\right) + h\left(b_j\right) - \varepsilon\left(\ell_j\right) \right] \right\}. \tag{59}$$

By solving for the optimal posted nominal wage W_t, in Appendix F we derive the following New Keynesian Phillips curve:

$$\Pi_t^W \left(\Pi_t^W - 1\right) = E_t \left[\rho_{t,t+1} \left(\Pi_{t+1}^W - 1\right) \frac{w_{t+1}\ell_{t+1}}{w_t \ell_t} \right] + \hat{\kappa} \left[\frac{\theta_w}{\theta_w - 1} \frac{\varepsilon'(\ell_t)}{u'(c_t)} \frac{p_t}{w_t} - 1 \right], \tag{60}$$

where $\hat{\kappa} \equiv (\theta_w - 1)/\kappa''$ determines the slope of the (linearized) New Keynesian Phillips curve.[22] Maximizing with respect to government bonds, b_t, implies that the expected liquidity premium of government bonds satisfies

$$h'(b_t) \quad = \quad \rho \mathbb{E}_t \left[\left(\iota_{t+1} - r_{t+1}\right) \frac{u'\left(c_{t+1}\right)}{p(\mu_{t+1})} \right]. \tag{61}$$

As in Proposition 2, adoption expenditure, x_t, satisfies (30) and the optimal demand of assets a_t implies (33).

There is a mutual fund that owns all firms in the economy and issues one-period assets, a_t, paying a risk-free return ι_{t+1} at $t+1$. The fund breaks even $\forall t$, which implies that $\forall t$ the fund's disbursements are equal to firms'realized profits net of R&D investment

$$\iota_t a_{t-1} - a_t = (1-\varphi)\, e_t - w_t\, l_{dt}. \tag{62}$$

Let g denote government purchases of varieties, which we assume are fully wasted, spent uniformly across available varieties and constant over time. To guarantee that (44) and (45) hold we posit a value added tax of $1-\varphi$ on firms selling products to the government. This implies the following government budget constraint

$$b_t = r_t\, b_{t-1} + \varphi g - \tau_t. \tag{63}$$

The lump sum tax τ_t is equal to the difference between the cost of servicing the debt plus the cost of government expenditure minus household transfers: $\tau_t = r_t\, b_{t-1} + \varphi g - \tau_t^{\ell}\, w_t \ell_t$.

[21] In equilibrium, the aggregate supply of government bonds affects the liquidity premium paid by government bonds $\iota_t - r_t > 0$.

[22] The linearized Phillips curve is $\hat{\Pi}_t^w = \rho E_t \left(\hat{\Pi}_{t+1}^w\right) + \hat{\kappa}(\gamma \hat{c}_t + \varepsilon_1 \hat{\ell}_t + \hat{p}_t - \varpi \hat{v}_{t-1})$, where '$\hat{z}$' denotes z in log-deviation from its steady state value.

Transfers are a proportion τ_t^ℓ of aggregate labor income (i.e. they do not affect households' labor supply decisions)). τ_t^ℓ evolves according to

$$\tau_t^\ell = \bar{\tau}^\ell + \varrho_\tau \left(\tau_{t-1}^\ell - \bar{\tau}^\ell\right) + \epsilon_t^\tau, \tag{64}$$

with ϵ_t^τ representing a (positive) shock to transfers.

The real rate on government bonds satisfies $r_t = \mathcal{R}_{t-1}/\Pi_t^P$, where $\Pi_t^P \equiv \Pi_t^W w_{t-1}/w_t$ is price inflation and $\mathcal{R}_{t-1}$ is the nominal interest rate set by the monetary authority at $t-1$ and paid at t. Since over our sample period nominal interest rates were constant (due to the zero lower bound), we assume that, over the entire period, the monetary authority keeps $\mathcal{R}_t$ at its steady state value $\bar{\mathcal{R}}$ and with probability ϕ_0 reverts to a conventional Taylor rule: $\mathcal{R}_t = 1/\rho \left(\Pi_t^P\right)^{\bar{\phi}}$ (see Appendix F for the details).[23]

The aggregate resource constraint equates net output to its uses so that

$$v_t^\varpi \left(\ell_t - l_{dt}\right) = e_t + g + \kappa_t. \tag{65}$$

Equilibrium An equilibrium is a tuple

$$\left(c_t, x_t, a_t, b_t, \mu_t, e_t, p_t, w_t, r_t, v_t, \ell_t, l_{dt}, \lambda_t, \tau_t^\ell, \mathcal{R}_t, D_t, \Pi_t^W, \Pi_t^P\right)$$

such that $\forall t$,

1. Each *household* maximizes utility at the adoption expenditure x_t, wage inflation Π_t^W and portfolio choices a_t and b_t, which satisfy (30), (33), (60) and (61), given μ_t in (26), e_t in (24), and p_t in (27);

2. *Firms* maximize profits so that v_t satisfies (44) with D_t given by (45);

3. The returns on assets and government bonds ι_t and r_t *clear the financial markets* at the asset supply a_t and b_t implied by (62) and (63), given the (constant) nominal interest rate $\mathcal{R}_t$ set by the monetary authority and price inflation $\Pi_t^P \equiv \Pi_t^W w_{t-1}/w_t$;

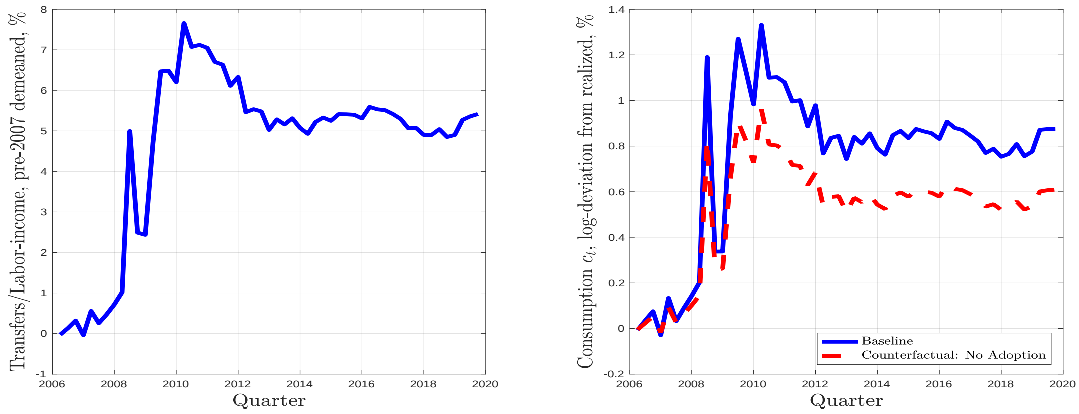
4. The *labor market* clears so that l_{dt} and ℓ_t satisfy (57) and (65) at wage w_t in (56);

5. The *driving forces* λ_t and τ_t^ℓ are given.

[23] We set $\phi_0 = 1/6$, to target the expected duration of the liquidity trap, and $\overline{\phi} = 1.5$, a standard value in the literature.

Calibration Data on fiscal transfers come from NIPA, Table 3.1, as in Oh and Reis (2012).[24] We express transfers in proportion of aggregate labor income and estimate (64) over the pre-sample period 1993-2007. We obtain a coefficient of serial correlation $\varrho_\tau = .985$ and a mean value of $\bar{\tau}^\ell = 20.9\%$. Given ϱ_τ and $\bar{\tau}^\ell$, we use (64) to back up the shocks to transfers ϵ_t^τ's. The solid blue line in panel (a) of Figure 5 plots the effects of ϵ_t^τ's on τ_t^ℓ over our sample period: in 2010 transfers increased by almost 8 percentage points relative to aggregate labor income, stabilizing to an increase of around 5 percent points over the recovery period.

Figure 5: Effects of transfers in the Great Recession and its recovery



(a) Effects on transfers, τ_t^ℓ **(b) Effects on log-consumption, $\ln c_t$**

Panel (a) shows the effects of transfer shocks ϵ_t^τ's on transfers over labor income, τ_t^ℓ. The solid blue line in panel (b) corresponds to the effects of ϵ_t^τ's on logged consumption $\ln c_t$. The dashed red line calculates the effects of ϵ_t^τ's in a version of the model where adoption expenditure x_t is assumed to remain at its steady state value throughout the entire sample period.

The disutility of working is: $\varepsilon(\ell) = \varepsilon_0/(1+\varepsilon_1) \times \ell^{1+\varepsilon_1}$ with ε_0 set to yield $\bar{e} = 1$ and $\varepsilon_1 = 1/3$, in line with the macroeconomic literature (see Peterman 2016). The utility from holding government bonds is: $h(b) = h_0/(1-h_1) \times b^{1-h_1}$ with $h_0 = 0.07$ and $h_1 = 0.5$ set to match a (partial equilibrium) marginal propensity to consume out of a tax rebate of $\Delta e/\Delta\tau = 14\%$ (Broda and Parker 2014), and a steady-state liquidity premium $\iota - r$ of 18 basis points (Fisher 2015). To calibrate R&D spill-overs we use the evidence presented in Table 5, column 5, of Colino (2017) to set $\varpi = 0.387$. The parameter governing the elasticity of the linearized Phillips curve $\hat{\kappa}$ is consistent with wages adjusting once every 4 quarters (Barattieri, Basu, and Gottschalk 2014). We follow Christiano, Eichenbaum, and Evans (2005) and Galí, Smets, and Wouters (2012) in settting $\theta_w = 10$. Government expenditure

[24]Government transfers correspond to Current transfer payments in Table 3.1, equal to the sum of government social benefits to either persons or firms, plus other current transfer payments to the rest of the world and subsidies.

Table 11: **Calibration of the general equilibrium parameters**

Model		Data	
Parameter	Value	Moment	Value
δ_f	0.050	Obsolescence rate of varieties in KNPC	0.05
δ_p	0.013	Persistence of varieties in consideration set, δ	0.063
ξ	1	R&D expenditure, wl_d, over total expenditure, e	0.05
φ	0.93	Mass of varieties at initial steady state, v	1
ϱ_τ	.985	Serial correlation of transfers, 1993-2007	.985
$\overline{\tau}_\ell$	.195	Mean value of transfer over labor income, 1993-2007	.209
ϵ_0	1	Steady state expenditure, e	1
ϵ_1	1/3	Frisch elasticity of labor supply	3
ϖ	0.387	Micro estimates of firm R&D spill-overs	0.387
g	0.12	Government expenditure as a share of output	10%
h_0	0.07	Liquidity premium $\iota - r$	0.18%
h_1	0.5	Partial equilibrium MPC out of tax rebate	.14
$\hat{\kappa}$	0.02	Slope of NKPC with wages changing once a year	0.02
θ_w	10	Estimates from the literature	10

g represents 10% of steady state gross output. Table 11 reports these additional parameter values. All the other values are as in Table 5.

Results To evaluate the expansionary effects of transfers, we calculate by how much logged consumption $\ln c_t$ would have fallen if transfer shocks ϵ_t^τ's had remained equal to zero during the entire sample period.[25] This effect corresponds to the solid blue line in panel (b) of Figure 5: on average over the period 2010-2019, fiscal transfers increased consumption

[25]Notice that to calculate the effect of transfer payments shocks we do not need to take a stand on the drivers of the Great Recessions and the magnitude of the associated shocks. We solve the model linearly so the effects of shocks are additive and can be evaluated separately.

by 80 basis points; at the peak of the response (2009-2011) consumption increased by 1.2 percent. The dashed red line in panel (b) of Figure 5 shows the effects of ϵ_t^{τ}'s on $\ln c_t$ in a version of the model where adoption expenditure x_t is assumed to remain at its steady state value throughout the entire sample period. The cumulated response of consumption to the transfer shocks ϵ_t^{τ}'s over the period 2007-2019 is 43 percent greater in our model than in the constant-adoption-expenditure benchmark.

There are two reasons why x_t amplifies the effects of transfer shocks in general equilibrium. First, there is an effect that works through *household-level inflation*: fiscal transfers stimulate adoption expenditure x_t that pushes down the price p_t today, generating expectations of higher future household level inflation, which, at constant $\mathcal{R}_t$, reduces the household level real rate and stimulates aggregate demand—an effect particularly valuable for an economy at the liquidity trap. Secondly, there is an effect on the *demand for innovation*: the increase in x_t pushes up the value of a new product D_t in (45), because new firms find easier to accumulate a customer base, causing an increase in v_t larger in our model than in the counterfactual, which stimulates aggregate productivity. The key idea is that new innovating firms to sell their product need customers, who can be acquired only if households are willing to bring new varieties into their consumption basket. To quantify the contribution of the inflation effect, we construct two intermediate benchmarks in which technological spill-overs are absent, $\varpi = 0$. In the first, x_t is endogenous, in the second it is maintained constant at its steady state value. By comparing the response in the two intermediate benchmarks with no spill-overs we identify the inflation effect. By taking the difference between the differential cumulated response of 43 percent in our full model and the contribution of the inflation effect, we measure the effect through the demand for innovation.[26] The household-level inflation effect counts for 20 percentage points, the effect through innovation demand for the remaining 23 percentage points.

8 Conclusions

We have shown that household's adoption of new varieties in the consumption basket increases in response to (transitory or permanent) changes in expenditure. There are two reasons for this. First, varieties are more valuable when expenditure is higher, owing to a scale effect. Second, adopting new varieties allows the household to smooth consumption better over time. Changes in adoption induce persistent differences in the consumption baskets of (ex-ante identical) households, which matter for the measurement of household-

[26] Essentially this residual measures the differential effect of adding technological spill-overs in a model with endogenous adoption and in one with constant adoption.

level inflation and the long-run welfare effects of shocks, including aggregate demand stabilization measures. Our model can be extended along several dimensions. Following the lead of Handbury (2013), the model could accommodate quality substitution of products by assuming that household's permanent income affects her preferences for quality. This would naturally lead to the conclusion that quality substitution and the between quality component of gross additions would respond mostly to permanent rather than temporary shocks, in line with the empirical evidence. In its current form, the model does not admit a balanced growth path, for two reasons: first, the elasticity of the household adoption rate to adoption expenditure is less than 1; and second, the elasticity of the welfare-relevant household price index with respect to the number of varieties in the consideration set is not constant. It would be easy to normalize the functional forms of the adoption technology and the price index so as to keep them constant along a balanced growth path. An alternative approach is discussed in Appendix G, where firm innovation, rather than increasing the number of varieties within a sector, leads to the formation of new sectors.

We think that the idea that households adjust consumption along the extensive margin by bringing new varieties into the consumption basket raises some interesting questions for further research. For example Neiman and Vavra (2018) document a fall in the number of varieties purchased by households and an increased segmentation in the products that they do buy. In theory this could be due to a prolonged contraction in household adoption expenditure, perhaps owing to greater income uncertainty or lower expected income, making households less prone to experiment with new varieties. We have also emphasized the implications of household adoption for firm innovation, but household adoption would also matter for firms' decisions to enter foreign markets which, as stressed by Melitz and Redding (2015), is a prime determinant of the welfare gains from trade in new trade models.

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ONLINE APPENDIX

Appendix A discusses the data and reports on several additional empirical results. Appendix B contains the proofs of the results discussed in Section 4. Appendix C contains all details of the maximum likelihood estimation discussed in Section 6. Appendix D derives the expression for the value of a new product in (45) and invert it to solve for the number of varieties in the market. Appendix E derives the formulas for the price indices discussed in Section 7.1. Appendix F fully characterizes the DSGE model discussed in Section 7.2. Appendix G extends the model to allow for a balanced growth path.

A Data and additional empirical results

Firstly, we describe the construction of the data (Section A.1). Secondly, we analyze the negative bias in the average growth rate of expenditure in our time series (Section A.2). Thirdly, we discuss how we identify the introduction of new varieties in the market (Section A.3). Fourthly, we report on several robustness checks discussed in the main text (Section A.4). Fifthly, we relate our results to those by Broda and Weinstein (2010) (Section A.5). Sixthly, we better characterize the process of adoption of new varieties by households (Section A.6).

A.1 Construction of sample and variables definition

Our analysis is based on the Kilts-Nielsen Consumer Panel (KNCP). KNCP contains information on a variety of non-durable consumption products purchased by a large, representative sample of US households. Households in the sample are provided with a scanning device which they use to record all their purchases, indicating the quantity purchased and its unitary price (inclusive of possible promotional discounts) as well as the identity of the retail chain and the date of the purchase.

In 2006 the sample size of KNCP increases from about 40,000 households to over 60,000 households. This sharp increase in sample size is also associated with an expansion in the product categories covered by KNCP. For this reason we use KNCP starting from 2006. KNCP has an important panel dimension: the median household stays in the sample for three years and 75% of the households stay in the sample for at least two years. Households are sampled across 76 different Scantrack Market, constructed by Nielsen to include all counties which are part of the same media market for consumer goods. Examples of Scantrack markets are Portland, New York and Raleigh-Durham. Nielsen assigns to each household in the sample a sampling weight which can be used to project statistics to both the national or the Scantrack market level. KNCP also reports information on households characteristics such as household's size, composition, age, gender, ethnicity, income (in ranges), and education.

A product in KNCP is identified by its Universal Product Code (UPC). Nielsen groups UPCs in homogeneous aggregates in the following hierarchical order: *Product modules* (e.g. "Ready to eat cereals", "Carbonated soft drinks"), *Product groups* (e.g. "Butter and margarine", "Coffee", "Detergents"), *Departments* (e.g. "Dairy", "Frozen food", "Non food grocery"). There are 1,075 product modules; 125 product groups and 10 departments.

The University of Chicago also attaches to every UPC a *brand code*: an identifier common to all products belonging to the same product line/manufacturer. Examples of brands are "Pantene Pro-V" or "Pepsi caffeine free". All white labels (called "private labels" in KNCP) within a product module have the same brand code and are identified as the same variety.

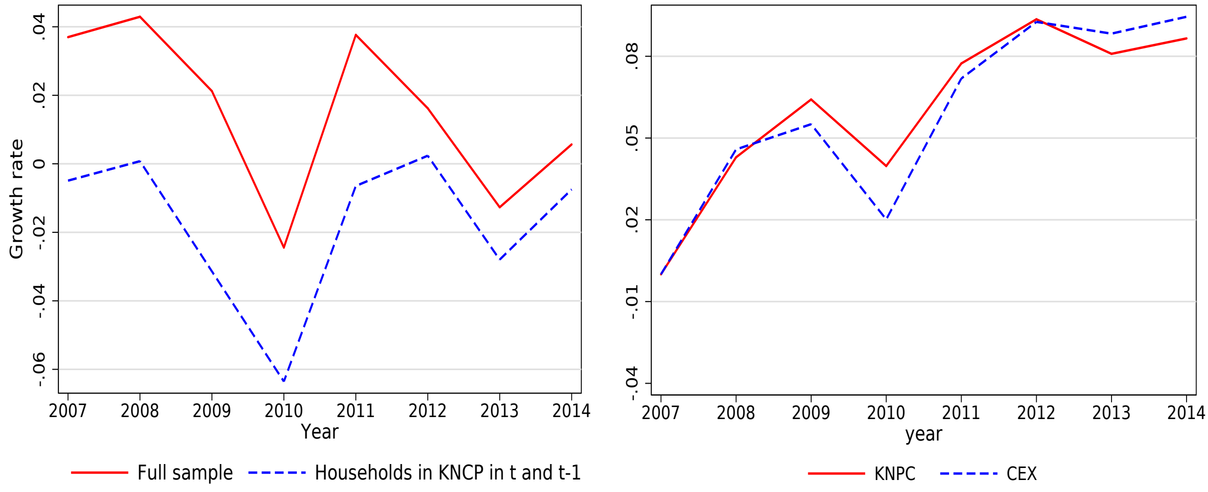
We restrict the sample to households who report positive expenditure in every month of a year. We also require the household to be in the sample for at least two consecutive years, and assign the household a projection weight equal to the average of the sampling weights assigned to the household in the two years. In the analysis, we discard purchases in Department 9 ("General merchandise") and 99 ("Fresh products"). General merchandise is a residual category including items (such as electronic appliances and motor vehicles) which are spottily covered in KNCP. Fresh products have no associated UPC and their purchases can only be tracked for a subsample of households in KNCP ("Magnet households"). To be able to estimate hedonic price regressions, we discard product modules whose items do not have a homogeneous measure of unit size.

Panel (a) of Figure O1 plots as a solid red line the growth rate of aggregate expenditure calculated as the percentage difference in aggregate expenditure between year t and year $t-1$, where aggregate expenditure in year t is the cross-sectional mean of households'expenditure in the full sample of households in KNCP who report some purchases in all months of the year. The dashed blue line is the average growth rate of households' expenditure in our sample of households present in KNCP both in year $t-1$ and t. The correlation between the two series is high (0.88), but the growth rate level is higher when considering the larger sample where growth rates are calculated starting from the cross-sectional means. Panel (b) of Figure O1 plots the (log of) yearly aggregate expenditure per household from the KNPC (solid red line) and from the Consumer Expenditure Survey (CEX) prepared by the US Census Bureau for the Bureau of Labor Statistics (dashed blue line). The CEX series is obtained by adding expenditures for the following categories intended to mimic the coverage of KNCP: food at home (mnemonic cxufoodhomelb0101m), alcoholic beverages (mnemonic cxualcbevglb0501m), tobacco (mnemonic cxutobaccolb0201m), drugs (mnemonic cxudrugslb0501m), health (mnemonics cxumedservslb0501m and cxumedsupplb0501m), housekeeping supplies (mnemonic cxuhkpgsupplb0201m), and health and personal care (mnemonic cxuperscarelb0201m). Expenditures in these categories represent around 13% of total (durable and non-durable) consumption expenditure in the CEX. Both series are normalized to zero in 2007. Expenditures in the KNPC are aggregated using the projection weights provided by Nielsen. Aggregate expenditure per household in CEX and KNPC track each other closely (the correlation between the two series is 0.89). This is in line with the evidence in Kaplan, Mitman, and Violante (2019) who show that the Kilts Nielsen Retail Scanner (KNRS) tracks well various definitions of non-durable consumption expenditure in NIPA.

A.2 Negative bias in average growth rates

First, we review the negative bias in the average growth rate of expenditure in our time series, as documented in Figure O1. We dismiss sample selection as a possible cause and show that it is due to duration dependence in the reporting behavior of households in KNCP. Finally we show that duration dependence has little effects on the time series properties of

Figure O1: Consumption expenditure per household: KNPC vs CEX data



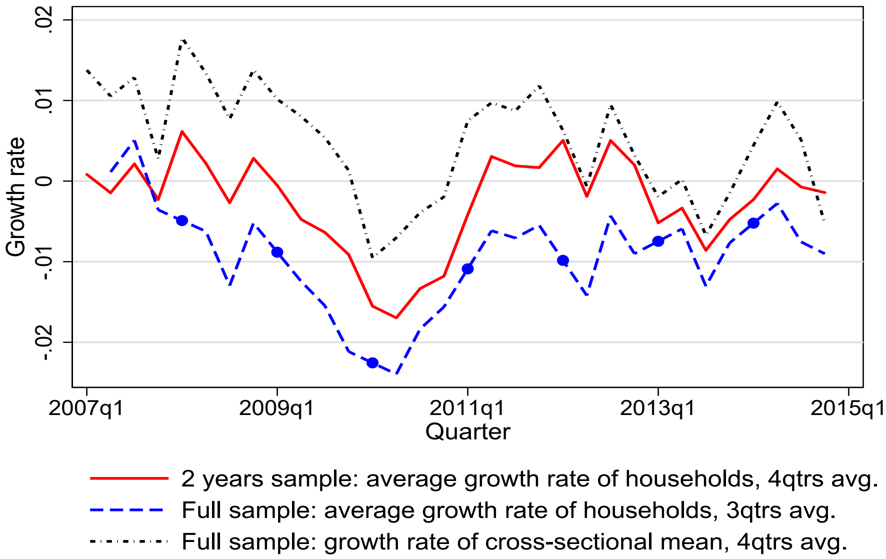
(a) Growth rates: full sample and subsample **(b) Level: KNPC vs CEX**

Panel (a) plots the yearly growth rate of aggregate expenditure. In the solid red line, the growth rate is obtained by first aggregating the expenditures of households in the full sample of KNCP and then taking the (year-on-year) growth rate of the aggregated (cross-sectional) data. In the dashed blue line, the growth rate is the average growth rate of households' expenditure in our sample of households present in KNCP both in year $t-1$ and t. Panel (b) plots the yearly level of aggregate expenditure per household from the cross-sectional data in KNCP (solid red line) and CEX (dashed blue line); both series are in logs and normalized to zero in 2007. The CEX series is obtained by summing expenditures in food at home (mnemonic cxufoodhomelb0101m), alcoholic beverages (mnemonic cxualcbevglb0501m), tobacco (mnemonic cxutobaccolb0201m), drugs (mnemonic cxudrugslb0501m), health (mnemonics cxumedservslb0501m and cxumedsuppllb0501m), housekeeping supplies (mnemonic cxuhkpgsupplb0201m), and health and personal care (mnemonic cxuperscarelb0201m).

the extensive margin emphasized in the paper.

