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Abstract

About half of the cyclical 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 depend mostly on fluctuations in the rate at which households add new products; removals are relatively acyclical. These patterns are largely explained by the fact that households respond to income increases by adopting new product varieties in their consumption basket. Fluctuations in household adoption are a prominent determinant of the aggregate demand for new products and amplify the long-run welfare effects of aggregate shocks.

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1 Introduction

At least since Dixit and Stiglitz (1977), Krugman (1980), and Romer (1990) a good deal of economic literature has maintained that greater product variety in the market increases the welfare of households. Quantitatively, the welfare gain due to love of variety is estimated to be large: see for example Bils and Klenow (2001) and Broda and Weinstein (2006, 2010). In practice, firms decide whether or not to introduce a new variety of product, but new varieties yield welfare gains only if households actually *adopt* them into their consumption basket, resulting in a change in consumption along the *extensive margin*. We show that the propensity of households to adopt new varieties varies cyclically, that it is an important determinant of the aggregate demand for innovation, and that it matters in evaluating the welfare effects of business cycles and aggregate demand stabilization measures.

We rely on the Kilts-Nielsen Consumer Panel (KNCP) in the 2000's to decompose changes in aggregate non-durable consumption expenditure in the United States into expenditure along the intensive and the extensive margin. The intensive margin reflects change in the amount spent on products already purchased by households in the previous period. The extensive margin reflects *net* additions of products to the consumption basket, which is the difference between gross *additions* (expenditure on products not previously purchased) and *removals* of products (previous-period expenditure on products no longer purchased). We find that 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. These patterns hold at different frequencies (quarterly and annual), within narrowly defined product sectors or quality categories, and across households differing in permanent income; they generally characterize business cycles across US regions, and they are only partly driven by changes in prices or product availability.

These results might be due to general equilibrium effects or changes in firms' marketing and/or pricing strategies rather than to household demand behavior. To address this issue, we build on Parker, Souleles, Johnson, and McClelland (2013) and Broda and Parker (2014) and focus on the effects of the federal government's Economic Stimulus Payment (ESP) to households in 2008. Since the response is gauged by comparing households that receive the payment randomly over time, we follow Kaplan and Violante (2014) in interpreting the estimated responses as characterizing household behavior in partial equilibrium. The marginal propensity to consume out of the ESP is about 50 percent, which 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. Household substitution of products across sectors or quality categories does not drive the extensive response. The household continues buying some new varieties added to her basket upon receipt of the ESP, but she also regrets having purchased some of them.

The previous evidence indicates that households respond to income shocks by adopting new varieties for consumption. We model household adoption by incorporating a conventional random utility model of discrete product choice à la McFadden (1973, 1974) in a standard household dynamic optimization problem, as in Ramsey (1928). The household has a set of varieties she considers for consumption (her "consideration set"). Varieties in the consideration set are subject to preference shocks, which induce changes in the consumption basket of the household even in the absence of adoption of new varieties. There is a continuum of sectors and the household's consideration set for each sector is discrete. Owing to the preference shocks, a larger set reduces the welfare-relevant household price index, which provides a micro-foundation for love of variety. The household decides how much to save and how many new varieties in the market to sample (adoption expenditure). Some of the newly sample varieties are brought into the consideration set (adoption return). In response to an income shock, the household adopts more varieties first because there is a *scale effect*, typical of love-of-variety models, which makes varieties more valuable when spending is higher, and second because it persistently reduces the welfare-relevant household price index, which serves to *smooth consumption* over time. We calibrate the model by drawing detailed statistics from the KNCP. The model matches the level of net and gross additions in the data and fairly closely approximates the intensive and extensive response of consumption to the 2008 Federal ESP.