Negative bias Figure O1 shows that the aggregate expenditure obtained by aggregating the cross-sectional data in KNCP tracks very closely the time series of aggregate expenditure from CEX, see Panel (b) of Figure O1. Yet the growth rate of aggregate expenditure obtained by calculating the average growth rate of expenditure of households in our sample is lower than the growth rate of aggregate expenditure as obtained from either CEX or the cross-sectional data in KNCP. The difference in the average yearly growth rate is by roughly 3 percentage points, see Panel (a) of Figure O1. Figure O2 below shows the analogous problem with the quarterly data. The dotted black line is the quarterly growth rate of expenditure obtained by first calculating the average expenditure of all households in the full sample of households in KNCP and then taking the (quarter-on-quarter) growth rate of the aggregated (cross-sectional) data. The series is smoothed (to correct for seasonal effects) using a 4-quarters moving average. The continuous red line is instead the growth rate of aggregate expenditure in our sample as reported in panel (c) of Figure 1 of the paper: it is the average growth rate of households' expenditure in our sample of households present in KNCP in two consecutive years; the resulting series is again smoothed using a 4-quarters moving average. Both series are aggregated using the sample weights provided

Figure O2: Sample selection of households vs. aggregation



Dotted black line: growth rate of expenditure obtained by first aggregating the expenditures of households in the full sample of KNCP and then taking the (quarter-on-quarter) growth rate of the aggregated (cross-sectional) data; the resulting series is deseasonilized taking a 4-quarters moving average. Continuous red line: average growth rate of households' expenditure in our sample of households present in KNCP both in this year and the previous year, again smoothed using a 4-quarters moving average. Dashed blue line: average growth rate of households' expenditure in the full sample of households in KNCP; the growth rate is missing in the first quarter of each year (indicated with a bullet point); the series is deseasonilized taking a 3-quarters moving average.

by Nielsen (normalized to add up to one in the relevant sample). The average difference between the two lines is roughly of 75 basis points.

Possible causes Essentially, there are two possible reasons for the negative bias in the average growth rates—i.e. for why the the dotted black line and the solid red line in Figure O2 differ. One is due to the *aggregation* procedure: in the dotted black line we first calculate the cross-sectional mean of the data and then calculate the growth rate of the aggregates; in the continuous red line, we first calculate the growth rate of households' expenditures in KNCP and then calculate the average growth rate across households. The other is due to differences in *sample selection*: the dotted black line uses the full sample of households in KNCP; the solid red line considers households who stay in KNCP for at least 2 consecutive years. We show that sample selection does not explain the difference. The difference is entirely due to aggregation. Essentially, on average, households in KNCP exhibit (negative) duration-dependence in reporting their expenditures: they tend to reduce their reported expenditures as they remain in KNCP. This implies that the average growth rate of expenditure of households in KNCP are downward biased: it is the sum of the *true* growth rate of aggregate expenditure minus the downward bias due to (negative) duration dependence in the sample. The cross-sectional data controls for this effect by re-sampling the data. After documenting this result, we show that the cyclical/time-series properties of additions and removals that we emphasize in the paper are (very) unlikely to be driven by this feature of KNCP.

Sample selection versus aggregation To show that sample selection does not explain why we underpredict the growth rate of aggregate expenditure, in Figure O2 we plot as a dashed blue line the average growth rate of households' expenditure in the full sample of households in KNCP. Since we restrict the analysis to the full sample and since the resampling of households in KNCP always happens in the first quarter of each year, the growth rate of expenditure is missing in the first quarter of each year: some households in the first quarter of the year are not present in the last quarter of the previous year. In the Figure, the missing value is identified by a bullet point. The resulting series is deseasonalized taking a 3-quarters moving average. The dashed blue line uses the same full sample as the dotted black line, and still the average growth rate is substantially lower. The dashed blue line uses the same aggregation procedure as the one used to construct the solid red line and they differ because of the sample.[O1] Overall Figure O2 shows that the bias is not due to sample selection but to duration dependence in the reporting behavior of households in KNCP. There are several different reasons for why duration dependence could emerge in KNCP. If households experience increasing fatigue in reporting their expenditures or their excitement of being part of KNCP progressively wears off, the expenditures reported by households fall over time leading to negative duration dependence. If Nielsen removes from subsequent waves of KNCP, households who start reporting unusual low expenditures over the current year—say households who report decreasing expenditures over the year—, we could have positive duration dependence. Positive duration dependence could also arise if households need some time to learn how to use the Nielsen' reporting technology. Both cases for positive duration dependence (detecting households uninterested in participating in the survey and learning) are more likely to apply at short tenure in KNCP. While fatigue and loss of excitement are more likely to apply at longer tenures in the survey. This is coherent with the evidence in Figure O2, which is consistent with the claim that negative duration dependence is present for households who remain in KNCP for at least two years (the solid red line lies below the dotted black line), while positive duration dependence is present for households who remain in KNCP for just one year (the solid red line lies above the dashed blue line).

Correction for duration dependence We now formally correct for the effects of duration dependence on the average growth rate of households' expenditure, by running the following regression on the full sample of households in KNCP:

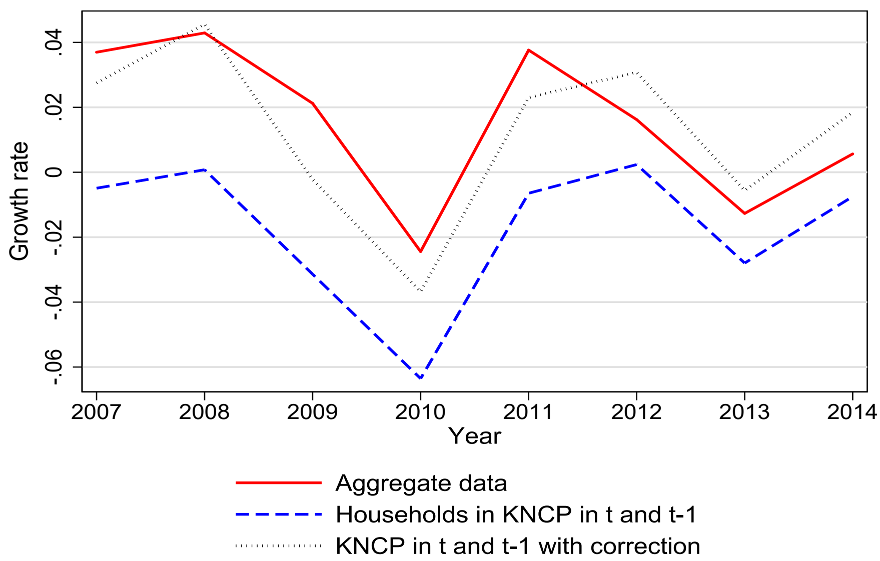
$$\ln e_{ht} = d_h + \sum_{k=1}^{12} \alpha_k \mathbb{I}(Tenure_{ht} = k) + \tau_t + \varepsilon_{ht} \tag{A1}$$

where e_{ht} is the expenditure reported by household h in year t, $\mathbb{I}(Tenure_{ht} = k)$ is a tenure-in-KNCP dummy equal to one if household h at time t is in their k-th year in KNCP and zero

[O1] The dashed blue line and the solid red line also differ because of the smoothing procedure: the dashed blue line uses a 3-quarters moving average, the solid red line a 4-quarters moving average. We checked that the difference in the smoothing algorithm matters little: if anything it tends to shift the solid red line upward, confirming that sample selection does not explain why we underpredict the growth rate of aggregate expenditure.

otherwise, d_h is a fixed effect for household h and τ_t denotes time dummies. The excluded category for the tenure dummy is a household who has just entered KNCP. We use the estimated coefficient α_k to correct for duration dependence in our sample of households: for each household h in her kth year in KNCP we first subtract the estimated value of α_k from her logged expenditure, then calculate the growth rate of expenditure of household h in the two consecutive years and then average the resulting growth rate across all households in the sample. The resulting average growth rate corrected for duration dependence corresponds to the dotted black line in Figure O3. Since there is no entry or exit of households in KNCP within a year, we consider just yearly growth rates of expenditures—i.e. we cannot correct for duration dependence for quarterly growth rates within a year. The solid red line in Figure O3 is the aggregate growth rate of expenditure using the full sample of households in KNCP obtained by first calculating cross-sectional averages and then taking growth rates of the aggregated data—which accurately tracks the profile of aggregate expenditures from CEX. The dashed blue line corresponds to the growth rates as in panel (a) of Figure 1 in the paper. It is apparent that the negative bias in the growth rate of aggregate expenditure has disappeared after correcting for duration dependence: the average growth rate of the dotted black line and of the solid red line are now roughly equal.

Figure O3: Correction for duration dependence



Solid red line is the yearly growth rate of expenditure obtained by first aggregating the expenditures of households in the full sample of KNCP and then taking the growth rate of the aggregated (cross-sectional) data. Dashed blue line is the average yearly growth rate of expenditures of households in KNCP, as in panel (a) of Figure 1 in the paper. The dotted black line corrects the dashed blue line for the effect of duration dependence by using the estimated coefficient α_k in (A1).

Duration dependence and the times series properties of the extensive margin

We have investigated whether duration dependence in the reporting behavior of households in KNCP could affect the time series properties of net additions N_t, gross additions A_t and removals R_t that we emphasize in the paper. To analyse this issue we consider the full sample of households in KNCP and calculate N_t, A_t, R_t and expenditure growth rates $\Delta E_t/E_{t-1}$ at the quarterly frequency, setting to missing the value of the series in the first quarter of the year—since some households in the first quarter of the year are not present in the last quarter of the previous year. The series are deseasonalized using a 3-quarters moving average. We repeat the same exercise for households with different years of tenure in KNCP: we considered households with at least 2 years of tenure in KNCP, households with at least 3 years of tenure, households with at least 4 years of tenure and finally households with at least 5 years of tenure. Again (for the sake of comparison with the full sample results), the observation in the first quarter of each year is set to missing. All series are deseasonalized using a 3-quarters moving average. In each of the 5 samples we regress N_t, A_t, and R_t against the growth rate of expenditure $\Delta E_t/E_{t-1}$ in the sample. Table O1 reports the contribution of net and (gross) additions and removals to fluctuations in expenditure growth as measured by the estimated OLS β-coefficients—the analogue of panel (b) in Table 1 in the paper. The contributions of net and (gross) additions to expenditure growth are quite stable across the 5 sub-samples suggesting that the cyclical behavior of households is little affected by how long households have remained in KNCP. This also suggests that duration dependence is unlikely to have strong effects on the time series properties that we emphasize in the paper.

Table O1: Time-series properties of the extensive margin by tenure in KNCP

Variable X_t:	N_t	A_t	R_t
Tenure $\geq$ 1 years (Full sample)	.54	0.53	-0.01
Tenure $\geq$ 2 years	.56	0.55	-0.01
Tenure $\geq$ 3 years	.55	0.54	-0.01
Tenure $\geq$ 4 years	.52	0.51	-0.02
Tenure $\geq$ 5 years	.55	0.54	-0.01

A.3 New varieties

Over the years, Nielsen has introduced new brands and product module codes and it has sometimes reassigned UPCs to different product modules. To maintain consistency in the classification, UPCs are always assigned to the brand/product module to which they were assigned the first time they appeared in KNCP. An expansion in the set of brands/product occurs only when a new brand/product module appears and it consists of UPCs which never appeared before in KNCP. To identify newly introduced or dismissed varieties by manufacturers, we use data from both KNCP and KNRS. KNRS is a companion dataset to

KNCP: it is a panel of around 40,000 representative stores located across the US reporting total sales (both quantities and prices) at the UPC level.

We combine KNCP with KNRS to identify the date of introduction and withdrawal of a variety. The date of introduction corresponds to the date of either the first purchase of the variety by a household in KNCP or the first appearance of the variety in KNRS, whichever occurred first. Introduction is defined at the Designated Market Area (DMA) level, which is a better measure of the market available to households in KNCP since a DMA, also referred to as a media market, identifies a region whose population is exposed to the advertisement of the same products. Analogously, the date of withdrawal is defined as the date of the last purchase of a product in KNCP or the date of the last appearance in KNRS, whichever occurred last. In practice, it matters little whether the availability of products is identified at the DMA level or at the US market level. In the data, 30% of the new varieties introduced for sale in a DMA are introduced in the same quarter also in all the other 210 DMAs. On average, a new variety introduced in a quarter in a DMA is introduced in the same quarter in around 60% of all the other DMAs. For DMAs where the new variety is not immediately available in the same quarter, the median delay is of around 2.07 quarters, which implies that most new varieties are introduced in all DMAs in the same year. In a year the average expenditures of households on varieties new to the entire US market represent 1.3 percent of the total expenditures of households in KNCP, which is closely in line with the value reported by Broda and Weinstein (2010) in their Table 4—which focuses on varieties defined in terms of brands as in our paper. When availability is defined at the local market (DMA) level, the average share of expenditures on new varieties increases to just 4.2 percent. These are the numbers reported in Footnote 1 of the paper.

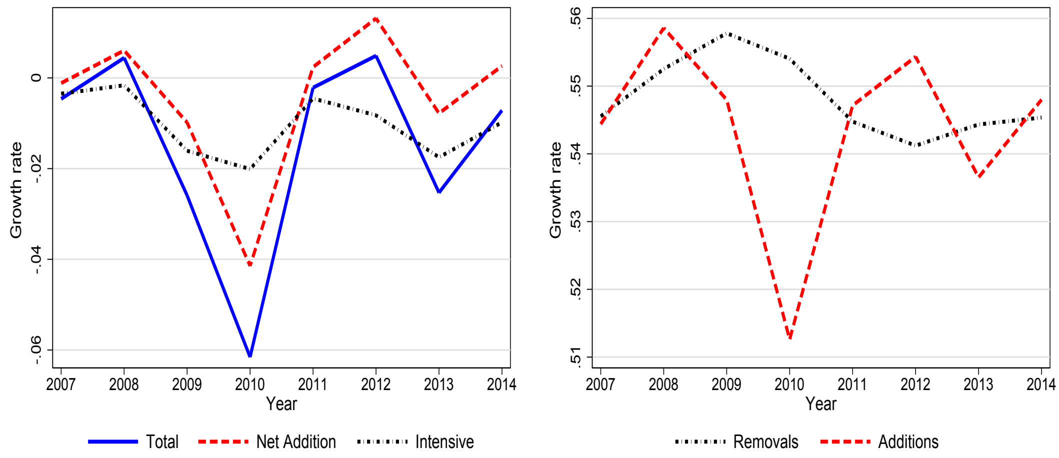
A.4 Robustness

We now report on several additional exercises and robustness checks.

Varieties as UPCs As a robustness check, we identified a variety with its UPC-ver—rather than with a brand/product-module pair as in the paper. This increases the number of varieties considered. Figure O4 shows the contribution of the intensive and extensive margin to expenditure growth (panel a) and the further disaggregation of the extensive margin into additions and removals (panel b). The patterns of the series are similar to those reported in Figure 1. Panel A of Table O2 shows that the contribution of net additions, gross additions and removals to expenditure growth increase when we identify a variety with its UPC-ver.

Constant prices So far we evaluated additions at current prices (price at t) and removals at past prices (price at $t-1$). As a result an increase in inflation could mechanically lead to an increase in net additions. Heterogeneity in pricing across firms could also influence our estimate of the contribution of additions and removals to expenditure growth. To control for changes in inflation and price dispersion, we now measure expenditure at constant prices rather than at (paid) current prices. Let $\bar{e}_{\nu ht} = u_{\nu ht}\,\bar{p}_v$ denote the time-t expenditure of household h in variety $\nu \in \mathcal{V}$ evaluated at the constant price p_ν, where $u_{\nu ht}$

Figure O4: Aggregate demand decomposition: a variety is a UPC



(a) Yearly flows decomposition **(b) Yearly flows, additions vs removals**

Panel (a) plots the growth rate of expenditure, $\Delta E_t / E_{t-1}$, (solid blue line) together with the contribution of the intensive margin I_t (dotted black line) and net additions N_t (dashed red line). Panel (b) plots additions A_t (dashed red line) and removals R_t (dotted black line). The analysis is at the yearly frequency and a variety is defined as a UPC-ver in KNPC.

denotes the units of variety ν purchased by the household. We identify varieties using a brand/product-module pair, and calculate p_ν by averaging the price of a variety ν across space and over time. We then aggregate the expenditure at constant prices and finally calculate net additions, gross net additions and removals exactly as explained in Section 2.1. The results of the decomposition are reported in Panel B) of Table O2.

Durability We partition varieties by durability, using the index employed by Kaplan, Rudanko, Menzio, and Trachter (2019).[O2] Panel C) of Table O2 reports the standard deviations and β-coefficients of expenditure growth when additions, removals and the intensive margin are calculated for five different groups of products characterized by a different degree durability: less than 2 months of durability, between 2 and 6 months of durability, between 6 and 12 months, between 1 and 2 years, and above 2 years. We find that the contribution of net and gross additions to expenditure growth is similar for varieties with different durability, except for those with durability less than two months, for which the contribution of additions is halved. This group of varieties accounts for only a small portion of household expenditure (around 12% in our sample) and is characterized by relatively small additions (at yearly frequency, around 22 percent compared with about a third for the aggregate).

Quality substitution Over the cycle, households substitute across products of different quality (Argente and Lee 2017). Quality substitution can occur along the intensive or the extensive margin. To measure whether net and gross additions reflect quality substitution,

[O2] We thank Guido Menzio and Leena Rudanko for sharing their data on durability with us.

Table O2: Further robustness

	β -decomposition			St.dev. (%)		
	N_t	A_t	R_t	N_t	A_t	R_t
A) Varieties as UPCs	0.73	0.59	-0.14	1.70	1.40	0.60
B) Constant prices	0.55	0.47	-0.08	1.50	1.20	0.50
C) Durability (months)						
-(0; 2]	0.17	0.21	0.04	1.20	0.90	0.80
-(2; 6]	0.40	0.44	0.04	1.30	1.40	0.70
-(6; 12]	0.46	0.40	-0.06	1.10	0.90	0.20
-(12; 24]	0.48	0.39	-0.09	1.40	1.40	1.60
-> 24	0.45	0.52	0.08	1.00	1.70	1.10
D) Robust	0.37	0.30	-0.06	1.00	0.80	0.30
E) Persistent vs temporary						
-Persistent	0.14	0.13	0.00	0.50	0.40	0.30
-Temporary	0.31	0.29	-0.02	0.90	0.80	0.20

All data are at the yearly frequency. The first three entries of each row are the estimated OLS coefficient β_X from regressing the variable $X_t = N_t, A_t, R_t$ in column against expenditure growth: $X_t = \alpha_X + \beta_X \, \Delta E_t/E_{t-1} + \epsilon_t$. The following 3 entries are the standard deviation of the variable. A variety is identified by a brand/product-module pair, with the exception of the first row where varieties are identified by their UPC-ver. The row "Constant prices" calculates (net and gross) additions and removals at constant prices. The row "Durability" computes additions and removals separately for groups of varieties according to their durability as measured by the index used by Kaplan, Rudanko, Menzio, and Trachter (2019). In the row "Robust additions & removals", an addition is defined as robust if the variety added at t was purchased neither at $t-1$ nor at $t-2$, while the removal is defined as robust if the variety removed at t was purchased both at $t-1$ and at $t-2$. In the row "Persistent vs temporary additions & removals", an addition is defined as persistent if the variety added at t is also purchased at $t+1$, while it is temporary if the variety is not purchased at $t+1$. Analogously, a removal is defined as persistent, if the variety removed at t is not purchased at $t+1$, while it is temporary if the variety is purchased again at $t+1$.

we construct a measure of quality for each variety $\nu \in \mathcal{V}$. First, we estimate a regression of the logarithm of the average quarterly price of variety ν in product group g in quarter t on a full set of variety dummies d_ν's and a full set of quarterly time dummies interacted with the product group dummies τ_{gt}'s:

$$\ln p_{\nu gt} = d_\nu + \tau_{gt} + e_{\nu gt}, \tag{A2}$$

The average per-unit price of variety ν in quarter t, $p_{\nu gt}$, is calculated using KNRS which includes a larger set of varieties than the set of varieties purchased by households in KNCP. The average is calculated over all weeks in the same quarter and across all stores. For each UPC, Nielsen reports its unit of measurement (fluid ounces, pounds, etc..), if available. In running the regression (A2), we retain only product groups for which at least 99% of its UPCs are measured in the same unit of measurement. This leaves us with 95 product groups. We take the brand fixed effect d_ν as a quality measure of variety ν within the product group. Within each product group, we rank varieties according to their value of d_ν. Then, we calculate the deciles of the implied distribution of quality and assign each variety ν to the corresponding decile. This partition the space of varieties into 950 groups: ten quality bins for each of the 95 product groups.

We apply the same methodology as in Section 2.3 to decompose additions and removals depending on whether they occur within the same quality bin of a given product group, between quality bins of the same product group or between product groups. The β-decomposition associated with this partition of the set of varieties is reported in panel b) of Table 2.

Household heterogeneity Table O3 explores differences across households. We run our decomposition of expenditure growth separately for households with different permanent income, which we proxy with their level of total expenditure in KNCP. Households are grouped according to the quintile of the distribution of past year's total expenditure and we run a separate β-decomposition for households in each quintile. Expenditure growth is less volatile for wealthier households, but in all groups net additions account for a substantial share of the change in total household expenditure, varying from 68 percent for the poorest to 51 percent for the wealthiest. In all groups, additions account for the bulk of the change in net additions.

Regional variation There are differences in the timing, duration and severity of Great Recession across US regions. We exploit this regional variation to study whether our results are robust to outliers and are a general feature of the US business cycle. Figure O5 documents differences across Scantrack markets. Over the years 2007-2014 KNCP is fully representative for 44 Scantrack markets. We construct series for additions, removals and intensive margin at the yearly frequency separately for each of the 44 Scantrack market and perform the β-decomposition of expenditure growth discussed in the main text separately for each market. Panel (a) shows the cross-market distribution of the coefficients for net additions β_N; panel (b) shows the across-market distribution of the coefficients for gross additions β_A. The contribution of net and gross additions to fluctuations in expenditure growth is more than 30 per cent in at least three fourths of the 44 (scantrack) markets for which KNCP is deemed to be representative.

Robust additions and removals We also considered a more restrictive definition—which we call "robust"—of additions and removals: an addition is defined as robust only if the variety added at t was not purchased either at $t-1$ or at $t-2$, a removal only if the variety removed at t was purchased both in $t-1$ and in $t-2$. As expected, the contribution of robust net additions to expenditure growth declines, from 50 to 40 percent, but it remains sizable, and three quarters of it is accounted for by gross additions. Panel D) of Table O2 shows the results. These statistics can be calculated only for households who remain in KNCP for at least three years.

Table O3: Household heterogeneity by permanent income

	ΔE_t	I_t	N_t	A_t	R_t
First quintile					
Standard deviation (%)	2.7	1.0	1.9	2.10	0.60
β-Decomposition, β_X	1.00	0.32	0.68	0.73	0.05
Second quintile					
Standard deviation (%)	2.3	1.1	1.4	1.30	0.40
β-Decomposition, β_X	1.00	0.44	0.56	0.52	-0.05
Third quintile					
Standard deviation (%)	2.4	1.2	1.4	1.20	0.50
β-Decomposition, β_X	1.00	0.46	0.54	0.46	-0.07
Fourth quintile					
Standard deviation (%)	2.4	1.2	1.4	1.10	0.50
β-Decomposition, β_X	1.00	0.45	0.55	0.44	-0.11
Fifth quintile					
Standard deviation (%)	2.5	1.3	1.3	1.10	0.50
β-Decomposition, β_X	1.00	0.49	0.51	0.43	-0.07

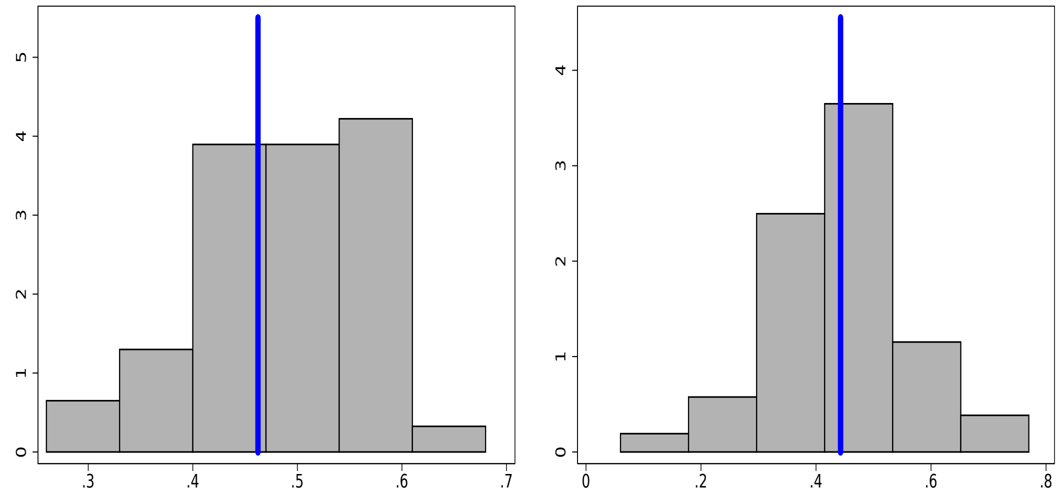
Data are at the yearly frequency. Households are assigned to their quintile of expenditure based on their expenditure level in year $t-1$.

Persistent vs temporary additions and removals We distinguished between additions in year t of varieties that are repurchased again in year $t+1$ (persistent additions) from additions in year t of varieties that are not repurchased in year $t+1$ (temporary additions). Similarly, we distinguished between removals at t of varieties repurchased again at $t+1$ (temporary removals) and removals at t of varieties that are not purchased also at $t+1$ (persistent removals). Panel E) of Table O2 reports results for "persistent" and "temporary" additions and removals. Temporary additions contribute more to the fluctuations in expenditure growth than persistent additions do. Persistent additions account for around 15 percent of the fluctuations in expenditure growth. To calculate these statistics households should be in the sample for at least three consecutive years. Moreover, we must restrict the analysis to the years 2007-2013 because we need an extra year of data to evaluate whether additions or removals are robust.

A.5 Relation with Broda and Weinstein (2010)

Panel c) of Table 2 reports the contribution of new varieties in the market or withdrawn from the market to expenditure growth. The number in the Table is smaller than the analogous value reported by Broda and Weinstein (2010) in their Table 7. The discrepancy can be due to differences in (i) sample period, (ii) the definition of variety, and (iii) the level of aggregation. Our estimates are obtained (i) considering the years 2007-2015, (ii) identifying

Figure O5: β-decomposition across scantrack markets



(a) Net Additions **(b) Gross Additions**

Note: Panel (a) and (b) plot the β coefficients for net additions and gross additions calculated at the yearly frequency for the 44 scantrack markets for which the Nielsen data are fully and continuously representative.

varieties as brand-product module pair and (iii) aggregating expenditures across all product categories. Table 7 in Broda and Weinstein (2010) is obtained using quarterly data (i) over the period 2000-2003, (ii) identifying varieties with their UPC and (iii) aggregating expenditures at the product group level. Table O4 investigates the source of the discrepancy between our results and those in Broda and Weinstein (2010). The first row in Table O4 corresponds to the results reported in Table 7 in Broda and Weinstein (2010). They are obtained using the 2000-2003 period, identifying a variety with its UPC and considering a panel of quarter-product group observations. The second row is again obtained from Broda and Weinstein (2010), but where the coefficients are estimated aggregating all expenditures of the different product groups (no cross-sectional variation). This regression is not reported in Broda and Weinstein (2010) but it is obtained using the information in their Figure 1b. These latter results are marginally closer to those reported in Table 2. The third row of Table O4 reports the estimates obtained by running the same regression as in the second row but aggregating expenditures across all product categories at the quarterly frequency over the sample-period 2007-2015, and where we identify a variety with its UPC as in Broda and Weinstein (2010). In the last two rows of Table O4, we run the same regression as in the first row (data disaggregated at the product group level) on our data using two alternative definitions of variety: in the fourth row, a variety is identified using the brand/product-module pair, in the fifth row using its UPC. Overall, the evidence in Table O4 indicates that the main reason why the results in Table 2 differ from those in Broda and Weinstein (2010) is that we identify a variety using its brand-product module pair, while Broda and Weinstein (2010) identify a variety using its UPC. Comparing the first row of Tables O2 to the third row of O4 we find that there is a sizable fraction (around forty percent) of the time series volatility of (net and gross) additions which is not driven by the introduction of new varieties or the withdrawal of old varieties even when identifying a variety with its

Table O4: Newly introduced and dismissed varieties: Relation with Broda and Weinstein (2010)

Sample Period	Disaggregation of Expenditures	Definition of Variety	$\beta_{\tilde{N}}$	β_C	β_D
From Broda and Weinstein (2010)					
2000q1-2003q3	Product group	UPC	0.35	0.30	-0.05
2000q1-2003q3	Total	UPC	0.19	0.09	-0.09
Our estimates					
2007q1-2015q2	Total	UPC	0.40	0.39	0.00
2007q1-2015q2	Product group	Brand	0.12	0.12	0.00
2007q1-2015q2	Product group	UPC	0.49	0.47	-0.02

Each number corresponds to the OLS coefficient of a regression where the independent variable is expenditure growth and the dependent variable is either additions in new varieties introduced in the market β_C, or removals due to varieties withdrawn from the market β_D or the difference between the two $\beta_{\tilde{N}} = \beta_C - \beta_D$. The first row reports the analogous numbers from Table 7 in Broda and Weinstein (2010); the second row is based on running the regression using the aggregate data by Broda and Weinstein (2010) as reported in their Figure 1b. The remaining four rows are computed using our KNCP data for different levels of aggregation and different definitions of a variety.

UPC,.

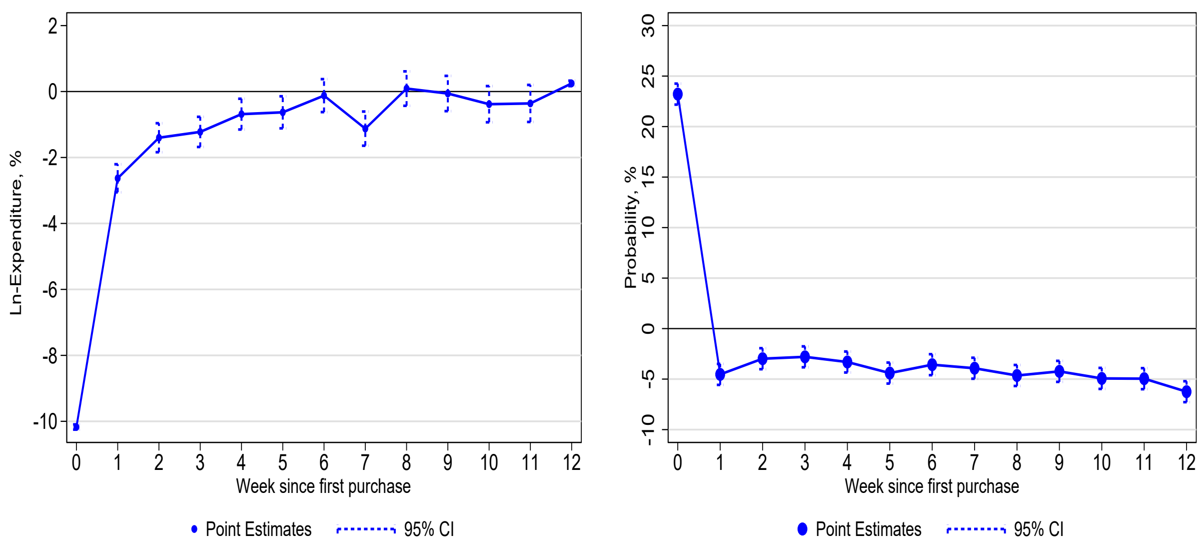
A.6 Adoption of varieties

We characterize the evolution over time of the expenditures in varieties added by households to their consumption basket. We select all households continuously present in KNCP since 2004, and focus on their expenditures in any week of year 2013. We are interested in comparing household's shopping behavior in varieties the household has never purchased before (*newly added* varieties) to the behavior in varieties she has recently purchased (*regular* varieties). We identify newly added varieties as all varieties purchased by the household in 2013 which the household had never purchased in any of the previous 9 years. We identify regular varieties as all varieties which the household has purchased at least once in the previous four years (2009-2012) and bought again in 2013. We denote by $n \geq 0$ the number of weeks since the household has first newly added the variety in 2013. For each household h and variety ν (in any group) we calculate the expenditure in week t of 2013, denoted by $e_{\nu ht}$. We also construct a dummy $\pi_{\nu ht}$, equal to one if household h purchases variety ν at least once in one of the 52 weeks after t. Note that this requires information on household expenditure in the year after the variety is added, explaining why we focus on shopping behavior in 2013 for this exercise. We then run the following regressions:

$$z_{\nu ht} = \sum_{n=0}^{52} \beta_n^z F_{\nu ht-n} + \beta_X^z X_{\nu ht} + \epsilon_{\nu ht} \tag{A3}$$

where the dependent variable $z_{\nu ht}$ is either $\ln e_{\nu ht}$ or $\pi_{\nu ht}$, and $F_{\nu ht}$ is a dummy equal to one if the variety ν is first purchased by household h in week t of 2013 (i.e. it was newly added in week t of 2013) and zero otherwise. The variable $X_{\nu ht}$ are controls including a full set of dummies for time, households, and product modules. The coefficient β_n^e measures, conditional on buying the variety, the percentage difference between the expenditure on a variety newly added to the basket n weeks ago and the expenditure on a regular variety. β_n^π measures the difference between the probability of future purchase (in the next 52 weeks) of a variety newly added to the basket n weeks ago and the probability of future purchase of a regular variety. Panel (a) of Figure O6 plots the estimated profile of β_n^e together with its 95 percent confidence bands. Panel (b) plots the estimated profile of β_n^π. The profile of β_n^e is increasing in n: in the first purchase of a newly added variety the household spends ten percent less than in a typical regular purchase, but this difference readily reaches a plateau 4 weeks after the first purchase, when there is no statistically significant difference in expenditure in newly added and regular varieties. Panel (b) indicates that at the time of the first purchase, a newly added variety is 24 percent more likely to be repurchased in the following 52 weeks. This comes from a probability of repurchase of a newly added variety of 34 percent against a probability of repurchase of any other regular variety of 9 percent. However, just one week after the first purchase, the probability of repurchase of a newly added variety drops permanently to about 4 percent, i.e. 5 percent below the average probability of purchase of a regular variety equal to 9 percent. Overall Figure O6 shows that (i) the first purchase of the household in a newly added variety is on average small in value, (ii) the probability of repurchasing the variety in the future (after the first

Figure O6: The time profile of newly added varieties

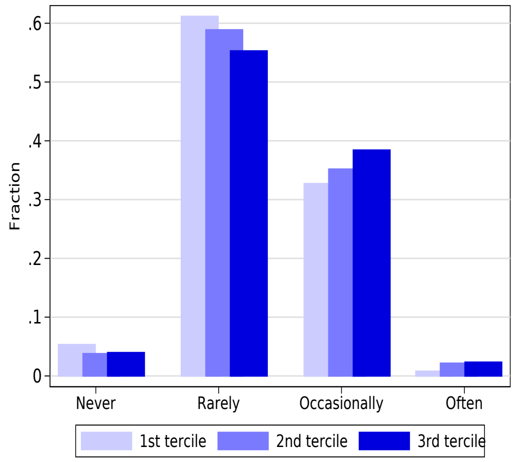


(a) Expenditure conditional on purchase, β_n^e **(b) Purchase probability in next 52 weeks, β_n^π**

week) is relatively low, but (iii) conditional on repurchasing the household spends in the newly added variety as much as she spends in other varieties she regularly buys.

In adopting new varieties in their consumption basket, households sometimes make "mistakes", sampling varieties that they discover to dislike. The survey administered to Nielsen households exploited in Broda and Parker (2014) contains the following question: "*Many people sometimes buy things that they later wish they had not bought. About how often do you or other household members make purchases that you later regret?*" The possible answers to the question are: *"Never"; "Rarely"; "Occasionally"; "Often"*. The question was asked to households between April and June 2008. For each household in the sample used to run the tax rebate regression in Section 3, we compute the average value of the additions in (17) over the first semester of 2008, which is the period households should have in mind when answering the question above. We examine whether the frequency at which households report regretting purchases correlates with their additions to the consumption basket. Figure O7 displays the fraction of respondents choosing one of the four answers available to the question: "never"; "rarely"; "occasionally"; "often" by terciles of the distribution of additions. Households who add more products to their basket have a greater probability of regretting some purchases.

Figure O7: Robust and persistent additions



The histogram shows the share of respondents choosing different options to the survey question on "how often the respondent makes purchases that she later regrets". The shares of respondents are partitioned into three groups, according to the terciles of the distribution of the average addition rates in the first semester of 2008.

In the first column of Table O5 we report the coefficient of an ordered probit whose dependent variable is the same as in Figure O7: it is a categorical variable corresponding to the four possible answers to how often household members make purchases that they later regret. As explanatory variables the ordered probit contains household average additions (in the first semester of 2008) as well as household's income, her age, her race, education, employment status, size, marriage status and presence of kids below age 18. The coefficient for additions is positive and significant, implying that households with greater additions are more likely to regret some past purchases. A one standard deviation increase in additions lowers the probability of reporting never having experienced some regret by 0.6 percentage points and that of having rarely regretted a purchase by 2.1 percentage points. Conversely, it raises the probability of having occasionally regretted some purchases by 2.5 percentage points and that of having often experienced some regret by 0.3 percentage points. As an alternative way of quantifying this effect, in the second column, we report the effect of additions on the probability that a household reports having regretted occasionally or often some purchases using a linear probability model. In this case the probability goes up by 2.9 percentage points in response to a one standard deviation increase in additions.

Table O5: Probit estimates for household propensity to regret

	Ordered probit	Linear probability model
a_{it} in first sem. 2008	0.57***	0.22***
	(.12)	(.1)

The first column reports the coefficient of an ordered probit where the dependent variable is a categorical variable that indicates how often the household has regretted some past purchases. The answers could be: "Never"; "Rarely"; "Occasionally"; "Often". The independent variables are the average value of the additions in (17) over the first semester of 2008 plus household's income, her age, her race, education, employment status, size, marriage status and presence of kids below age 18. The coefficients of the demographic variables are not reported for parsimony. The second column reports the results from estimating a linear probability model where the dependent variable is a dummy variable equal to 1 if the household reports to have experienced regret over the past purchases either occasionally or often; and 0 otherwise. The regressors are the same as those in the ordered probit in the first column.

B Proofs

This section contains the proofs of all results discussed in Section 4.

Proof of Proposition 1. Let

$$\hat{z}_{jt} \equiv \max_{i \in \Omega_{jt}} \{z_{\nu jt}\} \tag{A4}$$

denote the maximum value among all varieties in the consideration set of sector j at time t, with the convention $\hat{z}_{jt} = 0$ if the consideration set is empty, $\Omega_{jt} = \emptyset$. Without loss of generality, we assume that the household purchases at most one variety per sector: if two or more varieties achieve the value $\hat{z}_{jt}$–which is a zero probability event— the household randomly buys one of them. The total consumption expenditure of the household in sector j at time t satisfies

$$q_{jt} = c_t \left(\hat{z}_{jt}\right)^{\sigma-1} \theta_t{}^{-\sigma}, \tag{A5}$$

where θ_t is the Lagrange multiplier on the budget constraint (23). By integrating (A5) over j and after using (23), we obtain

$$\theta_t^{\sigma} = \frac{c_t}{s_t} \int_0^1 (\hat{z}_{jt})^{\sigma-1} dj, \tag{A6}$$

which can be substituted into (A5). The resulting expression is then substituted in (21) to yield:

$$c_t = s_t \left[\int_0^1 \left(\hat{z}_{jt}\right)^{\sigma-1} \, dj \right]^{\frac{1}{\sigma-1}}. \tag{A7}$$

Since the price index p_t should satisfy the identity $p_t c_t = s_t$, (A7) immediately implies that

$$p_t = \left(\int_0^1 \left(\hat{z}_{jt}\right)^{\sigma-1} \, dj \right)^{-\frac{1}{\sigma-1}}. \tag{A8}$$

To calculate (A8), we use the law of iterated expectations and partition the sectors according to the cardinality of their consideration set at time t, n_{jt}, which allows us to write

$$p_t = \left\{ \sum_{n=0}^{\infty} E[(\hat{z}_{jt})^{\sigma-1} \Big| \, n_{jt} = n] f(n;\mu_t) \right\}^{-\frac{1}{\sigma-1}}. \tag{A9}$$

To evaluate (A9), notice that the $z_{\nu jt}$'s in (A4) are i.i.d drawings from a Fréchet distribution G with shape parameter κ and scale parameter equal to one. Then the CDF of $\hat{z}_{jt}^{\sigma-1}$, given a consideration set of cardinality equal to n, satisfies

$$\Pr\left(\max_{i=1,2,\dots n_j} (z_{\nu jt})^{\sigma-1} \le u \Big| \, n_j = n \right) = \prod_{i=1}^{n} G\left(u^{\frac{1}{\sigma-1}}\right) = \exp\left(- \left(n^{-\frac{\sigma-1}{\kappa}} \, u \right)^{-\frac{\kappa}{\sigma-1}} \right),$$

which implies that $\hat{z}_{jt}^{\sigma-1}$ is distributed according to a Fréchet distribution with shape parameter $\kappa/(\sigma-1)$ and scale parameter equal to $n^{\frac{\sigma-1}{\kappa}}$. Since $\kappa > \sigma - 1$ we have that

$$E[(\hat{z}_{jt})^{\sigma-1} \Big| n_{jt} = n] = n^{\frac{\sigma-1}{\kappa}} \Gamma\left(1 - \frac{\sigma-1}{\kappa}\right), \tag{A10}$$

which can be substituted into (A9) to yield (27).

After substituting (A6) into (A5), we obtain that the expected expenditure in a sector with $n_{jt} = n$ varieties in the consideration set are equal to

$$s_{nt} = \frac{E[(\hat{z}_{jt})^{\sigma-1} \Big| n_{jt} = n]}{\int_0^1 (\hat{z}_{jt})^{\sigma-1} dj} s_t = \frac{\Gamma\left(1 - \frac{\sigma-1}{\kappa}\right) n^{\frac{\sigma-1}{\kappa}}}{\int_0^1 (\hat{z}_{jt})^{\sigma-1} dj} s_t,$$

where the second equality uses (A10). ■

Proof of Lemma 1. We prove that the number of varieties in the consideration set in a sector at time t, is equal to the sum of two independent Poisson random variables, one with mean $(1-\delta)\,\mu_{t-1}$, the other with mean $\Lambda_t(x_t)$. The proof then follows from the fact that the sum of two independent Poisson random variables is again a Poisson random variable, see for example Cox and Miller (1994). The first random variable, denoted by X_1, corresponds to the number of varieties in the consideration set in the sector after the shock δ has been realized and before the household has experimented for new varieties at time t. X_1 is Poisson because if Z_1 is Poisson with mean μ_{t-1} and the distribution of X_1 conditional on $Z_1 = k$ is a binomial distribution with number of trials k and success probability $1-\delta$, then X_1 is a Poisson random variable with mean $(1-\delta)\,\mu_{t-1}$, see for example Karlin and Taylor (1975). The second random variable X_2 corresponds to the number of new varieties discovered in a specific sector by spending $x_t \in R^2$ on adoption, which we show is a Poisson random variable with mean $\Lambda_t(x_t)$. To derive this last result assume for simplicity that in the household there is a measure one of shoppers who independently experiment for new varieties to be added to the consideration set. Each shopper has $x_t \in R$ to spend in experimenting and randomly search over the space of varieties $\mathcal{V}_t \in R^2$. The number of new varieties discovered by the shopper is a homogeneous Poisson process on R^2 with parameter $\Lambda_t(x_t)$, see Karlin and Taylor (1981) for an analysis of the properties of multidimensional homogeneous Poisson processes. Since shoppers search independently over the space of varieties, the total number of new varieties discovered on a given area of the space of varieties is the sum of independent Poisson random variables, corresponding to the outcomes of each different shopper. Let's now discretize the measure one of sectors and the measure one of shoppers in equal intervals of size $\widehat{z} \in R$ and then let $\widehat{z}$ go to zero. Given the definition of a homogeneous Poisson process on R^2 with parameter $\Lambda_t(x_t)$ (Karlin and Taylor 1981), the probability that a shopper discovers exactly k new varieties on a stripe of sectors of size $\widehat{z}$,—whose area is equal to $\widehat{z}$ in $\mathcal{V}_t$,—is given by

$$\frac{\left[\Lambda_t(x_t)\widehat{z}\right]^k e^{-\Lambda_t(x_t)\widehat{z}}}{k!},$$

which corresponds to a Poisson distribution with parameter equal to the product of the intensity of the process, $\Lambda_t(x_t)$, times the area of the interval, $\widehat{z}$. But over the same stripe there are $1/\widehat{z}$ shoppers who experiment independently for new varieties. Since the sum of independent Poisson processes is again Poisson, the probability that exactly k new varieties are discovered in a specific sector j is equal to

$$pr\,(n_{jt}=k)=\lim_{\widehat{z}\to 0}\frac{[\Lambda_t(x_t)]^k\,e^{-\Lambda_t(x_t)}}{k!}=\frac{[\Lambda_t(x_t)]^k\,e^{-\Lambda_t(x_t)}}{k!},$$

which concludes the proof. ■

Proof of Proposition 2. Let $\mathbb{E}_{\boldsymbol{\omega}}$ denote the expectation operator conditional on the information set $\boldsymbol{\omega}$. The household's problem in recursive form is as follows:

$$W(\boldsymbol{\omega},a,\mu_{-1})=\max_{\{e,a',x\}}\left\{u\left(\frac{e-x}{p(\mu)}\right)+\rho\mathbb{E}_{\boldsymbol{\omega}}\left[W(\boldsymbol{\omega'},a',\mu)\right]\right\} \tag{A11}$$

s.t.