The household chooses her optimal adoption expenditure *conditional* on her choice for total consumption expenditure. This separation property allows us to estimate the adoption expenditure by full information methods using data on net additions and total expenditure. The approach is robust to the exact nature of the shocks that drive total expenditure and to changes in mark-ups. In the estimation, we allow the return to adoption to vary over the cycle, in order to control for changes in either advertising by firms or search intensity by households, which, as is emphasized by Coibion, Gorodnichenko, and Hong (2015), Nevo and Wong (2019), and Kaplan and Menzio (2016) could be counter-cyclical. The model fits well with the data on the cyclical properties of net and gross additions. Household adoption expenditure is strongly pro-cyclical and are practically two-and-a-half times as volatile as total expenditure. Household adoption puts a wedge between expenditure and consumption whose magnitude increases during the post-recession recovery. This wedge reflects a bias in the measurement of inflation, which over the course of the Great Recession is around 15 basis points per year higher than the official statistics.

We embed our household's problem in a general equilibrium model where the number of varieties in the market is endogenous, as in Romer (1990) and Bilbiie, Ghironi, and Melitz (2012). We quantify the aggregate determinants of innovation and evaluate the long-run effects of aggregate demand policies given endogenous household adoption of varieties. Fluctuations in adoption account for more than 60 percent of the fluctuation in the aggregate innovation rate. This reflects the fact that the profitability of new products depends heavily on the rate of growth of their customer base, which in turn is directly affected by households' propensity to adopt new varieties. When, as in Romer (1990), labor productivity increases with the number of varieties available, due to increased specialization of labor, endogenous household adoption amplifies the long-run welfare effects of expansionary fiscal policies like ESP. Quantitatively, the long-run response of consumption to the ESP is greater by a factor of around two compared with constant household adoption.

Some references to the literature Several other authors have shown that households' consumption basket and shopping behavior change over the cycle. Jaimovich, Rebelo, and Wong (2019) and Argente and Lee (2017) document changes in product quality, while Aguiar and Hurst (2007), Coibion et al. (2015), Nevo and Wong (2019) and Campos and Reggio (2017) demonstrate that households may shop more or less intensively in the search for lower prices on the products they usually purchase. The focus on the extensive margin and household adoption under love of variety is novel. Of course households do adjust search intensity over the cycle, but we 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 investment that is more costly during recession owing to the relatively high marginal utility of consumption.

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 accounts for more than half of this cyclical pattern, which follows from the fact that 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 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 business cycle analysis and stabilization policy.

There is an abundant literature on the quantification of the marginal propensity to consume out of income shocks (Agarwal, Marwell, and McGranahan 2017, 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 Kaplan and Violante (2010, 2014), Attanasio and Pavoni (2011), Heathcote, Violante, and Storesletten (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 is driven primarily by gross additions, which partly reflect the adoption of additional varieties. Aguiar, Bils, and Boar (2018) have also studied how income shocks change the sectoral composition of the goods purchased along the extensive margin. Here we show that the extensive margin also responds substantially within given sectors and quality categories, which under love of variety matters for the long-run welfare effects of shocks, both in partial and in general equilibrium.

Section 2 decomposes fluctuations in expenditure into the intensive and extensive margin. Section 3 studies the 2008 tax rebate. Section 4 discusses some robustness issues. Section 5 presents the household's problem, and Section 6 parametrizes it. Section 7 analyzes the empirical properties of the model and Section 8 studies the general equilibrium. Section 9 concludes. The Appendix contains additional details on data and model.

2 Decomposing household consumption expenditure

We first decompose changes in consumption expenditure along the intensive and extensive margin, then discuss the data and present some empirical results.

2.1 Methodology

The consumption expenditure of household $h \in \mathcal{H}$ at time t are 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, i.e. total expenditure divided by the number of households in the economy in the period. $\mathcal{H}$ 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:

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

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 calculated as 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), ΔE_t in (2) can be written as

$$\Delta E_t = I_t + N_t \tag{7}$$

where I_t and N_t denote the changes in aggregate expenditure due respectively to the intensive margin and net additions. 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 the Appendix. The 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. The households report the prices and quantities of all the products purchased in stores, using a scanning device provided by Nielsen.[1] The sample is representative of the US population, and expenditures in the KNCP track the corresponding categories in the Consumer Expenditure Survey (CEX) quite well. Products are identified by their Universal Product Code (UPC). A problem in using UPC to identify a variety is that the same variety packaged differently has a different UPC, which could indicate a change along the extensive margin even when the household still consumes exactly the 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 the KNCP into 735 homogeneous product modules. Examples of product modules are "carbonated beverages," "laundry supplies," "ice cream in bulk" and "frozen yogurt." 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

[1]The product categories in the 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.

market in a year, with the average household buying 350.[2] 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 $t-1$. 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 the KNCP was redesigned in 2006, increasing sample size and product coverage, and the data for 2015 were not available to us.

2.3 Findings

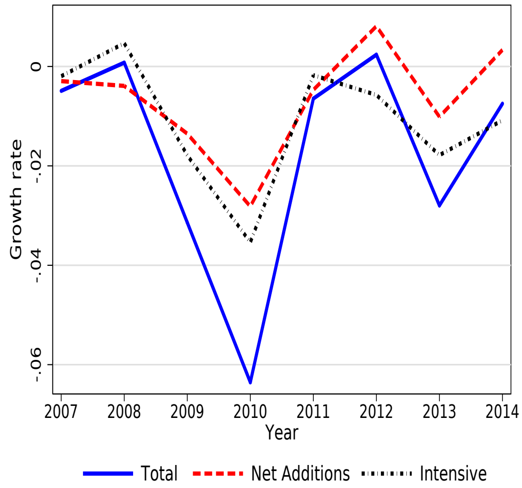
Panel (a) of Figure 1 plots the growth rate of aggregate expenditure ΔE_t (solid blue line) and the contribution of the intensive margin I_t (dotted black line) and net additions N_t (dashed red line). Panel (b) further decomposes net additions N_t into additions A_t (dashed red line) and removals R_t (dotted black line). The series are at yearly frequency, 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, ΔE_t, and the dependent variable X is reported by column. Formally:

$$X_t = \alpha_X + \beta_X \, \Delta E_t + \text{error}$$

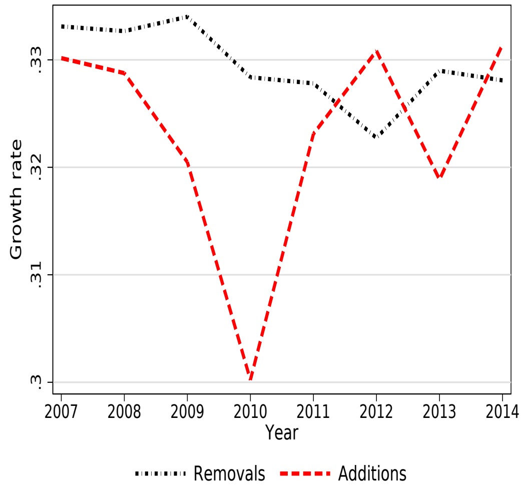
where $X_t = I_t, N_t, A_t, R_t$. OLS is a linear operator, which implies that the coefficients for the intensive margin and net additions sum to 1 ($\beta_I + \beta_N = 1$) and that the coefficient for net additions, β_N, equals the difference between that for additions and that for removals ($\beta_N = \beta_A - \beta_R$). In this sense β_X can be interpreted as a measure of the contribution of

[2] All white labels in a product module have the same brand code and are identified as the same variety.

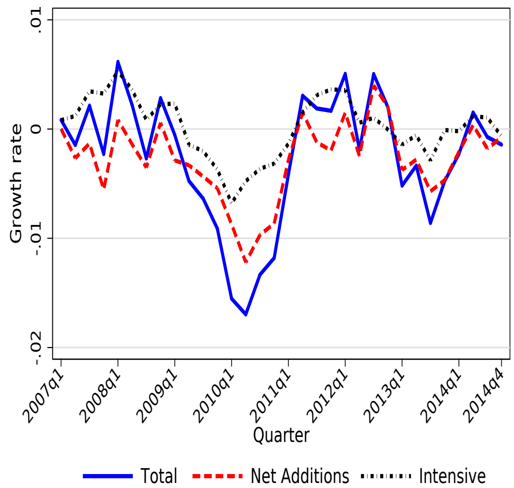
Figure 1: Flows in aggregate expenditure