$$e+a'=\iota a+y, \tag{A12}$$

$$\mu=(1-\delta)\,\mu_{-1}+\Lambda(x), \tag{A13}$$

$$p(\mu)=\left[\Gamma\left(1-\frac{\sigma-1}{\kappa}\right)\sum_{n=0}^{\infty}n^{\frac{\sigma-1}{\kappa}}\,\frac{\mu^n e^{-\mu}}{n!}\right]^{-\frac{1}{\sigma-1}}. \tag{A14}$$

where the function $p(\mu)$ is as in (27) and the law of μ_t is as in (26). The first order condition with respect to x in (A11) reads as follows:

$$-\frac{u'\,(c)}{p(\mu)}-\frac{u'(c)c}{p(\mu)}p'(\mu)\Lambda_t'(x)+\rho\Lambda_t'(x)\mathbb{E}_{\mathbf{e}}\left[W_3(\boldsymbol{\omega'},a',\mu)\right]=0$$

which can be rearranged to obtain

$$\frac{u'\,(c_t)}{p(\mu_t)}=\left\{-\frac{u'(c_t)c_tp'(\mu_t)}{p(\mu_t)}+\rho\mathbb{E}_t\left[W_3(\boldsymbol{\omega}_{t+1},a_{t+1},\mu_t)\right]\right\}\Lambda_t'(x_t) \tag{A15}$$

where we adopted the notation $\mathbb{E}_t\equiv\mathbb{E}_{\boldsymbol{\omega}_t}$. The envelope condition with respect to μ_{t-1} yields

$$W_3(\boldsymbol{\omega}_t,a_t,\mu_{t-1})=\left\{-\frac{u'(c_t)c_tp'(\mu_t)}{p(\mu_t)}+\rho\mathbb{E}_t\left[W_3(\boldsymbol{\omega}_{t+1},a_{t+1},\mu_t)\right]\right\}(1-\delta),$$

which after using (A15) can be expressed as follows:

$$W_3(\boldsymbol{\omega}_t,a_t,\mu_{t-1})=\frac{u'\,(c_t)}{p(\mu_t)}\frac{(1-\delta)}{\Lambda_t'(x_t)} \tag{A16}$$

After substituting (A16) into (A15) we obtain

$$\frac{u'\,(c_t)}{p(\mu_t)}=\left\{-\frac{u'(c_t)c_tp'(\mu_t)}{p(\mu_t)}+\rho\mathbb{E}_t\left[\frac{u'\,(c_{t+1})}{p(\mu_{t+1})}\frac{(1-\delta)}{\Lambda_{t+1}'(x_{t+1})}\right]\right\}\Lambda_t'(x_t)$$

which, after dividing the right and left hand side by $u'(c_t)/p(\mu_t)$ can be expressed as follows

$$1=\left\{-\frac{c_t p'(\mu_t)}{p(\mu_t)}+\rho\mathbb{E}_t\left[\frac{u'(c_{t+1})}{u'(c_t)}\frac{p(\mu_t)}{p(\mu_{t+1})}\frac{(1-\delta)}{\Lambda'(x_{t+1})}\right]\right\}\Lambda_t'(x_t)$$

which eventually yields

$$1=\frac{(e_t-x_t)\,\eta(\mu_t)}{\mu_t}\Lambda_t'(x_t)+(1-\delta)\mathbb{E}_t\left[\rho_{t,t+1}\frac{\Lambda_t'(x_t)}{\Lambda_{t+1}'(x_{t+1})}\right] \tag{A17}$$

where

$$\eta(\mu)\equiv-\frac{d\ln p(\mu)}{d\ln\mu}$$

and

$$\rho_{t,t+1}\equiv\rho\frac{u'(c_{t+1})}{u'(c_t)}\cdot\frac{p(\mu_t)}{p(\mu_{t+1})}.$$

(A17) corresponds to (30) in the main text.

Maximizing with respect to total expenditure e in (A11) yields the following Euler condition:

$$\frac{u'(c_t)}{p(\mu_t)}=\rho\mathbb{E}_t\left[\iota_{t+1}\frac{u'(c_{t+1})}{p(\mu_{t+1})}\right] \tag{A18}$$

which makes use of the envelope condition with respect to a. (A18) corresponds to (33) in the main text.

To prove that $\eta(\mu_t)\in[0,1/(\sigma-1)]$, let $u\equiv(\sigma-1)/\kappa\in(0,1]$. Notice that $E(n^{1+u})/E(n^u)-E(n)=0$ if $u=0$ and $E(n^{1+u})/E(n^u)-E(n)=1$ if $u=1$, which uses the fact that n is Poisson distributed. The result then follows from the fact that $E(n^{1+u})/E(n^u)$ is increasing in $u\in(0,1]$. ■

Analytical expression for $\tilde{e}^0_{t-1}$ in Section 4.4. $\tilde{e}^0_t$ denotes the fraction of total expenditure at $t-1$ in varieties that are purchased also at t, equal to

$$\tilde{e}^0_{t-1}=\left[\sum_{n=1}^{\infty}\kappa^r_{nt}\,f\left(n;\mu_{t-1}\right)\right]\frac{1}{e_{t-1}}, \tag{A19}$$

where κ^r_{nt} denotes the expenditure at time $t-1$ in varieties purchased also at time t, conditional on being at $t-1$ in a sector with n varieties in the consideration set and $f\left(n;\mu_{t-1}\right)$ denotes a Poisson distribution with mean μ_{t-1}. We now prove that κ^r_{nt} is equal to

$$\kappa^r_{nt}=s_{nt-1}\left(1-\delta\right)\sum_{m=0}^{\infty}f\left(m;\Lambda_t(x_t)\right)\left[\sum_{u=0}^{n-1}b\left(u;1-\delta,n-1\right)\frac{1}{m+u+1}\right] \tag{A20}$$

where

$$b(u;1-\delta,n)=\binom{n}{u}\left(1-\delta\right)^u\delta^{n-u},\qquad u=0,1...n \tag{A21}$$

denotes the probability of u successes in the case of a binomial random variable with success probability $1-\delta$ and number of trials equal to n. The first two terms in the right-hand side of (A20) is the product of the expenditure at time $t-1$ in a sector with n varieties in the considerations set, equal to s_{nt-1}, times the probability that the variety consumed at $t-1$ has remained in the consideration set at time t, equal to $1-\delta$. To understand the two summatories in (A20) notice that the index m refers to the number of new varieties added to the consideration set at time t, while $u \leq n-1$ refers to the number of old varieties (different from the one consumed at time $t-1$) present in the consideration set both at time $t-1$ and at time t. Notice that m and u are two independent random variables: m is Poisson with mean $\Lambda_t(x_t)$; u is binomial with success probability $1-\delta$ and number of trials equal to $n-1$. Then, for given number of new varieties m, the term in square brackets calculates the probability that the variety consumed at $t-1$ is also consumed at t. Since preferences are redrawn, the variety consumed at time $t-1$ is also consumed at time t only if the two following conditions are both verified: it is preferred to the $m \geq 0$ new varieties added to the consideration set at time t; and it is preferred to the $u \leq n-1$ other old varieties inherited from the consideration set at time $t-1$. Due to symmetry in preferences, these two conditions are simultaneously satisfied with probability $\frac{1}{m+u+1}$. By summing over the possible realizations of u, we obtain the term in square brackets in (A20), while by summing over the possible realizations of m we obtain the probability that, conditional on survival, the variety consumed at $t-1$ is also consumed at t. ■

Analytical expression for $\tilde{e}_t^1$ in Section 4.4. $\tilde{e}_t^1$ denotes the total expenditure at t (as a share of e_{t-1}) in varieties already in the consideration set at $t-2$, that were purchased also at $t-1$. We show that

$$\tilde{e}_t^1 = \left[\sum_{n=1}^{\infty} \kappa_{nt}^a f(n;\mu_t)\right] \frac{1}{e_{t-1}}, \tag{A22}$$

where κ_{nt}^a denotes the (expected) expenditure at time t in varieties that (i) were already in the consideration set at time $t-2$ and (ii) were also consumed at time $t-1$, conditional on being today in a sector with n varieties in the consideration set. To calculate κ_{nt}^a we first prove that the number of varieties in a sector which have exited the consideration set between time $t-1$ and t, denoted by k, given that $\widehat{u}$ varieties in the sector have survived until time t is Poisson with mean $\delta\mu_{t-1}$, which further implies that k is independent of $\widehat{u}$. To prove this result, notice that the joint probability that in the sector there were $\widehat{u}+k$ varieties in the consideration set at $t-1$ and that $\widehat{u}$ of them have survived at t is equal to

$$\binom{\widehat{u}+k}{k} (1-\delta)^{\widehat{u}} \delta^k \frac{(\mu_{t-1})^{\widehat{u}+k}}{(\widehat{u}+k)!} e^{-\mu_{t-1}}$$

The unconditional probability than $\widehat{u}$ varieties have survived at time t is equal to

$$\frac{[(1-\delta)\mu_{t-1}]^{\widehat{u}}}{\widehat{u}!} e^{-(1-\delta)\mu_{t-1}}$$

Then the probability that k varieties have exited the consideration set from $t-1$ to t given that $\widehat{u}$ varieties have remained in the set over the period is equal to

$$\frac{\binom{\widehat{u}+k}{k}(1-\delta)^{\widehat{u}}\,\delta^{k}\frac{(\mu_{t-1})^{\widehat{u}+k}}{(\widehat{u}+k)!}e^{-\mu_{t-1}}}{\frac{[(1-\delta)\mu_{t-1}]^{\widehat{u}}}{\widehat{u}!}e^{-(1-\delta)\mu_{t-1}}}=\frac{(\delta\mu_{t-1})^{k}\,e^{-\delta\mu_{t-1}}}{k!}=f\left(k;\delta\mu_{t-1}\right),$$

which is a Poisson distribution with mean $\delta\mu_{t-1}$.

We now use the fact that the number of varieties which have exited the consideration set from $t-1$ to t, k, and the number of varieties which have survived, $\widehat{u}$, are independent (Poisson) random variables. Moreover, notice that the number of varieties which have survived in the consideration set is the sum of two independent (Poisson) random variables: those which survived from the consideration set at $t-2$ (denoted by u in the expression below) and those newly added to the consideration set at $t-1$ which have survived until t (denoted by j in the expression below). Then the (expected) expenditure at time t in varieties that (i) were already in the consideration set at time $t-2$ and (ii) were also consumed at time $t-1$, conditional on being today in a sector with n varieties in the consideration set can be calculated as follows:

$$\kappa_{nt}^{a}=\sum_{k=0}^{\infty}\sum_{u=1}^{n}\sum_{j=0}^{n-u}f\left(k;\delta\mu_{t-1}\right)h\left(u,j;\frac{(1-\delta)^{2}\mu_{t-2}}{\mu_{t}},\frac{(1-\delta)\Lambda_{t-1}(x_{t-1})}{\mu_{t}},n\right)\times\frac{u}{k+u+j}\frac{s_{nt}}{n}. \tag{A23}$$

where

$$h\left(u,j;\frac{(1\text{-}\delta)^{2}\mu_{t-2}}{\mu_{t}},\frac{(1\text{-}\delta)\Lambda_{t-1}}{\mu_{t}},n\right)=\frac{n!}{(n\text{-}u\text{-}j)!u!j!}\left(\frac{\Lambda_{t}}{\mu_{t}}\right)^{n\text{-}u\text{-}j}\left[\frac{(1\text{-}\delta)^{2}\mu_{t-2}}{\mu_{t}}\right]^{u}\left[\frac{(1\text{-}\delta)\Lambda_{t-1}}{\mu_{t}}\right]^{j}$$

is the multinomial distribution characterizing the probability that given n varieties in the consideration set of the sector at time t, u of them were also in the consideration set at time $t-2$, j of them were added to the consideration set at time $t-1$, while the remaining $n-u-j$ were added just at t. Given n, and the properties of independent Poisson random variables we immediately have that $n-u-j$, u and j are multinomial random variables with success probabilities equal to $\frac{\Lambda_t(x_t)}{\mu_t}$, $\frac{(1-\delta)^2\mu_{t-1}}{\mu_t}$ and $\frac{(1-\delta)\Lambda_{t-1}(x_{t-1})}{\mu_t}$, respectively. Given k, u and j, the probability that the variety consumed a $t-1$ was in the consideration set at $t-2$ and has remained in the consideration set at t is equal to $u/(k+u+j)$. Given k, u and j, and that the variety consumed at $t-1$ has survived, the term in square brackets of (A23) calculates the expected expenditure at time t in the variety, which happens with probability $1/n$ and, conditional on consumption, expenditure is equal to s_{nt}, since the variety is the one preferred among the n varieties in the today consideration set. We now simplify (A23) by canceling out the term $k+u+j$. Then by using the property of the value of the mean of a multinomial random variable, we finally obtain that

$$\kappa_{nt}^{a}=\sum_{k=0}^{\infty}\left\{f\left(k;\delta\mu_{t-1}\right)\left[\frac{1}{n}s_{nt}\vartheta_{n,k,t}\right]\right\} \tag{A24}$$

with

$$\vartheta_{n,k,t} = \sum_{u=0}^{n} \sum_{j=0}^{n\text{-}u} h\left(u, j; \frac{(1-\delta)^2\mu_{t-2}}{\mu_t}, \frac{(1-\delta)\Lambda_{t-1}(x_{t-1})}{\mu_t}, n\right) \frac{u}{k+u+j}$$

■

Derivation of (37) in Section 4.4. Given the definition of $\tilde{e}_t^0$ and $\tilde{e}_t^1$ we just need to prove the first term, which measures the total expenditure at t in varieties added to the consideration set at $t-1$ (as a share of expenditure at $t-1$, e_{t-1}). If the variety newly added to the consideration set at $t-1$ is purchased at t in a sector with n varieties in the consideration set, the household spends (in expected value) s_{nt} in the variety. Conditional on being in a sector with n varieties, the probability that the household purchases the variety is equal to

$$\sum_{m=0}^{n} b\left(m; \frac{(1-\delta)\Lambda_{t-1}(x_{t-1})}{\mu_t}, n\right) \frac{m}{n} = \frac{(1-\delta)\Lambda_{t-1}(x_{t-1})}{\mu_t}, \tag{A25}$$

which allows to calculate the overall expenditure at t in varieties newly added to the consideration set at $t-1$ as equal to

$$\sum_{n=1}^{\infty} s_{nt} \frac{\Lambda_t(x_t)}{\mu_t} f(n; \mu_t) = \frac{(1-\delta)\Lambda_{t-1}(x_{t-1})}{\mu_t} s_t. \tag{A26}$$

To calculate the probability in (A25) we used the fact that if X_i, $i = 1, 2$ are independent Poisson random variables with mean λ_i, then the distribution of X_1 given $X_1 + X_2$ is a binomial distribution with success probability $\frac{\lambda_1}{\lambda_1+\lambda_2}$ and number of trials equal to $X_1 + X_2$ (see for example Cox and Miller (1994)). In our case $X_1 + X_2$ corresponds to the n varieties in the consideration set at time t which is the sum of the $m \geq 0$ new varieties resulting from the successful experimentation of the household at time $t-1$ which have survived until time t (a Poisson random variable with mean $(1-\delta)\Lambda_{t-1}(x_{t-1})$) and the other varieties in the consideration set, which is the sum of two independent Poisson distribution: those newly added at t with mean $\Lambda_{t-1}(x_{t-1})x_t)$ and the other old varieties inherited from the consideration set at time $t-2$ (which is a Poisson random variable with mean $(1-\delta)^2\mu_{t-2}$). The last equality in (A25) follows from the property of the mean of a binomial random variable. ■

Derivation of (35) in Section 4.4. We now prove that the expression for total additions in (35) holds true by deriving its second and third term.

Derivation of second term The second term of (35) measures the contribution of true additions. It is calculated as follows. If the new variety is purchased in a sector with n varieties in the consideration set, the household spends (in expected value) s_{nt} in the variety. Conditional on being in a sector with n varieties, the probability that the household purchases a newly added variety is equal to

$$\sum_{m=0}^{n} b\left(m; \frac{\Lambda_t(x_t)}{\mu_t}, n\right)\frac{m}{n} = \frac{\Lambda_t(x_t)}{\mu_t}, \tag{A27}$$

which allows to calculate the overall expenditure in varieties newly added to the consideration set as equal to

$$\sum_{n=1}^{\infty} s_{nt}\frac{\Lambda_t(x_t)}{\mu_t} f(n; \mu_t) = \frac{\Lambda_t(x_t)}{\mu_t} s_t. \tag{A28}$$

To calculate the probability in (A27) we used the previously mentioned result—used to derive (A25)— that if X_i, $i = 1, 2$ are independent Poisson random variables with mean λ_i, then the distribution of X_1 given X_1+X_2 is a binomial distribution with success probability $\frac{\lambda_1}{\lambda_1+\lambda_2}$ and number of trials equal to $X_1 + X_2$. In this case $X_1 + X_2$ corresponds to the n varieties in the consideration set at time t which is the sum of the $m \geq 0$ new varieties resulting from the successful experimentation of the household at time t (a Poisson random variable with mean Λ_t) and of the old varieties inherited from the consideration set at time $t - 1$ (a Poisson random variable with mean $(1 - \delta)\mu_{t-1}$). The last equality in (A27) uses the property of the mean of a binomial random variable.

Derivation of third term Notice that the expenditure at time t in varieties added to the consideration set at time $t - 1$ never leads to additions at time t, since the variety was necessarily consumed at $t - 1$ as part of x_{t-1}. The first term inside the square brackets of (A22) corresponds to the expenditure at time t in all varieties which were already in the consideration set at time $t - 2$, which can be obtained using a logic analogous to the one used to derive (A28). ■

Derivation of (36) in Section 4.4. The proof is analogous to the one used to prove (35). ■

Proposition 3. *The steady state level of adoption expenditure $\bar{x}$ is increasing in the discount factor ρ and in the steady state level of total expenditure $\bar{e}$. The elasticity of $\bar{x}$ with respect to $\bar{e}$ is smaller than or equal to 1, i.e. $d\ln(\bar{x})/d\ln(\bar{e}) \in (0,1]$.*

Proof of Proposition 3. We first prove that the derivative of the function $\eta(\mu)$ in (32) is negative:

$$\eta'(\mu) = \frac{1}{\sigma-1}\left\{\frac{E(n^{u+2})\,E(n^u)-[E(n^{u+1})]^2}{[E(n^u)]^2\,E(n)} - 1\right\}$$
$$= \left[\frac{E(n^{u+2})}{E(n^{u+1})E(n)} - \frac{E(n^{u+1})}{E(n^u)E(n)}\right]\frac{E(n^{u+1})}{E(n^u)} - \frac{1}{\sigma-1} < 0 \tag{A29}$$

where we used the notation

$$E(n^u) \equiv \sum_{n=0}^{\infty} n^u\, f(n;\bar{\mu}) \tag{A30}$$

with $u = \frac{\sigma-1}{\kappa} \in (0,1]$. The inequality in (A29) follows from the fact that the term in square brackets in (A29) is negative. To see this notice that $f(n;\bar{\mu}) = \frac{(\bar{\mu})^n e^{-\bar{\mu}}}{n!}$ implies that

$$E(n^{u+1}) = E(n)E[(n+1)^u] \tag{A31}$$

which implies that

$$\frac{E(n^{u+2})}{E(n^{u+1})E(n)} - \frac{E(n^{u+1})}{E(n^u)E(n)} = \frac{E[(n+2)^u]}{E[(n+1)^u]} - \frac{E[(n+1)^u]}{E[n^u]}$$

which is negative because the function

$$h(k) = \frac{E[(n+k)^u]}{E[(n+k-1)^u])}$$

is decreasing in k, since its derivative as the same sign as

$$h'(k) \simeq E[(n+k)^{u-1}]E[(n+k-1)^u] - E[(n+k-1)^{u-1}]E[(n+k)^u],$$

which is negative because, when $u \in (0,1]$, we simultaneously have $E[(n+k-1)^{u-1}] > E[(n+k)^{u-1}]$ and $E[(n+k)^u] > E[(n+k-1)^u]$. This concludes the proof that $\eta'(\mu)$ in (A29) is negative.

By taking derivatives in

$$\bar{x} = \frac{\delta\eta(\bar{\mu})\bar{e}}{1-(1-\delta)\rho+\delta\eta(\bar{\mu})},$$

we obtain that

$$\frac{d\bar{x}}{d\rho} = \frac{(1-\delta)\bar{x}}{1-(1-\delta)\rho+\delta\eta(\bar{\mu})-\eta'(\bar{\mu})\delta(\bar{e}-\bar{x})} > 0, \tag{A32}$$

and that

$$\frac{d\ln\bar{x}}{d\ln\bar{e}} = \frac{1-(1-\delta)\rho+\delta\eta(\bar{\mu})}{1-(1-\delta)\rho+\delta\eta(\bar{\mu})-\eta'(\bar{\mu})\delta(\bar{e}-\bar{x})} \in (0,1), \tag{A33}$$

where the inequality in (A32) and the range of variation in (A33) follows immediately from the fact that η' in (A29) is negative. ■

C Maximum likelihood estimation

First, we log-linearize the key equations of the household's problem. Secondly, we write the state space representation of the problem, taking into account time aggregation of the data. Thirdly, we discuss the construction of the likelihood function. Finally we describe the data.