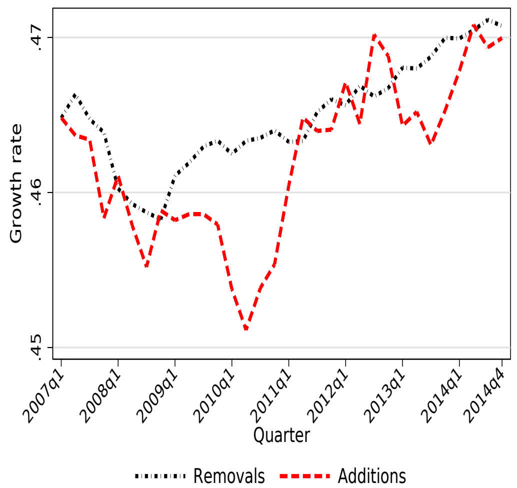
(a) Intensive vs extensive, yearly



(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, ΔE_t, 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-quarter moving averages. A variety is defined as a brand/product-module pair.

X_t to the cyclical fluctuation in ΔE_t. Using this metric, Table 1 shows that net additions N_t account for almost half of the variation in expenditure growth ΔE_t, 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: 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, $X_t = \alpha_X + \beta_X \, \Delta E_t + \text{error}$. 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.

(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 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 and started to buy in bulk to take advantage of quantity discounts (Nevo and Wong 2019). 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.

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, $\beta_X^w + \beta_X^b$	0.46	0.44	-0.02	0.57	0.58	0.01
a) Changes in sectoral composition						
Within, β_X^w	0.27	0.27	0.00	0.20	0.22	0.02
Between, β_X^b	0.19	0.17	-0.02	0.37	0.36	-0.01
b) Quality substitution						
Within, β_X^w	0.20	0.20	0.00	0.15	0.13	-0.02
Between quality within product group, β_X^b	0.21	0.20	-0.01	0.25	0.29	0.04
Between product group, β_X^b	0.05	0.04	-0.01	0.18	0.17	-0.01
c) Varieties available						
Within, β_X^w	0.42	0.40	-0.02	0.54	0.55	0.01
Between, β_X^b	0.05	0.05	0.00	0.03	0.03	0.01

Each entry is the estimated OLS coefficient β_X^s 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: $X_t^s = \alpha_X^s + \beta_X^s \, \Delta E_t + \text{error}$. The first row reports the total contribution of variable X_t (the sum of its between and within components) to the fluctuation in ΔE_t. A variety is identified by a brand/product-module pair. The sectors in panel (b) correspond to the 735 product modules defined by Nielsen. In panel (c), 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.

Jaimovich, Rebelo, and Wong (2019) and 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. To analyze the issue, we construct a measure of the quality of variety $\nu \in \mathcal{V}$ based on its average per unit price over time. In calculating this average unit price, we control for a full set of dummies for time, geographical location, and the 95 product groups (for additional detail, see the Appendix). 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. 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. Panel (c) of Table 1 shows that, at the yearly frequency, fluctuations in net and gross additions occur mainly in continuously present varieties. For example, additions in continuously available varieties contribute about 40 percent of the fluctuation in expenditure growth, $\beta_A^w = 0.40$, while the analogous contribution of additions in new varieties is around 5 percent, $\beta_A^b = 0.05$. 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. Section 4 further relates these findings to those in Broda and Weinstein (2010).

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 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 the 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 in 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.[3] 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

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

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), $\mathrm{MPC_E}$, into the sum of one marginal propensity to consume along the intensive margin, $\mathrm{MPC_I}$, and another due to net additions, $\mathrm{MPC_N}$, which can be further broken down into a component due to removals and one due to

[3]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.

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 account for roughly a third of the response of additions, which indicates that households respond to temporary income changes by adding new products, which then remain persistently in the consumption basket for several weeks after the income boost. As in Section 2.3, we also decompose the response of additions 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.

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

Response to ESP (MPC_A, %)	**Persistent Additions** $MPC_{A\text{-Per}}$	**Within quality & Within product groups**	**Between quality & Within product groups**	**Between product groups**
Month before, β_{-1}	0.65**	1.25**	0.07	0.24*
	(0.29)	(0.50)	(0.25)	(0.14)
Month of receipt, β_0	0.93**	2.33***	0.18	0.13
	(0.37)	(0.65)	(0.31)	(0.15)
Month after, β_1	1.42***	3.01***	0.13	0.20
	(0.52)	(0.86)	(0.39)	(0.18)
Number of observations	324324	324324	324324	324324
Number of households	6237	6237	6237	6237

Results from estimating (20) for different components of the additions $\widetilde{a}_{ht}$ in (17). In the first column the dependent variable is additions in (17) for products repurchased at least once in one of the 52 weeks after t. In columns 2, 3 and 4 the dependent variables are constructed based on a partition of the space of varieties at time t into 950 groups, i.e. 10 quality groups in each of Nielsen's 95 product groups (see Appendix for details).

4 Further discussion

We now report on several additional exercises and robustness checks and better characterize the way in which households adopt new varieties. For full details, see the Appendix.

Household heterogeneity We grouped households by expenditure quintile in the previous year. 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 recessions across US regions. Like Aguiar, Hurst, and Karabarbounis (2013), we exploit this regional variation to study whether our results are robust to outliers and are a general feature of the US business cycle. We find supportive evidence. For example, 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 the KNCP is deemed to be representative.

Varieties as UPCs We experimented with the alternative of identifying a variety by UPC alone.[4] This increases the number of varieties considered, it marginally increases the contribution of net and gross additions to the cyclical fluctuations in expenditure and makes removals slightly more countercyclical; but overall the results are little changed, with just one relevant exception: namely, the contribution of newly introduced varieties to fluctuations in additions increases by 20 to 25 percentage points over the contribution of 5 percent reported in panel (c) of 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.

Constant prices Additions are evaluated at the price in period t, removals at that in period $t-1$. So an increase in aggregate inflation or a reduction in the intensity of households' search for lower prices could mechanically lead to an increase in net additions. To study this, we constructed series for additions and removals at constant prices. This increases the yearly contribution of net additions from 0.46 to 0.55 and of gross additions from 0.44 to 0.47.

Durability We partition varieties by durability, using the index constructed by Alessandria, Kaboski, and Midrigan (2010).[5] 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).

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.

Persistent vs temporary additions and removals We distinguished between additions to the consumption basket in one year that are purchased for two consecutive years (persistent additions) from those in year t not repurchased in year $t+1$ (temporary additions). Similarly, we distinguished between removals of varieties repurchased the next year

[4]More precisely, we use the universal code of the product as homogenized by Nielsen, corresponding to the variable "UPC-ver"in the KNCP.

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

(temporary removals) and those of varieties not purchased for the next two years (persistent removals). Temporary additions turn out to influence cyclicality along the extensive margin, while temporary removals fluctuate little. Persistent additions account for around 15 percent of the fluctuation in expenditure growth.

Adoption of varieties To better characterize how households adopt new varieties, we studied the time profile of expenditure in varieties newly added by the household to her consumption basket. We selected all households continuously present in the KNCP since 2004, and focused on their expenditure in any week of 2013. We compared the expenditure in varieties that the household has first added to her consumption basket in 2013 (never purchased in the previous 9 years) to the expenditure in varieties that the household has regularly purchased over the previous years. We 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. There is also direct evidence that households sometimes regret adding varieties to their basket. The survey administered by Broda and Parker (2014) over the period April-June 2008 directly 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 spending more on additions (top tercile) are 7 percent more likely to occasionally regret their purchases than those spending less in additions (bottom tercile). 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.

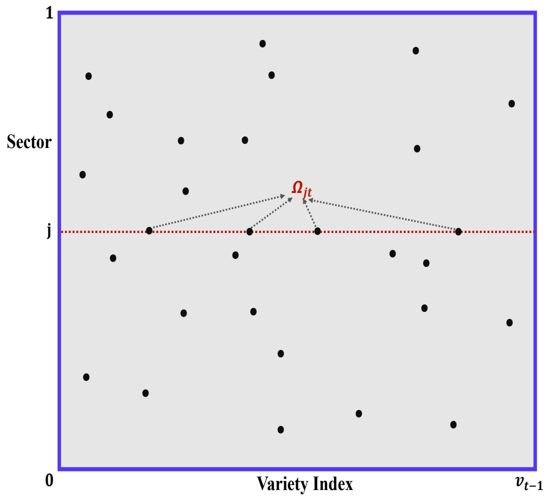
5 Household's problem: McFadden meets Ramsey