C.1 Log-linearization of household problem

We log-linearize the set of equations that govern the endogenous dynamics of x_t and μ_t for given exogenous path of e_t and λ_t, and solve for the linear state space representation of our economy. Let $\hat{x}_t = \ln x_t - \ln \bar{x}$, $\hat{e}_t = \ln e_t - \ln \bar{e}$ and $\hat{\mu}_t = \ln \mu_t - \ln \bar{\mu}$ denote the log-deviation of variables x, e, and μ from their steady state value; let also $\hat{\lambda}_t = \lambda_t - \bar{\lambda}$. A steady state is defined as the solution when $\forall t$, $e_t = \bar{e}$ and there are no foreseen shocks. By log-differentiating (30), (26) under the assumption that $\ln e_t$ and $\ln \lambda_t$ are two AR(1) processes we obtain

$$\begin{aligned}
& -\frac{1-\beta(1-\delta)}{\beta(1-\delta)}\left[(\zeta_{\eta,\mu}-1)\hat{\mu}_t + \zeta_{\Lambda',x}\hat{x}_t + \zeta_{\Lambda',\lambda}\hat{\lambda}_t + \frac{\bar{e}}{\bar{e}-\bar{x}}\hat{e}_t - \frac{\bar{x}}{\bar{e}-\bar{x}}\hat{x}_t\right] = \\
& -\gamma\,\frac{\bar{e}}{\bar{e}-\bar{x}}[E_t(\hat{e}_{t+1}) - \hat{e}_t] + \zeta_{\Lambda',x}(\hat{x}_t - \hat{x}_{t+1}) + \zeta_{\Lambda',\lambda}(\hat{\lambda}_t - \hat{\lambda}_{t+1}) \\
& +\gamma\,\frac{\bar{x}}{\bar{e}-\bar{x}}[E_t(\hat{x}_{t+1}) - \hat{x}_t] - (\gamma-1)\,\eta(\bar{\mu})\,[E_t(\hat{\mu}_{t+1}) - \hat{\mu}_t], \qquad \text{(A34)} \\
& \hat{\mu}_t = (1-\delta)\,\hat{\mu}_{t-1} + \delta\,\zeta_{\Lambda,x}\,\hat{x}_t + \delta\,\zeta_{\Lambda,\lambda}\,\hat{\lambda}_t, \\
& \hat{e}_t = \varrho_e\,\hat{e}_{t-1} + \epsilon^e_t, \\
& \hat{\lambda}_t = \varrho_\lambda\,\hat{\lambda}_{t-1} + \epsilon^\lambda_t,
\end{aligned}$$

where

$$\zeta_{\eta,\mu} \equiv \frac{\partial \log(\eta(\mu))}{\partial \log(\mu)} = \frac{E_f(n^{u+2})E_f(n^u) - [E_f(n^{u+1})^2]}{E_f(n^u)\,[E_f(n^{u+1}) - E_f(n^u)\,\mu]} - \frac{\bar{\mu}}{(\sigma-1)\,\eta(\bar{\mu})} < 0$$

with $u = (\sigma-1)/\kappa$ and E_f denoting the expectation with respect to a Poisson distribution with mean $\bar{\mu}$, while the elasticity of $\Lambda(x)$ with respect to x and λ are given by

$$\begin{aligned}
\zeta_{\Lambda,x} &\equiv \frac{\partial \log(\Lambda(x))}{\partial \log(x)} = 1 - \frac{\alpha}{1+\alpha}\left(\frac{\bar{x}}{\chi}\right)^\alpha, \\
\zeta_{\Lambda,\lambda} &= 1 \\
\zeta_{\Lambda',x} &\equiv \frac{\partial \log(\Lambda'(x))}{\partial \log(x)} = -\frac{\alpha\left(\frac{\bar{x}}{\chi}\right)^\alpha}{1-\left(\frac{\bar{x}}{\chi}\right)^\alpha} \\
\zeta_{\Lambda',\lambda} &\equiv 1,
\end{aligned}$$

After some algebra (A34) can be rewritten as follows

$$\left[\frac{1-\beta\,(1-\delta)}{\beta\,(1-\delta)}\left(\frac{\bar{x}}{\bar{e}-\bar{x}}-\zeta_{\Lambda',x}\right)+\gamma\frac{\bar{x}}{\bar{e}-\bar{x}}-\zeta_{\Lambda',x}\right]\hat{x}_t-\left(\gamma\frac{\bar{x}}{\bar{e}-\bar{x}}-\zeta_{\Lambda',x}\right)E_t(\hat{x}_{t+1})+$$
$$-\left[\frac{1-\beta\,(1-\delta)}{\beta\,(1-\delta)}\frac{\bar{e}}{\bar{e}-\bar{x}}+\gamma\frac{\bar{e}}{\bar{e}-\bar{x}}\right]\hat{e}_t+\gamma\frac{\bar{e}}{\bar{e}-\bar{x}}E_t(\hat{e}_{t+1})+$$
$$-\left[(\gamma-1)\,\eta(\bar{\mu})+\frac{1-\beta\,(1-\delta)}{\beta\,(1-\delta)}(\zeta_{\eta,\mu}-1)\right]\hat{\mu}_t+$$
$$-\left[\frac{1-\beta\,(1-\delta)}{\beta\,(1-\delta)}\zeta_{\Lambda',\lambda}+\zeta_{\Lambda',\lambda}\right]\hat{\lambda}_t+\zeta_{\Lambda',\lambda}\hat{\lambda}_{t+1}+(\gamma-1)\,\eta(\bar{\mu})E_t(\hat{\mu}_{t+1})=0$$

The log-lineraized system has three backward looking variables $\hat{e}_t$, $\hat{\lambda}_t$ and $\hat{\mu}_t$, and one forward looking, $\hat{x}_t$. Provided that $\varrho_e < 1$ and $\varrho_\lambda < 1$ there is a unique solution to the system, which can be written in matrix form as follows:

$$F_0\,E_t(Y_{t+1})+F_1\,Y_t+F_2\,Y_{t-1}+Q_0\,E_t(\hat{Z}_{t+1})+Q_1\,\hat{Z}_t=0 \tag{A35}$$

where $Y_t=[\hat{x}_t,\hat{\mu}_t]'$, $Z_t=[\hat{e}_t,\hat{\lambda}_t]'$,

$$F_0=\begin{bmatrix}-\gamma\frac{\bar{x}}{\bar{e}-\bar{x}}+\zeta_{\Lambda',x} & (\gamma-1)\,\eta(\bar{\mu})\\ 0 & 0\end{bmatrix},$$
$$F_1=\begin{bmatrix}\frac{1-\beta\,(1-\delta)}{\beta\,(1-\delta)}\frac{\bar{x}}{\bar{e}-\bar{x}}+\gamma\frac{\bar{x}}{\bar{e}-\bar{x}}-\frac{\zeta_{\Lambda',x}}{\beta\,(1-\delta)} & -(\gamma-1)\,\eta(\bar{\mu})-\frac{1-\beta\,(1-\delta)}{\beta\,(1-\delta)}(\zeta_{\eta,\mu}-1)\\ \delta\,\zeta_{\Lambda,x} & \text{-1}\end{bmatrix},$$
$$F_2=\begin{bmatrix}0 & 0\\ 0 & 1-\delta\end{bmatrix},$$
$$Q_0=\begin{bmatrix}\gamma\frac{\bar{e}}{\bar{e}-\bar{x}} & \zeta_{\Lambda',\lambda}\\ 0 & 0\end{bmatrix},$$
$$Q_1=\begin{bmatrix}-\frac{1-\beta\,(1-\delta)}{\beta\,(1-\delta)}\frac{\bar{e}}{\bar{e}-\bar{x}}-\gamma\frac{\bar{e}}{\bar{e}-\bar{x}} & -\frac{\zeta_{\Lambda',\lambda}}{\beta\,(1-\delta)}\\ 0 & \delta\,\zeta_{\Lambda,x}\end{bmatrix}.$$

The solution to the system in (A35) has the form

$$\begin{aligned}\hat{x}_t &= g^x_\mu\,\hat{\mu}_{t-1}+g^x_e\,\hat{e}_t+g^x_\lambda\,\hat{\lambda}_t,\\ \hat{\mu}_t &= g^\mu_\mu\,\hat{\mu}_{t-1}+g^\mu_e\,\hat{e}_t+g^\mu_\lambda\,\hat{\lambda}_t,\end{aligned}$$

where the coefficients g^j_i are solved numerically using the algorithm by Christiano (2002).

C.2 State space representation

We now write the household's problem in state space form (without any time aggregation) using the following vector of states:

$$\mathbf{s}_t = \begin{bmatrix} \ln e_t - \ln \overline{e} \\ \ln e_{t-1} - \ln \overline{e} \\ \ln x_t - \ln \overline{x} \\ \ln x_{t-1} - \ln \overline{x} \\ \ln \mu_t - \ln \overline{\mu} \\ \ln \mu_{t-1} - \ln \overline{\mu} \\ \ln \mu_{t-2} - \ln \overline{\mu} \\ \lambda_t - \overline{\lambda} \\ \lambda_{t-1} - \overline{\lambda} \end{bmatrix} = \begin{bmatrix} \widehat{e}_t \\ \widehat{e}_{t-1} \\ \widehat{x}_t \\ \widehat{x}_{t-1} \\ \widehat{\mu}_t \\ \widehat{\mu}_{t-1} \\ \widehat{\mu}_{t-2} \\ \widehat{\lambda}_t \\ \widehat{\lambda}_{t-1} \end{bmatrix} \tag{A36}$$

The state space representation is as follows

$$\mathbf{s}_t = D\mathbf{s}_{t-1} + u_t, \qquad u_t \sim N(0, Q) \tag{A37}$$
$$y_t = C\mathbf{s}_t + \zeta_t, \qquad \zeta_t \sim N(0, \Omega) \tag{A38}$$

The first equation is the so called transition or system equation. The second is the measurement equation. D is the system matrix (or transition matrix), C is the observation matrix, Q is the system covariance matrix while Ω is the observation covariance matrix. The observable variables are logged total expenditure and net additions (in real terms):

$$y_t = \begin{bmatrix} \ln e_t - \ln \overline{e} \\ N_{rt} - \overline{N}_r \end{bmatrix} \equiv \begin{bmatrix} \widehat{e}_t \\ n_t \end{bmatrix}$$

The vector of structural shocks is

$$u_t = B\epsilon_t \quad \text{with} \quad \epsilon_t = \begin{bmatrix} \epsilon_t^e \\ \epsilon_t^\lambda \end{bmatrix} \tag{A39}$$

so that

$$Q = B \begin{bmatrix} (\vartheta_e)^2 & \vartheta_{e\lambda}\vartheta_e\vartheta_\lambda \\ \vartheta_{e\lambda}\vartheta_e\vartheta_\lambda & (\vartheta_\lambda)^2 \end{bmatrix} B'$$

where ϑ^j denote the standard deviation of the structural shock ϵ_t^j, $j = e, \lambda$. The third row of the matrices D and B is obtained using the coefficients $g_\mu^x, g_e^x, g_\lambda^x$ computed above. The fifth row of the matrices D and B is obtained using the coefficients $g_\mu^\mu, g_e^\mu, g_\lambda^\mu$ computed above. The first and tenth rows of matrices D and B are obtained using the stochastic process for $\hat{e}_t$ and $\hat{\lambda}_t$.

We use (35)-(36) to construct the following two functions for additions and removals

$$\ln A_{rt} = A(\ln e_t, \ln e_{t\text{-}1}, \ln x_t, \ln x_{t\text{-}1}, \ln \mu_t, \ln \mu_{t\text{-}1}, \ln \mu_{t\text{-}2}, \lambda_t, \lambda_{t\text{-}1}) \tag{A40}$$
$$\ln R_{rt} = R(\ln e_t, \ln e_{t\text{-}1}, \ln x_t, \ln x_{t\text{-}1}, \ln \mu_t, \ln \mu_{t\text{-}1}, \ln \mu_{t\text{-}2}, \lambda_t, \lambda_{t\text{-}1}) \tag{A41}$$

We construct the observation matrix C, by calculating for each variable in $\mathbf{s}_t$ the value of the function A and R at z percentage differences, where all the other variables in s_t are at their steady state value. For example, the linearized coefficient for (logged) total expenditure for additions is calculated as follows

$$\frac{A(\ln \overline{e} + \frac{z}{2},\ \overline{\mathbf{s}}_{-\overline{e}}) - A(\ln \overline{e} - \frac{z}{2},\ \overline{\mathbf{s}}_{-\overline{e}})}{z}$$

where $z = 0.02$ and $\overline{\mathbf{s}}_{-\overline{e}}$ is the vector collecting all the variables different from $\ln e_t$ evaluated at their steady state value,

$$\overline{\mathbf{s}}_{-\overline{e}} = (\ln \overline{e},\ \ln \overline{x},\ \ln \overline{x},\ \ln \overline{\mu},\ \ln \overline{\mu},\ \ln \overline{\mu},\ \ln \overline{\lambda},\ \ln \overline{\lambda},\ \ln \overline{\delta},\ \ln \overline{\delta}).$$

In practice we need to modify the state space representation in (A37) and (A38) to deal with the time aggregation of net additions, which are expressed as four quarters moving averages. Let the matrix B in (A39) be written as the collection of two column vectors as follows:

$$\underset{11\times 2}{B} = \left[\begin{array}{cc} \underset{11\times 1}{B_1} & \underset{11\times 1}{B_2} \end{array} \right].$$

Let the observation matrix C in (A38) be written as the collection of two row vectors as follows:

$$\underset{2\times 11}{C} = \left[\begin{array}{c} \underset{1\times 11}{C_1' = \left[1\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\right]} \\ \underset{1\times 11}{C_2'} \end{array} \right]$$

Our vector of observables is given by

$$y_t^a = \left[\begin{array}{c} \hat{e}_t^a \\ n_t^a \end{array} \right] \tag{A42}$$

rather than by

$$y_t = \left[\begin{array}{c} \hat{e}_t \\ n_t \end{array} \right]$$

where

$$\begin{aligned} \hat{e}_t^a &= \frac{1}{4}\left(\hat{e}_t + \hat{e}_{t-1} + \hat{e}_{t-2} + \hat{e}_{t-3}\right) \\ n_t^a &= \frac{1}{4}\left(n_t + n_{t-1} + n_{t-2} + n_{t-3}\right) \end{aligned}$$

Given (A37) and (A38) specified at the quarterly frequency, we can deal with the time aggregation problem by using the following state space representation:

$$\mathbf{s}_t^a = D_{t-1}^a \mathbf{s}_{t-1}^a + u_t^a, \qquad u_t^a \sim N(0, Q^a) \tag{A43}$$

$$y_t^a = C_t^a \mathbf{s}_t^a + \zeta_t^a, \qquad \zeta_t^a \sim N(0, \Omega^a) \tag{A44}$$

where

$$\underset{20\times1}{\mathbf{s}_t^a} = \begin{bmatrix} \mathbf{s}_t \\ \hat{e}_{t-2} \\ \hat{e}_{t-3} \\ n_{t-1} = C_2' s_{t-1} \\ n_{t-2} = C_2' s_{t-2} \\ n_{t-3} = C_2' s_{t-3} \\ \zeta_t \\ \zeta_{t-1} \\ \zeta_{t-2} \\ \zeta_{t-3} \end{bmatrix} \tag{A45}$$

$\mathbf{s}_t$ is defined in (A36), and ζ_t corresponds to the measurement error shock in (A38). Notice that now the measurement error shock is defined as part of the vector of structural shocks in the transition equation in (A43) so that the variance of measurement error shocks in (A44) is now a matrix of zeros:

$$\underset{2\times2}{\Omega^a} = \left[\underset{2\times2}{0} \right] \tag{A46}$$

The transition matrix in (A43) is now given by:

$$\underset{20\times20}{D^a} = \begin{bmatrix}
\underset{11\times11}{D} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} \\
\underset{1\times11}{[0\ 1\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0]} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} \\
\underset{1\times11}{0} & \underset{1\times1}{1} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} \\
\underset{1\times11}{C_2'} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} \\
\underset{1\times11}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{1} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} \\
\underset{1\times11}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{1} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} \\
\underset{1\times11}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} \\
\underset{1\times11}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{1} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} \\
\underset{1\times11}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{1} & \underset{1\times1}{0} & \underset{1\times1}{0} \\
\underset{1\times11}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{1} & \underset{1\times1}{0}
\end{bmatrix} \tag{A47}$$

where A is the observation matrix in (A37). The vector of structural shocks in (A43) is given by

$$u_t^a = B^a \epsilon_t^a \quad \text{with} \quad \eta_t^a = \begin{bmatrix} \epsilon_t^e \\ \epsilon_t^\lambda \\ \zeta_t \end{bmatrix} \tag{A48}$$

where the transmission of structural shocks to states is now characterized by the following matrix:

$$\underset{20\times 3}{B^a} = \begin{bmatrix} \underset{11\times1}{B_1} & \underset{11\times1}{B_2} & \underset{11\times1}{0} \\ \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} \\ \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} \\ \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} \\ \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} \\ \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} \\ \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{1} \\ \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} \\ \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} \\ \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} \end{bmatrix} \tag{A49}$$

Then the observation matrix in (A44) can be written as follows:

$$\underset{2\times 20}{C^a} = \begin{bmatrix} \underset{1\times11}{\left[.25\ .25\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\right]} & \underset{1\times1}{.25} & \underset{1\times1}{.25} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{0} \\ \underset{1\times11}{.25C_2'} & \underset{1\times1}{0} & \underset{1\times1}{0} & \underset{1\times1}{.25} & \underset{1\times1}{.25} & \underset{1\times1}{.25} & \underset{1\times1}{.25} & \underset{1\times1}{.25} & \underset{1\times1}{.25} & \underset{1\times1}{.25} \end{bmatrix} \tag{A50}$$

C.3 Likelihood function

We maximize the likelihood function with respect to the vector of parameters

$$(\varrho_e, \varrho_\lambda, \vartheta_e, \vartheta_\lambda, \vartheta_{e\lambda})$$

plus the following initial vector of states

$$(\widehat{e}_{-3}, \widehat{\mu}_{-4}, \widehat{\lambda}_{-3}), \tag{A51}$$

which imply a value for $\widehat{x}_{-3}$ and thereby one for $\widehat{\mu}_{-3}$. The value of N_{-3} is then obtained using the fact that $N_{-3} = C_2'\mathbf{s}_{-3}$. Given (A51), and the implied values of $\widehat{x}_{-3}$ and $\widehat{\mu}_{-3}$ we calculate $\mathbf{s}_{-3}$ and construct $\mathbf{s}_0^a$ using the fact that

$$\mathbf{s}_0 = D^3\mathbf{s}_{-3}, \qquad N_0 = C_2'D^3\mathbf{s}_{-3}, \qquad N_{-1} = C_2'D^2\mathbf{s}_{-3}, \qquad N_{-2} = C_2'D\mathbf{s}_{-3}, \qquad N_{-3} = C_2'\mathbf{s}_{-3}. \tag{A52}$$

Let $P_{t|t}$ denote the square prediction error of $\mathbf{s}_t^a$ given information available at time t. The Kalman filter implies the following standard relations:

$$\begin{aligned}
\mathbf{s}^a_{t|t-1} &= D^a \mathbf{s}^a_{t-1|t-1} \\
P_{t|t-1} &= D^a P_{t-1|t-1} (D^a)' + Q^a \\
y^a_{t|t-1} &= C^A \mathbf{s}^a_{t|t-1} \\
\varsigma_t &= y^a_t - y^a_{t|t-1} \\
K_t &= C^a P_{t|t-1} (C^a)' + \Omega^a \\
\mathbf{s}^a_{t|t} &= \mathbf{s}^a_{t|t-1} + P_{t|t-1} C^a K_t^{-1} \varsigma_t \\
P_{t|t} &= P_{t|t-1} - P_{t|t-1} (C^a)' K_t^{-1} C^a P_{t|t-1}
\end{aligned}$$

We initialize $P_{0|0}$ at its unconditional covariance matrix. Since the prediction errors are Gaussian, the likelihood is proportional to

$$\mathcal{L} \propto - \sum_{t=0}^{T} \varsigma_t' K_t^{-1} \varsigma_t.$$

C.4 Data

Several authors (Attanasio et al. 2006, and Bee et al. 2015) have noticed that household surveys such as CEX (and KNCP) appear to underestimate the growth rate of personal consumption expenditure in food and beverages for off-premises consumption as calculated by the Bureau of Economic Analysis (BEA), due to a positive low frequency trend in under-reporting. Moreover, as previously discussed, th ereporting behaviors of households in KNCP i ssubject to duration dependence. To correct for all this, we rescale the growth rate of expenditure in KNCP by a constant factor to match a growth of 18.3% over the period 2007:Q1 and 2014:Q4 in the per-household personal consumption expenditure in food and beverages from BEA (Mnemonic DFXARC1Q027SBEA), so that in the series used for the estimation we have that $(E_{2014:Q4} - E_{2007:Q1}) / E_{2007:Q1} = 0.183$. In the model net additions are expressed in real value (measured in unit of varieties), so we rescale the series for net additions in the data using the deflator of household personal consumption expenditure in food and beverages from BEA (Mnemonic DFXARG3Q086SBEA). More formally let P_t denote the price deflator from BEA. Nominal expenditure is converted into real expenditure as follows: $E_{rt} = \frac{E_t}{P_t}$. The growth rate of real expenditure is equal to

$$\frac{\Delta E_{rt}}{E_{rt-1}} \equiv \frac{E_{rt} - E_{rt-1}}{E_{rt-1}}.$$

Additions are converted into real value by writing

$$A_{rt} = \frac{P_{t-1}}{P_t} A_t$$

which follows from aggregating household level additions expressed in real value, equal to

$$a_{hrt} = \sum_{\nu \in \mathcal{V}} \frac{\frac{e_{\nu ht}}{P_t}}{\frac{e_{ht-1}}{P_{t-1}}} \times \mathbb{I}(e_{\nu ht-1} = 0) \times \mathbb{I}(e_{\nu ht} > 0), \tag{A53}$$

to yield

$$A_{rt} = \sum_{h \in \mathcal{H}} a_{hrt} \times \frac{e_{hrt-1}}{E_{rt-1}} = \frac{P_{t-1}}{P_t} A_t, \tag{A54}$$

Removals are defined as the ratio of expenditure at time $t-1$, so they are unaffected by the choice of the price deflator, $R_{rt} = R_t$. Net additions in real value are then defined as equal to

$$N_{rt} = A_{rt} - R_{rt}$$

The intensive margin in real value is then obtained as a residual by writing

$$I_{rt} = \frac{\Delta E_{rt}}{E_{rt-1}} - N_{rt}.$$

The real series from the model are converted into nominal value analogously: $E_t = P_t E_{rt}$, $A_t = \frac{P_t}{P_{dt-1}} A_{rt}$ and $R_t = R_{rt}$.

D Value of a new product

We derive the expression for the value of a new product in (45) and invert the expression to solve for the number of varieties in the market.

D.1 Derivation of expenditures of a potential customer in (45)

If follows from (A5), (A6) and (A8) that household consumption in a variety νj in sector j is equal to

$$q_{jt} = (\widehat{z}_{jt})^{\sigma-1} p_t^{\sigma-1} \cdot (e_t - x_t) \tag{A55}$$

where $\hat{z}_{jt} \equiv \max_{\nu \in \Omega_{jt}} \{z_{\nu jt}\}$ as defined in (A4). Let m denote the number of potential customer of a variety νj: the mass of households who have the variety in their consideration set. Then we can see that the revenue from potential customers of the variety is equal to

$$p_t^{\sigma-1} \cdot (e_t - x_t)\, m\, \Gamma\left(1 - \frac{\sigma-1}{\kappa}\right) \frac{\sum_{n=1}^{\infty} \frac{1}{n} n^{\frac{\sigma-1}{\kappa}} n f(n;\mu_t)}{\mu_t} = \frac{e_t - x_t}{\mu_t} m \tag{A56}$$

To understand the expression in the left hand side of (A56) , notice that in a sector there are μ_t potential customers. The fraction of potential customers with n varieties in their consideration set is $nf(n;\mu_t)/\mu_t$, since each household with n varieties in their consideration set (there are $f(n;\mu_t)$ of them) generate n potential customers in the market. A household with n varieties in the consideration set will buy the variety supplied by the firm with probability $1/n$ and conditional on buying the variety will spend

$$E\left[(\widehat{z}_{jt})^{\sigma-1} \middle| n_{jt} = n \right] p_t^{\sigma-1} \cdot (e_t - x_t) = \Gamma\left(1 - \frac{\sigma-1}{\kappa}\right) n^{\frac{\sigma-1}{\kappa}} p_t^{\sigma-1} \cdot (e_t - x_t)\,,$$

which follows from (A55) and the fact that $(\widehat{z}_{jt})^{\sigma-1}$ is distributed according a Fréchet distribution with shape parameter $\kappa/(\sigma-1)$ and scale parameter equal to $n^{\frac{\sigma-1}{\kappa}}$, so it has expected value $\Gamma\left(1 - \frac{\sigma-1}{\kappa}\right) n^{\frac{\sigma-1}{\kappa}}$. The last equality in (A56) follows from the fact that $\Gamma\left(1 - \frac{\sigma-1}{\kappa}\right) \sum_{n=1}^{\infty} n^{\frac{\sigma-1}{\kappa}} f(n;\mu_t) = p_t^{1-\sigma}$.

D.2 Inversion of the free-entry condition in (44)

We normalize the steady state number of varieties to one, log-linearize the free-entry condition in (44) and invert it to obtain the following expression for the logged number of varieties in the market at $t+1$

$$\ln v_{t+1} = \mathbf{\Pi}\left(\mathbf{e_t}, \boldsymbol{\rho}_\mathbf{t}, \boldsymbol{\lambda}_\mathbf{t}, \mathbf{x_t}\right), \tag{A57}$$

where $\mathbf{h_t} = \{h_0, ...h_t, \mathbb{E}_t\left(h_{t+1}\right), \mathbb{E}_t\left(h_{t+2}\right).....\}$ (written in bold) denotes the past and future expected history of variable $h = e, \rho, \lambda, x$ (in logs) given the information available at time t and the function $\mathbf{\Pi}$ is derived below.

The present value of the revenue of a new variety at time t is equal to the ratio between

D_t in (45) and $1-\phi$, equal to

$$D_{Rt} = \frac{D_t}{1-\phi} = \mathbb{E}_t \left[\sum_{j=1}^{\infty} (1-\delta_f)^{j-1} \rho_{t,t+j} \left(\frac{e_{t+j} - x_{t+j}}{\mu_{t+j}} m_{t,t+j} + \frac{x_{t+j}}{v_{t+j}} \right) \right] \tag{A58}$$

where

$$\begin{aligned} \rho_{t,t+j} &= \rho^k \frac{p_t c_t^\gamma}{p_{t+j} c_{t+j}^\gamma} \\ m_{t,t+j} &= \sum_{i=1}^{j} (1-\delta_p)^{j-i} \frac{\Lambda_{t+i}}{v_{t+i}} \\ \Lambda_{t+i} &= e^{\lambda_{t+i}} x_{t+i} \left[1 - \frac{1}{1+\alpha} \left(\frac{x_{t+i}}{\chi} \right)^{\alpha} \right] \end{aligned}$$

Notice that D_{Rt} is independent of ξ and ϕ. We focus on a steady state where the initial number of varieties in the market is equal to one $v = 1$. In steady state the number of customers of a firm of age j is equal to

$$m_j = \Lambda \sum_{i=1}^{j} (1-\delta_p)^{i-1} = \frac{\Lambda}{\delta_p} \left[1 - (1-\delta_p)^j \right] \tag{A59}$$

and the average number of variety in the consideration set is equal to $\mu = \frac{\Lambda}{\delta}$. Let adopt the notation $\rho = \frac{1}{\iota}$. In steady state D_{Rt} is equal to

$$D_R = \frac{\iota \delta e + (\iota - 1)(1-\delta) x}{(\iota - 1 + \delta_f)(\iota - 1 + \delta)}.$$

We adopt the notation:

$$\begin{bmatrix} \widehat{e}_t \\ \widehat{\mu}_t \\ \widehat{x}_t \\ \widehat{m}_{t,k} \\ \widehat{\lambda}_t \\ \hat{\rho}_{t,k} \\ \hat{v}_{t+1} \end{bmatrix} \equiv \begin{bmatrix} \ln e_t - \ln e \\ \ln \mu_t - \ln \mu \\ \ln x_t - \ln x \\ m_{t,t+k} - m_k \\ \lambda_t - \bar{\lambda} \\ \ln \rho_{t,t+k} - k \ln \rho \\ \ln v_{t+1} \end{bmatrix}$$

Let

$$\widehat{\beta} = \rho (1 - \delta_f)$$

denote the firm discount factor in steady state. After log-linearizing (A58) and after using (44) we obtain that in an equilibrium with free-entry:

$$\widetilde{D}_t^e + \widetilde{D}_t^\mu + \widetilde{D}_t^x + \widetilde{D}_t^m + \widetilde{D}_t^v + \widetilde{D}_t^\rho = 0 \tag{A60}$$

where

$$
\begin{aligned}
\widetilde{D}_t^e &= \frac{\rho e}{\mu D_R} \sum_{j=1}^{\infty} \widehat{\beta}^{j-1} m_j \mathbb{E}_t \left(\widehat{e}_{t+j} \right) && \text{(A61)} \\
\widetilde{D}_t^\mu &= -\frac{\rho \left(e-x \right)}{\mu D_R} \sum_{j=1}^{\infty} \widehat{\beta}^{j-1} m_j \mathbb{E}_t \left(\widehat{\mu}_{t+j} \right) && \text{(A62)} \\
\widetilde{D}_t^x &= \frac{\rho x}{D_R} \sum_{j=1}^{\infty} \widehat{\beta}^{j-1} \left(1 - \frac{m_j}{\mu} \right) \mathbb{E}_t \left(\widehat{x}_{t+j} \right) && \text{(A63)} \\
\widetilde{D}_t^m &= \frac{\rho \left(e-x \right)}{\mu D_R} \sum_{j=1}^{\infty} \widehat{\beta}^{j-1} \mathbb{E}_t \left(\widehat{m}_{t,j} \right) && \text{(A64)} \\
\widetilde{D}_t^v &= -\frac{\rho x}{D_R} \sum_{j=1}^{\infty} \widehat{\beta}^{j-1} \mathbb{E}_t \left(\widehat{v}_{t+j-1} \right) && \text{(A65)} \\
\widetilde{D}_t^\rho &= \frac{\rho}{D_R} \sum_{j=1}^{\infty} \widehat{\beta}^{j-1} \left[\frac{e-x}{\mu} m_j + x \right] \mathbb{E}_t \left(\widehat{\rho}_{t,j} \right) && \text{(A66)}
\end{aligned}
$$

where $\widehat{\mu}_{t+j}$ is calculated using (26) to obtain

$$
\widehat{\mu}_t = \left(1-\delta \right)^{t+1} \widehat{\mu}_{-1} + \delta \sum_{i=0}^{t} \left(1-\delta \right)^{t-i} \left[\zeta_{\Lambda,\lambda} \mathbb{E}_t \left(\widehat{\lambda}_i \right) + \zeta_{\Lambda,x} \mathbb{E}_t \left(\hat{x}_i \right) \right], \qquad \text{(A67)}
$$

the household discount factor $\widehat{\rho}_{t,j}$ satisfies

$$
\mathbb{E}_t \left(\widehat{\rho}_{t,j} \right) = \hat{p}_t + \gamma \hat{c}_t - \left(\hat{p}_{t+j} + \gamma \hat{c}_{t+j} \right),
$$

while $\widehat{m}_{t,j}$ is calculated using (46) to obtain

$$
\mathbb{E}_t \left(\widehat{m}_{t,j} \right) = \Lambda \sum_{i=1}^{j} (1-\delta_p)^{j-i} \mathbb{E}_t \left[\zeta_{\Lambda,\lambda} \widehat{\lambda}_{t+i} + \zeta_{\Lambda,x} \hat{x}_{t+i} - \widehat{v}_{t+i-1} \right].
$$

Now notice that $\widetilde{D}_t^m$ in (A64) can be rewritten as follows

$$
\begin{aligned}
\widetilde{D}_t^m &= \frac{\rho \left(e-x \right)}{D_R [1-\rho(1-\delta)]} \frac{\Lambda}{\mu} \sum_{i=1}^{\infty} \widehat{\beta}^{i-1} \mathbb{E}_t \left[\zeta_{\Lambda,\lambda} \widehat{\lambda}_{t+i} + \zeta_{\Lambda,x} \hat{x}_{t+i} - \widehat{v}_{t+i-1} \right] \\
&= \frac{\delta (e-x)}{D_R (\iota - 1 + \delta)} \sum_{i=1}^{\infty} \widehat{\beta}^{i-1} \mathbb{E}_t \left[\zeta_{\Lambda,\lambda} \widehat{\lambda}_{t+i} + \zeta_{\Lambda,x} \hat{x}_{t+i} - \widehat{v}_{t+i-1} \right] && \text{(A68)}
\end{aligned}
$$

where $\iota = 1/\rho$. We then define

$$
H_t = \widetilde{D}_t^e + \widetilde{D}_t^\mu + \widetilde{D}_t^x + \widetilde{D}_t^\rho + \frac{\delta \left(e-x \right)}{D_R \left(\iota - 1 + \delta \right)} \sum_{i=1}^{\infty} \widehat{\beta}^{i-1} \mathbb{E}_t \left(\zeta_{\Lambda,\lambda} \widehat{\lambda}_{t+i} + \zeta_{\Lambda,x} \hat{x}_{t+i} \right)
$$

The condition (A60) can then be written as follows:

$$\widehat{\alpha}\mathbb{E}_t\left(H_t\right) - \frac{\mathbb{E}_t\left(\hat{v}_{t+1}\right)}{1-\widehat{\beta}F} = 0 \tag{A69}$$

where F denotes the forward operator and

$$\widehat{\alpha} = \frac{\left(\iota - 1 + \delta\right) D_R}{\delta\left(e-x\right) + \rho\left(\iota - 1 + \delta\right) x}$$

After multiplying the left and right-hand side of (A69) by $1-\widehat{\beta}F$ and then solving for $\hat{v}_{t+1}$ we obtain that

$$\hat{v}_{t+1} = \widehat{\alpha}\left[\mathbb{E}_t\left(H_t\right) - \widehat{\beta}\mathbb{E}_t\left(H_{t+1}\right)\right] \tag{A70}$$

Let $\mathbf{h_t} = \{h_0, h_1, ...h_{t-1}, h_t, \mathbb{E}_t\left(h_{t+1}\right), \mathbb{E}_t\left(h_{t+2}\right).....\}$ $\forall h = e, \lambda, x, \rho,$ then (A60) can be rewritten as follows:

$$\hat{v}_{t+1} = D^e\left(\mathbf{e_t}\right) + D^\rho\left(\rho_\mathbf{t}\right) + D^\lambda\left(\lambda_\mathbf{t}\right) + D^x\left(\mathbf{x_t}\right) \tag{A71}$$

where

$$\begin{aligned}
D^e\left(\mathbf{e}_t\right) &= \frac{\widehat{\alpha}\rho\bar{e}}{\mu D_R}\sum_{j=1}^{\infty}\widehat{\beta}^{j-1}m_j\left[\mathbb{E}_t\left(\widehat{e}_{t+j}\right) - \widehat{\beta}\mathbb{E}_t\left(\widehat{e}_{t+1+j}\right)\right] \\
D^\rho\left(\rho_t\right) &= \frac{\widehat{\alpha}\rho}{D_R}\sum_{j=1}^{\infty}\widehat{\beta}^{j-1}\left[\frac{e-x}{\mu}m_j + x\right]\left[\mathbb{E}_t\left(\widehat{\rho}_{t,j}\right) - \widehat{\beta}\mathbb{E}_t\left(\widehat{\rho}_{t,j+1}\right)\right] \\
D^\lambda\left(\lambda_t\right) &= \frac{\widehat{\alpha}\delta\,\left(e-x\right)}{D_R(\iota-1+\delta)}\zeta_{\Lambda,\lambda}\mathbb{E}_t\left(\widehat{\lambda}_{t+1}\right) - \frac{\widehat{\alpha}\rho\left(e-x\right)}{\mu D_R}\sum_{j=1}^{\infty}\widehat{\beta}^{j-1}m_j\left[\mathbb{E}_t\left(\widehat{\mu}^\lambda_{t+j}\right) - \hat{\beta}\mathbb{E}_t\left(\widehat{\mu}^\lambda_{t+1+j}\right)\right] \\
D^x\left(\mathbf{x}_t\right) &= \frac{\widehat{\alpha}\delta\,\left(e-x\right)}{D_R(\iota-1+\delta)}\zeta_{\Lambda,x}\mathbb{E}_t\left(\widehat{x}_{t+1}\right) + \frac{\widehat{\alpha}\rho x}{D_R}\sum_{j=1}^{\infty}\widehat{\beta}^{j-1}\left(1-\frac{m_j}{\mu}\right)\left[\mathbb{E}_t\left(\widehat{x}_{t+j}\right) - \widehat{\beta}\mathbb{E}_t\left(\widehat{x}_{t+1+j}\right)\right] \\
&\quad - \frac{\widehat{\alpha}\rho\left(e-x\right)}{\mu D_R}\sum_{j=1}^{\infty}\widehat{\beta}^{j-1}m_j\left[\mathbb{E}_t\left(\widehat{\mu}^x_{t+j}\right) - \hat{\beta}\mathbb{E}_t\left(\widehat{\mu}^x_{t+1+j}\right)\right].
\end{aligned}$$

and we defined

$$\widehat{\mu}^\lambda_t = \left(1-\delta\right)^{t+1}\widehat{\mu}^\lambda_{-1} + \delta\zeta_{\Lambda,\lambda}\sum_{i=0}^{t}\left(1-\delta\right)^{t-i}\mathbb{E}_t\left(\widehat{\lambda}_i\right), \tag{A72}$$

$$\widehat{\mu}^x_t = \left(1-\delta\right)^{t+1}\widehat{\mu}^x_{-1} + \delta\zeta_{\Lambda,x}\sum_{i=0}^{t}\left(1-\delta\right)^{t-i}\zeta_{\Lambda,x}\mathbb{E}_t\left(\hat{x}_i\right) \tag{A73}$$

with

$$\widehat{\mu}_t = \widehat{\mu}^\lambda_t + \widehat{\mu}^x_t$$

which denote the fluctuations in $\hat{\mu}$ due to fluctuations in λ_t and x_t, respectively. This concludes the derivation of the decomposition in (A57). Notice that none of the terms in

(A71) depend on ξ or φ.

For each t the components of (A71) are calculated using the state space representation of the household's problem used to estimate the model, as discussed in Section C. Formally, let $\mathbf{s}_t$ denote the state vector of the economy and let D denote the associated transition matrix as defined in (A37). Moreover, let $\mathcal{I}$ denote an identity matrix of arbitrary dimension and let I_z denote a column vector whose entries are all equal to zero except for the one corresponding to the variable z, which is equal to 1. Finally let $\mathcal{B}$ denote the following matrix:

$$\mathcal{B} = \mathcal{I} - (1-\delta_p)\left[\mathcal{I} - (1-\delta_p)\hat{\beta}\, D\right]^{-1}\left(\mathcal{I} - \hat{\beta}\, D\right)$$

After some algebra we obtain:

$$\begin{aligned}
D^e\left(\mathbf{e}_t\right) &= \frac{\widehat{\alpha}\rho e}{D_R}\frac{\delta}{\delta_p}\, I_e' \mathcal{B} D \mathbf{s}_t, \\
D^\rho\left(\rho_t\right) &= \frac{\widehat{\alpha}\rho\,(e-x)}{D_R} I_\rho' \left[\frac{\delta}{1-\rho(1-\delta)}\mathcal{I} - \frac{\delta}{\delta_p}\mathcal{B}D\right]\mathbf{s}_t + \frac{\widehat{\alpha}\rho x}{D_R} I_\rho' \left(\mathcal{I} - D\right)\mathbf{s}_t, \\
D^\lambda\left(\lambda_t\right) &= \frac{\widehat{\alpha}\delta\ (e-x)}{D_R(\iota - 1 + \delta)}\zeta_{\Lambda,\lambda}\,\rho_\lambda \hat{\lambda}_t + \breve{D}^\mu\left(\lambda_t\right), \\
D^x\left(\mathbf{x}_t\right) &= \frac{\widehat{\alpha}\delta\ (e-x)}{D_R(\iota - 1 + \delta)}\zeta_{\Lambda,x}\, I_x' D\,\mathbf{s}_t + \frac{\widehat{\alpha}\rho x}{D_R}\, I_x' \left[\mathcal{I} - \frac{\delta}{\delta_p}\mathcal{B}\right] D\mathbf{s}_t + \breve{D}^\mu\left(\mathbf{x}_t\right)
\end{aligned}$$

where we have defined

$$\begin{aligned}
\breve{D}^\mu\left(\lambda_t\right) &= -\frac{\widehat{\alpha}\rho\,(e-x)}{D_R}\frac{\delta\,(1-\delta)}{1-\widehat{\beta}(1-\delta)(1-\delta_p)}(\hat{\mu}_t^\lambda + \hat{\gamma}\hat{\lambda}_t) + \frac{\widehat{\alpha}\rho\,(e-x)}{D_R}\frac{\delta\,\varrho_\lambda}{1-\widehat{\beta}\varrho_\lambda(1-\delta_p)}\hat{\gamma}\hat{\lambda}_t, \\
\breve{D}^\mu\left(\mathbf{x}_t\right) &= -\frac{\widehat{\alpha}\rho\,(e-x)}{D_R}\frac{\delta}{\delta_p}\, I_\mu' \mathcal{B}\, D\,\mathbf{s}_t - \breve{D}^\mu\left(\lambda_t\right).
\end{aligned}$$

E Construction of price indices in Section 7

Derivation of ACUPI in (50) Given the utility function in (47) and the price index in (48), the demand for a variety νj satisfies

$$\frac{e_{\nu jt}}{e_t} = \frac{\left(\frac{1}{\varphi_{\nu jt}}\right)^{1-\sigma_w}}{\left(p_t^A\right)^{1-\sigma_w}} \tag{A74}$$

By inverting (A74) at $t-1$ and at t to solve for $\ln p_t^A$ and $\ln p_{t-1}^A$ and after remembering that $s_{\nu jt}^A \equiv e_{\nu jt}/(\lambda_t^{AF} e_t)$, we obtain that

$$\ln p_t^A = -\ln \varphi_{\nu jt} + \frac{1}{\sigma_w - 1} \ln\left(s_{\nu jt}^A\right) + \frac{1}{\sigma_w - 1} \ln\left(\lambda_t^{AF}\right), \ \forall \upsilon j \in \Omega_{jt}^A \tag{A75}$$

$$\ln p_{t-1}^A = -\ln \varphi_{\nu jt-1} \frac{1}{\sigma_w - 1} \ln\left(s_{\nu jt-1}^A\right) + \frac{1}{\sigma_w - 1} \ln\left(\lambda_{t-1}^{AF}\right), \ \forall \upsilon j \in \Omega_{jt}^A \tag{A76}$$

Redding and Weinstein (2019) assume that (49) holds for all t and then integrate the left and right hand side of (A75) and (A76) over Ω_{jt}^A. After subtracting side by side, we immediately obtain the expression for $\Phi^{ACUPI} \equiv \Delta \ln\left(P_t p_t^A\right)$ in (50).

To evaluate (50), we now provide analytical expressions for λ_{t-1}^{AF}, λ_t^{AF}, $\int_{\Omega_{jt}^A} \ln s_{\nu jt}^A d\nu$ and $\int_{\Omega_{jt}^A} \ln s_{\nu jt-1}^A d\nu$. We denote by $\tilde{R}_{s,t}$ the revenue at t of a firm created at $s < t$, which is equal to

$$\tilde{R}_{s,t} = \frac{e_t - x_t}{\mu_t} m_{s,t} + \frac{x_t}{v_t} \tag{A77}$$

where $m_{s,t}$ are the potential customers of the firm, which satisfies

$$m_{s,t} = \sum_{i=1}^{t-s} (1-\delta_p)^{t-s-i} \frac{\Lambda_{s+i}\left(x_{s+i}\right)}{v_{s+i}}, \quad \forall s < t$$

Given (57), we know that the mass of new varieties created at s is equal to $\frac{w_s l_{ds}}{\xi}$ and we know that only a fraction $(1-\delta_f)^{t-s-1}$ of them survive until time t. To calculate

$$\lambda_t^{AF} = \frac{\int_{\Omega_{jt}^A} e_{\nu jt} d\nu}{e_t}$$

we sum the expenditures at t on all varieties created up to time $t-2$ (first on sale at $t-1$) and then divide by the total expenditures at t, equal to e_t. We obtain

$$\lambda_t^{AF} = \frac{\sum_{j=2}^{\infty} \left(1-\delta_f\right)^{j-1} \frac{w_{t-j} l_{dt-j}}{\xi} \tilde{R}_{t-j,t}}{e_t} \tag{A78}$$

Analogously, to calculate λ_{t-1}^{AF}, we sum the expenditures at $t-1$ on all varieties created up to time $t-3$ (first on sale at $t-2$) and we divide the resulting sum by the total expenditures at $t-1$, equal to e_{t-1} :

$$\lambda_{t-1}^{AF}=\frac{\sum_{j=2}^{\infty}\left(1-\delta_f\right)^{j-1}\frac{w_{t-1-j}\ell_{t-1-j}}{\xi}\tilde{R}_{t-1-j,t-1}}{e_{t-1}} \tag{A79}$$

Remember that $s_{\nu jt}^{A}=\frac{e_{\nu jt}}{\lambda_t^{AF}e_t}$ and that $N_t^A=(1-\delta_f)v_{t-1}=\sum_{j=2}^{\infty}\left(1-\delta_f\right)^{j-1}\frac{w_{t-j}\ell_{t-j}}{\xi}$. By following the same steps as in (A78), we immediately obtain that

$$\frac{\int_{\Omega_{jt}^A}\ln s_{\nu jt}^A d\nu}{N_t^A} = \frac{\sum_{j=2}^{\infty}\left(1-\delta_f\right)^{j-1}\frac{w_{t-j}\ell_{t-j}}{\xi}\ln\left(\tilde{R}_{t-j,t}\right)}{(1-\delta_f)v_{t-1}}-\ln\left(\lambda_t^{AF}e_t\right) \tag{A80}$$

Similarly remember that $s_{\nu jt-1}^{A}=\frac{e_{\nu jt-1}}{\lambda_{t-1}^{AF}e_{t-1}}$, which we can use to write

$$\frac{\int_{\Omega_{jt}^A}\ln s_{\nu jt-1}^A d\nu}{N_t^A} = \frac{\sum_{j=2}^{\infty}\left(1-\delta_f\right)^{j-1}\frac{w_{t-j}\ell_{t-j}}{\xi}\ln\left(\tilde{R}_{t-j,t-1}\right)}{(1-\delta_f)v_{t-1}}-\ln\left(\lambda_{t-1}^{AF}e_{t-1}\right). \tag{A81}$$

We use the expressions A77-A81 to calculate ACUPI in (50), using the estimated time series of x_t, μ_t, and Λ_t (and their predicted value) as discussed in Section 5.2 while the number of varieties in the economy v_t is obtained by imposing that (45) holds for all t.

Derivation of HCUPI in (53) From household maximization, (see A5), we obtain that $\forall j\in\Omega_t^H$

$$s_{jt}^H\equiv\frac{q_{jt}}{e_t\lambda_t^{HF}}=\left(\widehat{z}_{jt}\right)^{\sigma-1}p_t^{\sigma-1}\cdot\frac{e_t-x_t}{e_t}\cdot\frac{1}{\lambda_t^{HF}} \tag{A82}$$

where $\hat{z}_{jt}\equiv\max_{i\in\Omega_{jt}}\{z_{\nu jt}\}$ is defined in (A4). By inverting (A82), we obtain

$$p_t=\left(\widehat{z}_{jt}\right)^{-1}\left(\frac{e_t}{e_t-x_t}\cdot\lambda_t^{HF}s_{jt}^H\right)^{\frac{1}{\sigma-1}} \tag{A83}$$

Notice that $\forall j\in\Omega_t^H$ we have $s_{jt-1}^H>0$ and $s_{jt}^H>0$. We evaluate (A83) both at $t-1$ and at t and take logs $\forall j\in\Omega_t^H$. We then integrate the left and right hand side of the two resulting expression over all varieties $j\in\Omega_t^H$ and divide by the mass of varieties in Ω_t^H, N_t^H. After adding $\Delta\ln(P_t)$ to both sides, we immediately obtain the expression for $\Delta\ln(P_tp_t)$ in (52)-(54).

We now provide analytical expressions for all terms present in (52)-(54). The mass of varieties consumed by the household both at $t-1$ and at t is equal to

$$N_t^H=(1\text{-}\delta)\sum_{n=1}^{\infty}f(n,\mu_{t-1})\sum_{m=0}^{\infty}f\left(m;\Lambda_t\right)\left[\sum_{u=0}^{n-1}\frac{b\left(u;1\text{-}\delta,n\text{-}1\right)}{m+u+1}\right]\sum_{n=1}^{\infty}f(n,\mu_{t-1})\frac{\kappa_{nt}^r}{s_{nt-1}} \tag{A84}$$

where we adopted the notation $\Lambda_t\equiv\Lambda_t(x_t)$. The logic to construct (A84) is the same as the one used to construct κ_{nt}^r in (A20). The first two terms in the right-hand side of (A84) is the probability that the variety consumed at $t-1$ has remained in the consideration set at t, equal to $1-\delta$. To understand the first summatory in (A84) notice that the index m

refers to the number of new varieties added to the consideration set at t. $u \leq n-1$ refers to the number of old varieties (different from the one consumed at $t-1$) present in the consideration set both at $t-1$ and at t. Notice that m and u are two independent random variables: m is Poisson with mean Λ_t; u is binomial with success probability $1-\delta$ and number of trials equal to $n-1$. Then, for given number of new varieties m, the term in square brackets calculates the probability that the variety consumed at $t-1$ is also consumed at t. Since preferences are redrawn, the variety consumed at $t-1$ is also consumed at t only if the two following conditions are both verified: it is preferred to the $m \geq 0$ new varieties added to the consideration set at t; and it is preferred to the $u \leq n-1$ other old varieties inherited from the consideration set at $t-1$. Due to symmetry in preferences, these two conditions are simultaneously satisfied with probability $\frac{1}{m+u+1}$. By summing over the possible realizations of u, we obtain the term in square brackets in (A84), while by summing over the possible realizations of m we obtain the probability that, conditional on survival, the variety consumed at $t-1$ is also consumed at t.