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. 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 changes in the consumption basket. We embed the discrete choice model in a standard household dynamic optimization problem à la Ramsey (1928). The household decides saving and *adoption expenditure,* i.e. how many varieties to sample so as to enlarge the consideration set. We characterize the problem in two steps: first static maximization, taking the consideration set as given, and then dynamic optimization. In Section 6 we parametrize the model and recover adoption expenditure in the data. In Section 7 we study the model's empirical fit. In Section 8 we embed the household problem in a general equilibrium model with endogenous innovation.

5.1 Static maximization

Figure 2 describes the varieties available in the market at time t: $\mathcal{V}_t = [0,1] \times [0, v_{t-1}]$ varieties corresponding to a measure 1 of sectors, each containing v_{t-1} distinct varieties, endogenously determined in general equilibrium. 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 $\Omega_{jt} \subseteq [0, v_{t-1}]$ (see Figure 2). Varieties are differentiated across sectors

Figure 2: The space of varieties and the household 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.

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.[6] All varieties

[6]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

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

have the same marginal production cost, charge the same mark-up, and are therefore sold at the same price, normalized to 1. For given consumption expenditure s_t, consumption c_t solves the following maximization problem:

$$c_t = \max_{q_{\nu j} \geq 0} \left[\int_0^1 \left(\sum_{\nu \in \Omega_{jt}} z_{\nu jt} q_{\nu j} \right)^{\frac{\sigma-1}{\sigma}} dj \right]^{\frac{\sigma}{\sigma-1}}, \tag{21}$$

$$\text{subject to} \int_0^1 \sum_{\nu \in \Omega_{jt}} q_{\nu j} dj = s_t, \tag{22}$$

where $q_{\nu j}$ denotes the amount of the household's purchase of variety $\nu \in \Omega_{jt}$ in sector $j \in [0, 1]$. Let $f_t(n)$ denote the fraction of sectors with a consideration set of n varieties at time t. In the Appendix we prove the following proposition:

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

$$p_t = \left[\Gamma \left(1 - \frac{\sigma - 1}{\kappa} \right) \sum_{n=0}^{\infty} n^{\frac{\sigma-1}{\kappa}} f_t(n) \right]^{-\frac{1}{\sigma-1}}. \tag{23}$$

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

$$s_{nt} = \frac{n^{\frac{\sigma-1}{\kappa}}}{\sum_{m=0}^{\infty} m^{\frac{\sigma-1}{\kappa}} f_t(m)} s_t \tag{24}$$

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

The welfare-relevant household price index p_t in (23) 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} 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.

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

5.2 Dynamics of the consideration set and preference shocks

Time is discrete. At the beginning of period t the household spends $x_t \in R_+^2$ on experimenting with new varieties to be added to her time-t consideration sets. We denote the household adoption expenditure as x. Experimentation is fully random over the space of varieties $\mathcal{V}_t$.[7] When the household finds that she likes a new variety ν in sector j, she adds it to the consideration set in the sector Ω_{jt}. To learn whether she likes the variety, she has to consume at least one unit of it and there is no gain from buying more than the minimum quantity. If the household spends $\widehat{\delta} \in R_+$ units on $\widehat{\delta}$ different varieties, the probability of discovering one that she likes is $\Lambda_t(x)\widehat{\delta}$, the probability of liking none is $1 - \Lambda_t(x)\widehat{\delta}$, and the probability of liking more than one is of an order smaller than $\widehat{\delta}$.[8] In brief, household adoption of new varieties is a Poisson process over the space $\mathcal{V}_t$ with intensity $\Lambda_t(x)$, which is increasing and concave in x, $\Lambda_t'(x) > 0$ and $\Lambda_t''(x) < 0$. The subscript t in $\Lambda_t(x)$ refers to possible changes in the return to adoption over time, due to changes either in firms' advertising or in household's search effort. From time $t-1$ to t, there is an iid probability $\delta \in (0,1)$ that a variety will be dropped from the consideration set. This might be because of change in preferences, which happens with probability δ_p, or because of the variety's withdrawal 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 the household's consideration set for a sector is distributed as a Poisson distribution with expected value μ_{-1}. In the Appendix 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 with mean*