The fraction of expenditures at t on varieties consumed by the household both at $t-1$ and at t, can be expressed as equal to

$$\lambda_t^{HF} = \frac{\sum_{n=1}^{\infty} \gamma_{nt} f(n, \mu_{t-1})}{e_t}$$

where

$$\gamma_{nt} = (1\text{-}\delta) \sum_{m=0}^{\infty} f(m; \Lambda_t) \left[\sum_{u=0}^{n-1} \frac{b(u; 1\text{-}\delta, n\text{-}1)}{m+u+1} s_{m+u+1,t} \right]$$

denotes the expected expenditures at t in varieties purchased also at $t-1$ conditional on being at $t-1$ in a sector with n varieties in the consideration set. The logic of the construction of γ_{nt} is the same as the one used to derive (A84), where the term in the square brackets of (A84) are weighted by the expenditures in a sector with $m+u+1$ varieties in the consideration set (equal to $s_{m+u+1,t}$).

Let $L_n \equiv E(\ln z_n)$ with z_n denoting a random variable distributed according to Fréchet distribution with scale parameter $n^{\frac{1}{\kappa}}$ and shape parameter equal to κ $z \sim F(n^{\frac{1}{\kappa}}, \kappa)$:

$$L_n \equiv \int_0^{\infty} \ln x \frac{\kappa}{n^{\frac{1}{\kappa}}} \left(\frac{x}{n^{\frac{1}{\kappa}}} \right)^{-1-\kappa} e^{-\left(\frac{x}{n^{\frac{1}{\kappa}}} \right)^{-\kappa}} dx.$$

We notice that

$$\int_{\Omega_t^H} \ln \widehat{z}_{jt} dj = (1\text{-}\delta) \sum_{n=1}^{\infty} f(n, \mu_{t\text{-}1}) \sum_{m=0}^{\infty} f(m; \Lambda_t) \left[\sum_{u=0}^{n-1} \frac{b(u; 1\text{-}\delta, n\text{-}1)}{m+u+1} L_{m+u+1} \right] \tag{A85}$$

This uses the fact that the variety is consumed at $t-1$ with probability $1/(m+u+1)$ and the expected value of $\ln \widehat{z}$ is equal to the expected value of a maximum over $m+u+1$ varieties, with $\widehat{z}$ being a Fréchet distribution with scale parameter $(m+u+1)^{\frac{1}{\kappa}}$ and scale parameter κ.

By a similar logic we can also write

$$\int_{\Omega_t^H} \ln \widehat{z}_{jt-1} dj \quad = \quad (1\text{-}\delta) \sum_{n=1}^{\infty} f(n, \mu_{t-1}) L_n \sum_{m=0}^{\infty} f\left(m; \Lambda_t\right) \sum_{u=0}^{n-1} \frac{b\left(u; 1\text{-}\delta, n\text{-}1\right)}{m+u+1} \tag{A86}$$

This uses the fact that the utility value of a variety at $t-1$ in a sector with n varieties in the consideration set is a drawing from a Fréchet distribution with scale parameter $(n)^{\frac{1}{\kappa}}$ and scale parameter κ. We use (A85) and (A86) to calculate the second term in the right hand side of (52) as follows:

$$\int_{\Omega_t^H} \Delta \ln \widehat{z}_{jt} dj \equiv \int_{\Omega_t^H} \ln \widehat{z}_{jt} dj - \int_{\Omega_t^H} \ln \widehat{z}_{jt-1} dj.$$

F DSGE model in Section 7

First, we characterize the household's problem. Secondly, we show how to write firm profits recursively. Thirdly, we discuss our modelling on nominal interest rates. Finally we define an equilibrium.

F.1 Household's problem

Nominal wages W_t are sticky and subject to nominal rigidities which are modelled as in Erceg, Henderson, and Levin (2000). There is a measure 1 of labor markets indexed by $m \in [0,1]$ and household $m \in [0,1]$ supplies ℓ_{mt} labor units monopolistically in market m by setting the nominal wage W_{mt}. The aggregate supply of labor is

$$\ell_t = \left[\int_0^1 (\ell_{mt})^{1-\frac{1}{\theta_w}} dm\right]^{\frac{\theta_w}{\theta_w - 1}},$$

which implies that household m faces a labor demand given by

$$\ell_{mt} = \left(\frac{W_{mt}}{W_t}\right)^{-\theta_w} \ell_t, \tag{A87}$$

where $W_t = \left[\int_0^1 W_{mt}^{1-\theta_w} dm\right]^{\frac{1}{1-\theta_w}}$ is the aggregate nominal wage. Household m faces a convex cost to adjust her nominal wage W_{mt}, equal to $\tilde{\kappa}\left(\frac{W_{mt}}{W_{mt-1}}\right) = \kappa\left(\frac{W_{mt}}{W_{mt-1}}\right) w_t \ell_t$ with $w_t \equiv W_t/P_t$ with $\kappa(1) = \kappa'(1) = 0$ and

$$\kappa\left(\frac{W_{mt}}{W_{mt-1}}\right) = \frac{\kappa_0}{2} \times \left(\frac{W_{mt}}{W_{mt-1}} - 1\right)^2$$

is adjustment costs as a share of aggregate labor income. All households start with the same initial nominal wage $W_{m0} = W_0$, and in equilibrium they set the same nominal wage $W_{mt} = W_t \; \forall m$, where W_t satisfies (60). Let $\mathbb{E}_{\boldsymbol{\omega}}$ denote the expectation operator conditional on the information set $\boldsymbol{\omega}$. Let $\boldsymbol{s} \equiv (a, b, \mu_{-1}, W_{m-1})$ the set of individual state variables.

The household's problem in recursive form is as follows:

$$V(\boldsymbol{\omega}, \boldsymbol{s}) = \max_{\{e,a',b',x,W_m,\ell_m\}} \left\{ u\left(\frac{e-x}{p(\mu)}\right) + h\left(b'\right) - \varepsilon\left(\ell_m\right) + \rho \mathbb{E}_{\boldsymbol{\omega}}\left[V(\boldsymbol{\omega'}, \boldsymbol{s'})\right] \right\} \tag{A88}$$

s.t.

$$e + a' + b' = ra + \iota b + \frac{W_m}{P}\ell_m - \kappa\left(\frac{W_m}{W_{m-1}}\right)\frac{W}{P}\ell - \tau, \tag{A89}$$

$$\mu = (1-\delta)\,\mu_{-1} + \Lambda(x), \tag{A90}$$

$$p(\mu) = \left[\Gamma\left(1 - \frac{\sigma-1}{\kappa}\right)\sum_{n=0}^{\infty} n^{\frac{\sigma-1}{\kappa}} \frac{\mu^n e^{-\mu}}{n!}\right]^{-\frac{1}{\sigma-1}}. \tag{A91}$$

$$\ell_m = \left(\frac{W_m}{W}\right)^{-\theta_w} \ell, \tag{A92}$$

where ℓ, W and P denotes aggregate labor supply, the aggregate nominal wage and the aggregate nominal price, respectively. The constraint (A92)) corresponds to (A87). The first order conditions with respect to x and a' in (A88) reads as (30) and (33), respectively. The Euler equation for the holding of government bonds b' reads as follows

$$\frac{u'\left(c_t\right)}{p(\mu_t)} - h'(b_t) = \rho \mathbb{E}_t\left[r_{t+1}\,\frac{u'\left(c_{t+1}\right)}{p(\mu_{t+1})}\right], \tag{A93}$$

which makes use of the envelope condition with respect to b. To derive (60) in the main text we take the first order condition for the optimal setting of W_m in (A88) which reads as follows:

$$\begin{aligned}(1-\theta_w)\,\frac{u'(c_t)}{p_t P_t}\left(\frac{W_{mt}}{W_t}\right)^{-\theta_w}\ell_t + \theta_w\left(\frac{W_{mt}}{W_t}\right)^{-\theta_w}\frac{\ell_t}{W_{mt}}\varepsilon'(\ell_t) + \\ -\frac{u'(c_t)}{p_t}\frac{\kappa_0}{W_{t-1}}\left(\frac{W_t}{W_{t-1}} - 1\right)w_t\ell_t + \frac{\kappa_0}{W_t}E_t\left[\rho\frac{u'(c_{t+1})}{p_{t+1}}\left(\frac{W_{t+1}}{W_t} - 1\right)w_{t+1}\ell_{t+1}\right] = 0,\end{aligned} \tag{A94}$$

where the last term in (A94) follows from the envelope theorem and we used the fact that in symmetric equilibrium we have $\ell_{mt} = \ell_t$. In symmetric equilibrium we also have $W_{mt} = W_t$. After dividing the left and right hand side of (A94) by $\frac{u'(c_t)}{p_t P_t}\,\ell_t$ we obtain

$$\begin{aligned}(1-\theta_w) + \theta_w\frac{p_t}{w_t}\frac{\varepsilon'(\ell_t)}{u'(c_t)} + \\ -\frac{P_t\kappa_0}{W_{t-1}}\left(\frac{W_t}{W_{t-1}} - 1\right)w_t + \kappa_0 E_t\left[\rho\frac{u'(c_{t+1})}{u'(c_t)}\frac{p_t}{p_{t+1}}\left(\frac{W_{t+1}}{W_t} - 1\right)\frac{P_t}{W_t\,\ell_t}w_{t+1}\ell_{t+1}\right] = 0\end{aligned}$$

which can be finally written as follows

$$0 = 1 - \theta_w + \theta_w\frac{\varepsilon'(\ell_t)}{u'(c_t)}\frac{p_t}{w_t} - \frac{\kappa_0 W_t}{W_{t-1}}\left(\frac{W_t}{W_{t-1}} - 1\right) + \kappa_0 E_t\left[\rho_{t,t+1}\left(\frac{W_{t+1}}{W_t} - 1\right)\frac{w_{t+1}\ell_{t+1}}{w_t\ell_t}\right]$$

which, after defining $\hat{\kappa} = (\theta_w - 1)/\kappa_0$ and remembering that $\Pi_t^W = W_t/W_{t-1}$, corresponds to (60) in the main text.

F.2 Recursive expression for firm profits

We show that the value of a new variety D_t solves the following recursive expression

$$\begin{aligned} D_t &= E_t\left\{\rho_{t,t+1}\left(1-\varphi\right)\left[\frac{e_{t+1}-x_{t+1}}{\mu_{t+1}}\frac{\Lambda_{t+1}\left(x_{t+1}\right)}{v_{t+1}}+\frac{x_{t+1}}{v_{t+1}}\right]\right\} \\ &+E_t\left\{\rho_{t,t+1}(1-\delta_f)\left[D_{t+1}+\overline{D}_{mt+1}\frac{\Lambda_{t+1}\left(x_{t+1}\right)}{v_{t+1}}\right]\right\} \end{aligned} \tag{A95}$$

where $\overline{D}_{mt}$ is the marginal increase in firm value due to an additional past customer of the firm which satisfies

$$\overline{D}_{mt} = (1-\delta_p)\,E_t\left\{\rho_{t,t+1}\left[(1-\varphi)\,(e_{t+1}-x_{t+1})\,\tilde{\sigma}\,(\mu_{t+1})+\overline{D}_{mt+1}\right]\right\}. \tag{A96}$$

Derivation of (A95) and (A96) The (expected) profits at t of a firm of age τ (i.e. created at time $t-\tau$) are equal to

$$\pi_t(\tau) = (1-\varphi)\left[\frac{e_t - x_t}{\mu_t} m_{t,t+\tau} + \frac{x_t}{v_t}\right] \tag{A97}$$

The value of a firm with a mass of customers m at the end of period t that knows it will produce at $t+1$ can be written recursively as follows

$$\overline{D}_t\,(m) = E_t\left\{\rho_{t,t+1}\left[(1-\varphi)\,\frac{e_{t+1}-x_{t+1}}{\mu_{t+1}}m' + (1-\varphi)\,\frac{x_{t+1}}{v_{t+1}} + (1-\delta_f)\,\overline{D}_{t+1}\,(m')\right]\right\}$$

where m' is the customer base of the firm in the next period equal to

$$m' = (1-\delta_p)m + \frac{\Lambda_{t+1}\left(x_{t+1}\right)}{v_{t+1}}$$

We guess and then verify that the value of the firm is linear in m:

$$\overline{D}_t\,(m) = D_t + \overline{D}_{mt} m$$

where $D_t \equiv \overline{D}_t\,(0)$ is the value of a newly created variety at t. For the guess to be verified it has to be the case that

$$\begin{aligned} D_t + \overline{D}_{mt} m &= (1-\varphi)\,E_t\left\{\rho_{t,t+1}\left[\frac{e_{t+1}-x_{t+1}}{\mu_{t+1}}m' + \frac{x_{t+1}}{v_{t+1}}\right]\right\} \\ &+ (1-\delta_f) E_t\left[\rho_{t,t+1}\left(D_{t+1} + \overline{D}_{mt+1} m'\right)\right] \end{aligned}$$

which implies that

$$
\begin{aligned}
D_t &= (1-\varphi)\, E_t \left\{ \rho_{t,t+1} \left[\frac{e_{t+1}-x_{t+1}}{\mu_{t+1}} \cdot \frac{\Lambda_{t+1}(x_{t+1})}{v_{t+1}} + \frac{x_{t+1}}{v_{t+1}} \right] \right\} \\
&\quad +(1-\delta_f)E_t \left\{ \rho_{t,t+1} \left[D_{t+1} + \overline{D}_{mt+1} \frac{\Lambda_{t+1}(x_{t+1})}{v_{t+1}} \right] \right\} \\
\overline{D}_{mt} &= (1-\delta_p)E_t \left\{ \rho_{t,t+1} \left[(1-\varphi) \frac{e_{t+1}-x_{t+1}}{\mu_{t+1}} + (1-\delta_f)\, \overline{D}_{mt+1} \right] \right\}
\end{aligned}
$$

which are analogous to (A95) and (A96), respectively.

F.3 Modelling of nominal interest rates

To model the fact that over our entire sample period nominal interest rates were constant and to guarantee exhistence and stability of the equilibrium, we assume that $R_t = \bar{R}\, \forall t < \tilde{\tau}$, where $\tilde{\tau}$ is a stopping time which is a geometric random variable with success probability ϕ_0, so that $Pr(\tilde{\tau} = \tau) = (1-\phi_0)^{\tau}\, \phi_0$. At $t \geq \tilde{\tau}$, the central bank sets $\mathcal{R}_t$ following a conventional Taylor rule which relates $\mathcal{R}_t$ to price inflation $\Pi_t^P \equiv P_t/P_{t-1}$ with elasticity $\bar{\phi} > 1$. In brief, R_t evolves as follows:

$$
R_t = \begin{cases} \bar{R} & \text{if } t < \tilde{\tau} \\ \frac{1}{\rho} \left(\Pi_t^P\right)^{\bar{\phi}} & \text{if } t \geq \tilde{\tau} \end{cases}. \tag{A98}
$$

We use the standard value $\overline{\phi} = 1.5$ in the Taylor rule in (A98) and assume that agents expect $\mathcal{R}_t$ to remain constant for 6 quarters, $\phi_0 = 1/6$. Over the simulated path of Figure 4, we assume that realized nominal interest rates remain equal to $\bar{R}$, mimicking the liquidity trap.

F.4 Equilibrium

The equilibrium of the economy is a tuple

$$
\left(c_t, a_t, x_t, p_t, e_{t,}\mu_t, \Pi_t^W, \Pi_t^P, w_t, R_t, r_t, \iota_t, v_t, \ell_t, l_{dt}, D_t, \overline{D}_{mt}, b_t, \lambda_t, \tau_t, \tau_t^{\ell}\right) \tag{A99}
$$

such that

1. Household consumption c_t satisfies:

$$
\frac{u'(c_t)}{p_t} = \rho \mathbb{E}_t \left[r_{t+1} \frac{u'(c_{t+1})}{p_{t+1}} \right] \tag{A100}
$$

2. The holdings of government bonds b_t satisfy:

$$
\frac{u'(c_t)}{p_t} - h'(b_t) = \rho \mathbb{E}_t \left[r_{t+1}\, \frac{u'(c_{t+1})}{p_{t+1}} \right] \tag{A101}
$$

3. Adoption expenditure x_t satisfies:

$$1 = \frac{\Lambda_t'(x_t)\,\eta(\mu_t)}{\mu_t}\,(e_t - x_t) + (1-\delta)\,\mathbb{E}_t\left[\rho_{t,t+1}\,\frac{\Lambda_t'(x_t)}{\Lambda_{t+1}'(x_{t+1})}\right], \tag{A102}$$

4. The welfare relevant price index p_t is:

$$p_t = \left[\Gamma\left(1 - \frac{\sigma-1}{\kappa}\right)\sum_{n=0}^{\infty} n^{\frac{\sigma-1}{\kappa}} f(n;\mu_t)\right]^{-\frac{1}{\sigma-1}} \tag{A103}$$

with

$$f(n;\mu_t) = e^{-\mu_t}\,\frac{(\mu_t)^n}{n!}$$

5. Total household expenditure e_t satisfies the identity:

$$e_t = p_t c_t + x_t \tag{A104}$$

6. The average number of varieties in the consideration set μ_t evolves according to:

$$\mu_t = (1-\delta)\,\mu_{t-1} + \Lambda_t\,(x_t) \tag{A105}$$

7. The optimal wage inflation Π_t^W evolves as follows:

$$\Pi_t^W\,\left(\Pi_t^W - 1\right) = E_t\left[\rho_{t,t+1}\,\left(\Pi_{t+1}^W - 1\right)\frac{w_{t+1}\ell_{t+1}}{w_t\ell_t}\right] + \hat{\kappa}\,\left(\frac{\theta_w}{\theta_w - 1}\,\frac{\varepsilon'(\ell_t)}{u'(c_t)}\,\frac{p_t}{w_t} - 1\right). \tag{A106}$$

8. Price level inflation Π_t^P satisfies the identity:

$$\Pi_t^P = \frac{\Pi_t^W w_{t-1}}{w_t} \tag{A107}$$

9. The real wage w_t satisfies the identity:

$$w_t = \varphi v_t^{\varpi} \tag{A108}$$

10. The central bank control the nominal interest rate $\mathcal{R}_t$ according to the following Taylor rule:

$$R_t = \begin{cases} \frac{1}{\rho} & \text{if } t \leq \tilde{\tau} \\ \frac{1}{\rho}\left(\Pi_t^P\right)^{\bar{\phi}} & \text{if } t > \tilde{\tau} \end{cases} \tag{A109}$$

where $\tilde{\tau}$ is stopping time characterized by a geometric random variable with success probability $\phi_0 : Pr(\tilde{\tau} = \tau) = (1-\phi_0)^{\tau}\,\phi_0$.

11. The real return on government bonds r_t satisfies the identity:

$$r_t = \frac{\mathcal{R}_{t-1}}{\Pi_t^P} \tag{A110}$$

12. Clearing of the financial markets determines the supply of assets as follows:

$$\iota_t a_{t-1} - a_t = (1-\varphi)\, e_t - w_t\, l_{dt}, \tag{A111}$$

13. The number of varieties v_t evolves according to:

$$v_{t+1} = (1-\delta_f)\, v_t + \frac{w_t\, l_{dt}}{\xi}, \tag{A112}$$

14. The resource constraint of the economy is satisfied, which implies that:

$$v_t^{\varpi}\,(\ell_t - l_{dt}) = e_t + g + \kappa(\Pi_t^W) w_t \ell_t \tag{A113}$$

15. The free entry condition in the R&D sector is satisfied:

$$D_t = \xi \tag{A114}$$

16. The value of an innovation D_t satisfies (A95):

$$\begin{aligned} D_t \quad = \quad & (1-\varphi)\, E_t \left\{ \rho_{t,t+1} \left[\frac{e_{t+1} - x_{t+1}}{\mu_{t+1}} \cdot \frac{\Lambda_{t+1}\,(x_{t+1})}{v_{t+1}} + \frac{x_{t+1}}{v_{t+1}} \right] \right\} \\ & + (1-\delta_f) E_t \left\{ \rho_{t,t+1} \left[D_{t+1} + \overline{D}_{mt+1} \frac{\Lambda_{t+1}\,(x_{t+1})}{v_{t+1}} \right] \right\} \end{aligned} \tag{A115}$$

17. The marginal value of an additional customer $\overline{D}_{mt}$ satisfies (A96):

$$\overline{D}_{mt} = (1-\delta_p) E_t \left\{ \rho_{t,t+1} \left[(1-\varphi)\, \frac{e_{t+1} - x_{t+1}}{\mu_{t+1}} + (1-\delta_f)\, \overline{D}_{mt+1} \right] \right\} \tag{A116}$$

18. The supply of government bonds b_t satisfies:

$$b_t = r_t\, b_{t-1} + \varphi g - \tau_t \tag{A117}$$

19. Net taxes τ_t are such that

$$\tau_t = r_t\, b_{t-1} + \varphi\, \bar{g} - \tau_t^{\ell}\, w_t \ell_t. \tag{A118}$$

20. The aggregate law of motion of the aggregate shocks for search efficiency, λ_t, and

transfers, τ_t^ℓ, are given by

$$\lambda_t = \bar{\lambda} + \varrho_\lambda \left(\lambda_{t-1} - \bar{\lambda}\right) + \epsilon_t^\lambda \tag{A119}$$

$$\ln \tau_t^\ell = \ln \bar{\tau}^\ell + \varrho_\tau \left(\ln \tau_{t-1}^\ell - \ln \bar{\tau}^\ell\right) + \epsilon_t^\tau \tag{A120}$$

G Growth model and balanced growth path

We now briefly discuss how our household's problem could be incorporated into a growth model that allows for a balanced growth path. For completeness we also introduce capital accumulation, an endogenous labor supply and allow growth to be endogenous. Endogenous growth also helps in clarifying how adoption expenditure stimulates innovation and growth. The model borrows from Romer (1990) and Rivera-Batiz and Romer (1991). For simplicity we solve the model in the absence of aggregate shocks, but it would be easy to introduce aggregate uncertainty. We first describe the economy and characterize key equilibrium conditions of the model. Then we formally define the equilibrium. Finally we characterize the balanced growth path of the economy.

G.1 Assumption and equilibrium conditions

In the economy at t there are S_t sectors and in each of them there is a measure one of varieties. As a result at t there are $[0, S_t] \times [0, 1] \in R^2$ varieties in the economy. The first dimension denotes the sector, the second the variety within a sector. At the end of period $t-1$, the household has found at least one variety she likes in s_{t-1} sectors of the economy. At the end of period $t-1$, the number of varieties the household likes in a sector $s \in [0, s_{t-1}]$ is characterized by a Poisson distribution with mean μ_{t-1}. From time $t-1$ to t, the preferences of households changes and there is an iid probability δ that the household no longer likes a variety—which then drops from her consideration set. At (the beginning of) time t the household also spends x_t units on experimenting for new varieties to be added to her time t consideration set. As in the baseline model, we assume that experimentation is fully random in that the household when buying a new variety does not know the sector of the variety. The sector gets known only if the household likes the new variety—which is then incorporated into the household's consideration set. The idea is that bad varieties are all equally bad to the household, while good varieties have a sectoral identity. To learn whether the household likes the variety, the household has to purchase (and consume) at least one unit of the variety. If the household spends $\widehat{\delta}$ units on $\widehat{\delta}$ different varieties the probability that the household discovers one she likes is $\lambda\widehat{\delta}$, the probability that the household likes none of them is $1 - \lambda\widehat{\delta}$, while the probability that she likes more than one is of order smaller than $\widehat{\delta}$. If the household discovers a new variety in a sector where she has never consumed before, the new sector becomes equal (in expectation) to all the other sectors in the consideration set. To formalize this we assume that the number of varieties the household likes in the new sector is a random draw from a Poisson distribution with expected value μ_t. We assume that the initial (at time zero) number of varieties the household likes in a sector is distributed as a Poisson distribution with expected value μ_{-1}. We can then prove that the consideration set and the number of sectors in the consideration set evolves as follows:

Lemma At time t, the number of varieties in a sector is distributed as a Poisson distribution with parameter

$$\mu_t = (1-\delta)\,\mu_{t-1} + \frac{\lambda x_t}{S_t} \tag{A121}$$

while s_t evolves as follows

$$s_t = s_{t-1} + (S_t - s_{t-1})\left(1 - e^{-\frac{\lambda x_t}{S_t}}\right) \tag{A122}$$

where $e^{-\frac{\lambda x_t}{S_t}}$ is the probability that the household after spending x_t/S_t in a sector she finds no variety she likes in a specific sector in the interval $[0, S_t]$.

The household In the economy there is a measure one of identical households. The supply of labor is set endogenously. We set to one the price at t of the first variety introduced in the market,

$$p_{0t} = 1, \forall t, \tag{A123}$$

which is therefore the numeraire of the economy. The household chooses consumption c_t, investment in physical capital i_t, adoption expenditure x_t, labor supply l_t, the average number of varieties in the consideration set $\mu_{t,}$ the number of sector she is aware of s_t, and next period capital stock k_{t+1}. As in the conventional Ramsey-Cass-Koopmans model, we assume the household can substitute one-for-one consumption with investment. The household's problem reads as follows:

$$\max_{\{c_t,i_t,x_t,l_t,\mu_t,s_t,k_{t+1}\}_{t\geq 0}} \sum_{t=0}^{\infty} \beta^t \left[\ln(c_t) - \psi_0 \frac{l_t^{1+\psi}}{1+\psi}\right] \tag{A124}$$

s.t.

$$p(s_t,\mu_t)(c_t + i_t) + x_t \leq r_t k_t + w_t l_t + \tau_t \tag{A125}$$

$$c_t = \left[\int_0^{s_t} \max_{q_{\nu j}\geq 0} \left(\sum_{\nu\in\Omega_{jt}} z_{\nu jt}\, q_{\nu j}\right)^{\frac{\sigma-1}{\sigma}} dj\right]^{\frac{\sigma}{\sigma-1}} \tag{A126}$$

$$p(s_t,\mu_t) = \left[\Gamma\left(1 - \frac{\sigma-1}{\alpha}\right) s_t \sum_{n=0}^{\infty} n^{\frac{\sigma-1}{\alpha}} f(n;\mu_t)\right]^{-\frac{1}{\sigma-1}} \tag{A127}$$

$$k_{t+1} = (1-\varkappa)\,k_t + i_t \tag{A128}$$

$$f(n;\mu_t) = e^{-\mu_t}\frac{(\mu_t)^n}{n!}$$

$$\mu_t = (1-\delta)\,\mu_{t-1} + \frac{\lambda x_t}{S_t} \tag{A129}$$

$$s_t = e^{-\frac{\lambda x_t}{S_t}} s_{t-1} + \left(1 - e^{-\frac{\lambda x_t}{S_t}}\right) S_t = s_{t-1} + \left(1 - e^{-\frac{\lambda x_t}{S_t}}\right)(S_t - s_{t-1}) \tag{A130}$$

with $\sigma > 1$, $\alpha > 0$, $\frac{\sigma-1}{\alpha} < 1$, $R > 1/\beta$. We work with log-preferences to guarantee a balanced growth path with constant labour supply. τ_t is a lump sum taxes equal to firm profits. The above problem can be written in recursive form as follows:

$$v_t(k_t, \mu_{t-1}, s_{t-1}) = \max_{\{c_t,\, i_t,\, x_t,\, l_t,\, \mu_t,\, s_t,\, k_{t+1}\}} \ln(c_t) - \psi_0 \frac{l_t^{1+\psi}}{1+\psi} + \beta\, v_{t+1}(k_{t+1}, \mu_t, s_t) \Big\}$$

subject to the budget constraint in (A125) and the evolution of the three state variables of the problems, k_t, μ_{t-1}, and s_{t-1}, whose law of motion is given by (A128), (A129) and (A130), respectively.

Solution to the household's problem By writing the first order conditions of the problem in (A124) with respect to c_t, and i_t, and after using the envelope condition, we obtain that:

$$\frac{1}{c_t} = \beta \left[(1-\varkappa) + \frac{r_{t+1}}{p_{t+1}} \right] \frac{1}{c_{t+1}} \tag{A131}$$

$$\frac{\partial v_t}{\partial k_t} = \frac{1}{c_t} \left[(1-\varkappa) + \frac{r_t}{p_t} \right] \tag{A132}$$

Let

$$\eta(\mu_t) = -\frac{(\sigma-1)dp_t}{p_t d\mu_t} = \frac{\sum_{n=0}^{\infty} n^{\frac{\sigma-1}{\alpha}} \frac{\partial f(n;\mu_t)}{\partial \mu_t}}{\sum_{n=0}^{\infty} n^{\frac{\sigma-1}{\alpha}} f(n;\mu_t)}$$

The first order condition with respect to x_t implies that

$$\frac{1}{p_t c_t} = \left[\frac{1}{\sigma-1} \frac{1}{s_t} \frac{c_t+i_t}{c_t} + \beta \frac{\partial v_{t+1}}{\partial s_t} \right] \lambda \left(\frac{S_t - s_{t-1}}{S_t} \right) e^{-\frac{\lambda x_t}{S_t}} + \left[\frac{\eta(\mu_t)}{\sigma-1} \cdot \frac{c_t+i_t}{c_t} + \beta \frac{\partial v_{t+1}}{\partial \mu_t} \right] \frac{\lambda}{S_t} \tag{A133}$$

where from the envelope conditions we know that

$$\frac{\partial v_t}{\partial s_{t-1}} = e^{-\frac{\lambda x_t}{S_t}} \left[\frac{1}{\sigma-1} \frac{1}{s_t} \frac{c_t+i_t}{c_t} + \beta \frac{\partial v_{t+1}}{\partial s_t} \right] \tag{A134}$$

$$\frac{\partial v_t}{\partial \mu_{t-1}} = (1-\delta) \left[\frac{1}{\sigma-1} \eta(\mu_t) \frac{c_t+i_t}{c_t} + \beta \frac{\partial v_{t+1}}{\partial \mu_t} \right] \tag{A135}$$

The first order conditions for the choice of l_t yields

$$\psi_0\, l_t^{\psi} = \frac{w_t}{p_t c_t} \tag{A136}$$

Production Firm i can produce q_{it} units of the variety i according to the following Cobb-Douglas production function

$$q_{it} = (\sigma l_{it})^{\frac{1}{\sigma}} \left(\frac{\sigma k_{it}}{\sigma-1} \right)^{\frac{\sigma-1}{\sigma}} \tag{A137}$$

implying a marginal cost of production of one unit of variety $i \in [0, S_t]$ equal to

$$m_t = (w_t)^{\frac{1}{\sigma}} (r_t)^{1-\frac{1}{\sigma}}. \tag{A138}$$

The derivation of (A138) from first principles is at the end of this note. Cost minimization also implies that

$$l_{it} = \frac{m_t q_{it}}{\sigma w_t} = \frac{1}{\sigma} \left(\frac{r_t}{w_t}\right)^{1-\frac{1}{\sigma}} q_{it} \tag{A139}$$

$$k_{it} = \frac{(\sigma - 1) m_t q_{it}}{r_t \sigma} = \left(1 - \frac{1}{\sigma}\right) \left(\frac{w_t}{r_t}\right)^{\frac{1}{\sigma}} q_{it} \tag{A140}$$

Prices and profits Firms' mark-ups are exogenously given and equal to $\theta > 1$, implying that the price of a variety i is given by

$$p_{it} = \theta m_t, \quad \forall i \in [0, S_t]$$

We notice that all firms charge the same price $p_{it} = p_t = \theta m_t$, which given our choice for the numeraire implies that

$$p_t = 1 = \theta m_t \tag{A141}$$

which implies that marginal costs are constant and equal to

$$m_t = \frac{1}{\theta} \tag{A142}$$

Combining (A141) with (A138) yields

$$r_t = \frac{1}{\theta^{\frac{\sigma}{\sigma-1}} (w_t)^{\frac{1}{\sigma-1}}} \tag{A143}$$

Firm profits The (expected) profits at t of a firm of age τ (i.e. created at $t - \tau$) are equal to

$$\pi_t(\tau) = \left(1 - \frac{1}{\theta}\right) \left[\frac{p_t (c_t + i_t)}{s_t} \left(1 - e^{-\lambda \sum_{j=0}^{\tau} \frac{x_{t-j}}{S_{t-j}}}\right) + \frac{x_t}{S_t}\right] \tag{A144}$$

This the product of the difference between the price and the marginal cost times the expected expenditure in the sector given the fraction of households who have discovered the sector. This uses the fact that all firms are symmetric and they are equally likely to be chosen by the household for consumption. The expected value of this firm is equal to

$$V_t(\tau) = \left(1 - \frac{1}{\theta}\right) \left[\frac{p_t (c_t + i_t)}{s_t} \left(1 - e^{-\lambda \sum_{j=0}^{\tau} \frac{x_{t-j}}{S_{t-j}}}\right) + \frac{x_t}{S_t}\right] + \beta E_t \left[\frac{p_t c_t}{p_{t+1} c_{t+1}} V_{t+1}(\tau + 1)\right] \tag{A145}$$

This capitalizes the future value of profits using the household discount factor β times the value of income at different point in times as measured by the Lagrange multiplier of the household budget constraint in (A125). The value upon entry of the firm at t is equal to

$V_t(0)$. Notice that $V_t(0)$ can be written recursively as follows:

$$V_t(0) = V_{1t} - e^{-\lambda \frac{x_t}{S_t}} V_{2t} \tag{A146}$$

where

$$V_{1t} = \left(1 - \frac{1}{\theta}\right) \left[\frac{p_t\left(c_t + i_t\right)}{s_t} + \frac{x_t}{S_t}\right] + \beta E_t \left(\frac{p_t c_t}{p_{t+1} c_{t+1}} V_{1t+1}\right) \tag{A147}$$

$$V_{2t} = \left(1 - \frac{1}{\theta}\right) \frac{p_t\left(c_t + i_t\right)}{s_t} + \beta E_t \left(\frac{e^{-\lambda \frac{x_{t+1}}{S_{t+1}}} p_t c_t}{p_{t+1} c_{t+1}} V_{2t+1}\right) \tag{A148}$$

V_{1t} measures the hypothetical expected value of a firm in a sector which is in the consideration set of all household in the economy. V_{2t} is the present value of all hypothetical losses due to the fact that the customer base of the firm increases slowly over time. This customer base accumulates faster the greater the adoption expenditure of the household.

The R&D sector R&D can be intensive in labor or capital. We assume that the marginal cost of discovering a new variety is equal to

$$\xi_t = \omega_0 \left(\frac{w_t}{S_{t-1}}\right)^{\omega} \left(m_t\right)^{1-\omega} = \omega_0 \left(\frac{w_t}{S_{t-1}}\right)^{\omega} \left(\frac{1}{\theta}\right)^{1-\omega} \tag{A149}$$

where the last equality comes from our choice of the numeraire. With $\omega = 1$ we have the formulation in Romer (1990) with an associated intertemporal technological spill-over. With $\omega = 0$, R&D is no more intensive in labor than the production of any other good in the economy as in the formulation by Rivera-Batiz and Romer (1991). ω measures whether the factor content of R&D is relatively intensive in labor. For simplicity it is convenient to define

$$\overline{\omega}_0 = \omega_0 \left(\frac{1}{\theta}\right)^{1-\omega}$$

Under free entry in the R&D sector the following condition should hold:

$$V_t(0) = \xi_t. \tag{A150}$$

Aggregate profits Aggregate profits are equal to

$$\tau_t = \left[p_t\left(c_t + i_t\right) + x_t\right] \left(1 - \frac{1}{\theta}\right) - (S_t - S_{t-1})\xi_t \tag{A151}$$

This is the sum of the profits of all firms in the market plus the (negative profits) of all firms which invest to discover new varieties.

Labor market clearing Clearing in the labor market implies that

$$\begin{aligned} l_t &= \left[\frac{1}{\sigma} + (1-\frac{1}{\sigma})\omega\right] \frac{\xi_t}{w_t} (S_t - S_{t-1}) + \frac{p_t (c_t + i_t) + x_t}{w_t \sigma \theta} \\ &= \left[\frac{1}{\sigma} + (1-\frac{1}{\sigma})\omega\right] \left(\frac{S_{t-1}}{\theta w_t}\right)^{1-\omega} \left(\frac{S_t}{S_{t-1}} - 1\right) + \frac{1}{\sigma} \frac{p_t (c_t + i_t) + x_t}{\theta w_t} \end{aligned} \tag{A152}$$

The left hand side is the labor supply. The right-hand side is labor demand that comes from the producers of all varieties in the economy plus the R&D sector.

Capital market clearing Clearing in the capital market implies that

$$\begin{aligned} k_t &= \frac{(1-\frac{1}{\sigma})(1-\omega)\xi_t}{r_t} (S_t - S_{t-1}) + \frac{\left(1-\frac{1}{\sigma}\right)[p_t (c_t + i_t) + x_t]}{\theta r_t} \qquad \text{(A153)} \\ &= \frac{1-\frac{1}{\sigma}}{r_t \theta^{1-\omega}} \left[(1-\omega)\omega_0 \left(\frac{w_t}{S_{t-1}}\right)^{\omega} (S_t - S_{t-1}) + \frac{p_t (c_t + i_t) + x_t}{\theta^{\omega}}\right] \end{aligned}$$

which says that capital grows at rate $\frac{\sigma}{\sigma-1}$ in steady state.

Goods clearing To clear the good market it has to be the case that

$$p_t (c_t + i_t) + x_t = \left\{\sigma \left[l_t - \left[\frac{1}{\sigma} + (1-\frac{1}{\sigma})\omega\right] \frac{\xi_t}{w_t} (S_t - S_{t-1})\right]\right\}^{\frac{1}{\sigma}} \left\{\frac{\left[k_t - \frac{(1-\frac{1}{\sigma})(1-\omega)\xi_t}{r_t} (S_t - S_{t-1})\right]}{1-\frac{1}{\sigma}}\right\}^{\frac{\sigma-1}{\sigma}} \tag{A154}$$

which says that the amount of varieties produced comes from using all labor and capital that is not used by the R&D sector.

G.2 Equilibrium

An equilibrium is a tuple

$$\left(c_t, i_t, x_t, l_t, \frac{\partial v_t}{\partial k_t}, \frac{\partial v_t}{\partial s_{t-1}}, \frac{\partial v_t}{\partial \mu_{t-1}}, w_t, r_t, p_t, k_{t+1}, \mu_t, s_t, S_t, \xi_t, V_t(0)\right) \tag{A155}$$

such that

1. The optimal saving decision of households in (A132) holds:

$$\frac{1}{c_t} = \beta \left[(1-\varkappa) + \frac{r_{t+1}}{p_{t+1}}\right] \frac{1}{c_{t+1}} \tag{A156}$$

2. The optimal choice for experimentation of households in (A133) is satisfied:

$$\frac{1}{p_t c_t} = \left[\frac{1}{\sigma-1} \frac{1}{s_t} \frac{c_t + i_t}{c_t} + \beta \frac{\partial v_{t+1}}{\partial s_t}\right] \lambda \left(\frac{S_t - s_{t-1}}{S_t}\right) e^{-\frac{\lambda x_t}{S_t}} + \left[\frac{\eta(\mu_t)}{\sigma-1} \frac{c_t + i_t}{c_t} + \beta \frac{\partial v_{t+1}}{\partial \mu_t}\right] \frac{\lambda}{S_t} \tag{A157}$$

where

$$\eta\left(\mu_t\right)=\frac{\sum_{n=0}^{\infty} n^{\frac{\sigma-1}{\alpha}} \frac{\partial f(n;\mu_t)}{\partial \mu_t}}{\sum_{n=0}^{\infty} n^{\frac{\sigma-1}{\alpha}} f(n;\mu_t)}$$

3. The optimal choice of labor supply in (A136) holds:

$$\psi_0\, l_t{}^{\psi}=\frac{w_t}{p_t c_t} \tag{A158}$$

4. The marginal value of capital satisfies (A132):

$$\frac{\partial v_t}{\partial k_t}=\frac{1}{c_t}\left[(1-\varkappa)+\frac{r_t}{p_t}\right] \tag{A159}$$

5. The marginal value of a new sector in the consideration set evolves as in (A134):

$$\frac{\partial v_t}{\partial s_{t-1}}=e^{-\frac{\lambda x_t}{S_t}}\left[\frac{1}{\sigma-1}\frac{1}{s_t}\frac{c_t+i_t}{c_t}+\beta\frac{\partial v_{t+1}}{\partial s_t}\right] \tag{A160}$$

6. The marginal value of a new variety in the consideration set evolves as in (A135):

$$\frac{\partial v_t}{\partial \mu_{t-1}}=(1-\delta)\left[\frac{1}{\sigma-1}\eta\left(\mu_t\right)\frac{c_t+i_t}{c_t}+\beta\frac{\partial v_{t+1}}{\partial \mu_t}\right] \tag{A161}$$

7. The aggregate budget constraint of the economy in (A125) is satisfied:

$$\left[p_t\left(c_t+i_t\right)+x_t\right]\frac{1}{\theta}+(S_t-S_{t-1})\xi_t=r_t k_t+w_t L_t \tag{A162}$$

8. Aggregate prices satisfy (A127):

$$p_t=\left[\Gamma\left(1-\frac{\sigma-1}{\alpha}\right)\, s_t\sum_{n=0}^{\infty} n^{\frac{\sigma-1}{\alpha}} f(n;\mu_t)\right]^{-\frac{1}{\sigma-1}} \tag{A163}$$

with

$$f(n;\mu_t)=e^{-\mu_t}\frac{(\mu_t)^n}{n!}$$

9. The capital stock evolves as in (A128):

$$k_{t+1}=(1-\varkappa)\,k_t+i_t \tag{A164}$$

10. The average number of varieties in the consideration set evolves as in (A129):

$$\mu_t=(1-\delta)\,\mu_{t-1}+\frac{\lambda x_t}{S_t} \tag{A165}$$

11. The number of sectors in the consideration set evolve as in (A130):

$$s_t = e^{-\frac{\lambda x_t}{S_t}} s_{t-1} + \left(1 - e^{-\frac{\lambda x_t}{S_t}}\right) S_t \tag{A166}$$

12. The value of an innovation satisfies (A146):

$$V_t(0) = V_{1t} - e^{-\lambda \frac{x_t}{S_t}} V_{2t} \tag{A167}$$

where

$$V_{1t} = \left(1 - \frac{1}{\theta}\right) \left[\frac{p_t (c_t + i_t)}{s_t} + \frac{x_t}{S_t}\right] + \beta E_t \left(\frac{p_t c_t}{p_{t+1} c_{t+1}} V_{1t+1}\right) \tag{A168}$$

$$V_{2t} = \left(1 - \frac{1}{\theta}\right) \frac{p_t (c_t + i_t)}{s_t} + \beta E_t \left(\frac{e^{-\lambda \frac{x_{t+1}}{S_{t+1}}} p_t c_t}{p_{t+1} c_{t+1}} V_{2t+1}\right) \tag{A169}$$

13. There is free entry in R&D so that (A150) holds true:

$$V_t(0) = \xi_t \tag{A170}$$

14. The marginal cost of an innovation is equal to (A149):

$$\xi_t = \omega_0 \left(\frac{w_t}{S_{t-1}}\right)^{\omega} \left(\frac{1}{\theta}\right)^{1-\omega} \tag{A171}$$

15. The labor market clears so that (A152) holds true:

$$l_t = \left[\frac{1}{\sigma} + (1 - \frac{1}{\sigma})\omega\right] \frac{\xi_t}{w_t} (S_t - S_{t-1}) + \frac{p_t (c_t + i_t) + x_t}{w_t \sigma \theta} \tag{A172}$$

16. The aggregate resource constrain in (A154) is satisfied:

$$p_t (c_t + i_t) + x_t = \left\{\sigma \left[l_t - \left[\frac{1}{\sigma} + (1 - \frac{1}{\sigma})\omega\right] \frac{\xi_t}{w_t} (S_t - S_{t-1})\right]\right\}^{\frac{1}{\sigma}} \left\{\frac{\left[k_t - \frac{1}{r_t}\left(1 - \frac{1}{\sigma}\right)(1 - \omega)\, \xi_t (S_t - S_{t-1})\right]}{1 - \frac{1}{\sigma}}\right\}^{1 - \frac{1}{\sigma}} \tag{A173}$$

G.3 Balanced Growth path

Along a balanced growth path we have that $\frac{S_t}{S_{t-1}}$ is growing at a constant rate γ :

$$\frac{S_t}{S_{t-1}} = 1 + \gamma$$

All the other quantities in the tuple in (A155) that defines the equilibrium behaves as follows:

$$\begin{bmatrix} c_t \\ i_t \\ x_t \\ l_t \\ \frac{\partial v_t}{\partial k_t} \\ \frac{\partial v_t}{\partial s_{t-1}} \\ \frac{\partial v_t}{\partial \mu_{t-1}} \\ w_t \\ r_t \\ p_t \\ k_{t+1} \\ \mu_t \\ s_t \\ \xi_t \\ V_t(0) \\ S_t \end{bmatrix} = \begin{bmatrix} cS_t^{\frac{\sigma}{\sigma-1}} \\ iS_t^{\frac{\sigma}{\sigma-1}} \\ xS_t \\ l \\ \frac{\partial v}{\partial k} S_t^{-\frac{\sigma}{\sigma-1}} \\ \frac{\partial v}{\partial s}\frac{1}{S_t} \\ \frac{\partial v}{\partial \mu} \\ wS_t \\ rS_t^{-\frac{1}{\sigma-1}} \\ pS_t^{-\frac{1}{\sigma-1}} \\ kS_t^{\frac{\sigma}{\sigma-1}} \\ \mu \\ sS_t \\ \xi \\ V(0) \\ S_t \end{bmatrix},$$

This means that the vector (c_t, k_t, i_t) grows at rate

$$g = (1+\gamma)^{\frac{\sigma}{\sigma-1}} - 1,$$

that the vector (x_t, w_t, s_t) grows at rate γ, the vector (r_t, p_t) grows at rate $(1+\gamma)^{-\frac{1}{\sigma-1}} - 1$, the vector $(\frac{\partial v_t}{\partial \mu_{t-1}}, \mu_t, \xi_t, V_t(0))$ is constant, $\frac{\partial v_t}{\partial k_t}$ grows at rate $(1+\gamma)^{-\frac{\sigma}{\sigma-1}} - 1$, while $\frac{\partial v_t}{\partial s_{t-1}}$ grows at rate $(1+\gamma)^{-1} - 1$. The steady state equilibrium is characterized by the following tuple of constants

$$\left(c, i, x, l, \frac{\partial v}{\partial k}, \frac{\partial v}{\partial s}, \frac{\partial v}{\partial \mu}, w, r, p, k, \mu, s, S_t, \xi, V(0)\right). \tag{A174}$$