$$\mu_t = (1-\delta)\,\mu_{t-1} + \Lambda_t(x_t). \tag{25}$$

Given the evolution of $f_t(n)$, the values of varieties $z_{\nu jt}$ are iid drawings from a Fréchet distribution with shape parameter κ and scale parameter equal to 1. Upon entry into the consideration set at time t, there is a first draw of $z_{\nu jt}$. Conditional on survival, the value of varieties in the consideration set of a sector are redrawn with probability $\psi \in [0,1)$.[9]

[7] 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.

[8] Given the infinitesimal amount spent on varieties that the household might turn out to like, these expenditures have no effects on the consumption utility in (21).

[9] Notice that the resulting unconditional distribution of $z_{\nu jt}$ is still Fréchet with shape parameter κ and scale parameter equal to 1, which justifies the iid assumption in Section (5.1).

5.3 Optimal adoption expenditure

The household is infinitely lived and maximizes the expected sum of the utility flows from consumption c, $u(c)$, minus the disutility of working hours ℓ, $\varepsilon(\ell)$, discounted by a factor $\rho \in (0,1)$. The functions $u(c)$ and $\varepsilon(\ell)$ have the usual properties: they are twice continuously differentiable and strictly increasing, $u(c)$ is concave, and $\varepsilon(\ell)$ is convex. The period-t budget constraint of the household is given by

$$p_t\, c_t + x_t + b_{t+1} \leq w_t\, \ell_t + \iota_t\, b_t - \tau_t, \tag{26}$$

where b_t denotes household's current financial wealth paying a gross return ι_t at t, w_t is the wage rate and τ_t is a lump-sum tax. Maximizing with respect to b_{t+1} yields the conventional Euler equation for consumption

$$\frac{u'(c_t)}{p(\mu_t)} = \rho \mathbb{E}_t \left[\iota_{t+1} \frac{u'(c_{t+1})}{p(\mu_{t+1})} \right], \tag{27}$$

while the first order condition for ℓ_t yields the familiar expression

$$\varepsilon'(\ell_t) = u'(c_t)\, w_t. \tag{28}$$

To solve for adoption expenditure x_t we exploit a separation property of the model (see the Appendix) that implies that x_t maximizes household's expected utility from consumption for a given path of total expenditure e_t equal to

$$e_t \equiv p_t\, c_t + x_t. \tag{29}$$

More formally, let $\mathbf{e}$ denote the information set available to the household to predict total current and future expenditure and let $\mathbb{E}_{\mathbf{e}}$ denote the associated conditional expectation operator. Then the optimal adoption policy solves the following recursive problem:

$$V_t(\mathbf{e}, \mu_{-1}) = \max_x \left\{ u\left(\frac{e-x}{p(\mu)}\right) + \rho \mathbb{E}_{\mathbf{e}}\left[V(\mathbf{e}', \mu)\right] \right\} \tag{30}$$

subject to

$$\mu = (1-\delta)\, \mu_{-1} + \Lambda_t(x), \tag{31}$$

$$p(\mu) = \left[\Gamma\left(1 - \frac{\sigma-1}{\kappa}\right) \sum_{n=0}^{\infty} n^{\frac{\sigma-1}{\kappa}} \frac{\mu^n e^{-\mu}}{n!} \right]^{-\frac{1}{\sigma-1}}, \tag{32}$$

and subject to the law of motion of the information set $\mathbf{e}$ (which is exogenous to the problem). The function $p(\mu)$ in (32) is obtained by combining (23) with Lemma (1), while the law of motion of μ_t in (31) comes from (25). By taking the first order condition with respect to x in (30) and using the envelope theorem to calculate $\partial V/\partial\mu_{-1}$, we get that adoption expenditure should satisfy the following Euler condition:

$$1 = \frac{\Lambda_t'(x_t)\,\eta(\mu_t)}{\mu_t}\,(e_t - x_t) + (1-\delta)\,\mathbb{E}_t\left[\rho_{t,t+1}\,\frac{\Lambda_t'(x_t)}{\Lambda_{t+1}'(x_{t+1})}\right], \tag{33}$$

where, using the notation $c_t = (e_t - x_t)/p(\mu_t)$, we have that

$$\rho_{t,t+1} \equiv \rho\frac{p_t}{p_{t+1}}\frac{u'(c_{t+1})}{u'(c_t)} \tag{34}$$

is the household discount factor between time t and $t+1$, while

$$\eta(\mu) \equiv -\frac{d\ln p(\mu)}{d\ln\mu} = \frac{1}{\sigma-1}\left[\frac{\sum_{n=0}^{\infty} n^{\frac{\sigma-1}{\kappa}+1} f(n;\mu)}{\sum_{n=0}^{\infty} n^{\frac{\sigma-1}{\kappa}} f(n;\mu)} - \mu\right] \tag{35}$$

is the elasticity of the household price index with respect to the average number of varieties in the consideration set μ. Notice that $\eta(\mu)$ in (35) is positive ($d\ln p(\mu)/d\ln\mu$ is negative) and it is smaller than or equal to $1/(\sigma-1)$.[10] The left-hand-side of (33) is the marginal cost of sampling the space of exhisting 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 (34). As a result, the household spends more on adoption, which persistently lowers the household price index. Essentially, by adopting more varieties, the household achieves better *consumption smoothing*. The effects of changes in the discount factor ρ and in total expenditure e_t can also be evaluated in a hypothetical steady state where $e_t = \bar{e}$, $\forall t$ so that $x_t = \bar{x}$, $\forall t$, which, given (31), implies $\mu_t = \bar{\mu} = \frac{\bar{\Lambda}}{\delta}$. Then (33) yields

$$\bar{x} = \frac{\delta\eta(\bar{\mu})\bar{e}}{1-(1-\delta)\rho+\delta\eta(\bar{\mu})}, \tag{36}$$

which, after some algebra, leads to the following proposition:

Proposition 2. *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. $d\ln(\bar{x})/d\ln(\bar{e}) \in (0,1]$.*

[10] To see this, 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 $u \in (0,1]$.

5.4 Additions, removals and the intensive margin

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

$$\frac{e_t - e_{t-1}}{e_{t-1}} = N_t + I_t = A_t - R_t + I_t, \tag{37}$$

where net additions N_t, additions A_t, removals R_t and the intensive margin I_t are defined exactly as in Section (2.1), with $N_t = A_t - R_t$. In the Appendix 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:

$$A_t = \frac{x_t}{e_{t-1}} + \frac{\Lambda_t(x_t)}{\mu_t}\frac{s_t}{e_{t-1}} + \left[\frac{(1-\delta)^2\mu_{t-2}}{\mu_t}\frac{s_t}{e_{t-1}} - \tilde{e}_t^1\right]. \tag{38}$$

The first term on the right-hand side of (38) stands for adoption expenditure x_t, which by definition involve 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 *false* 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. False 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 the Appendix).[11]

Analogously, removals can be expressed as

$$R_t = \frac{x_{t-1}}{e_{t-1}} + \frac{\delta s_{t-1}}{e_{t-1}} + \left[\frac{(1-\delta)s_{t-1}}{e_{t-1}} - \tilde{e}_{t-1}^0\right]. \tag{39}$$

The first term on the right-hand side of (39) 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

[11]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.

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 *false* 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 the Appendix). Finally the intensive margin is obtained as a residual using (37), which yields

$$I_t = \frac{(1-\delta)\Lambda_{t-1}(x_{t-1})}{\mu_t}\frac{s_t}{e_{t-1}} + \tilde{e}^1_t - \tilde{e}^0_{t-1}. \tag{40}$$

6 Calibration and estimation

We calibrate the model by targeting detailed statistics from the KNCP. We then estimate the time series profile of adoption expenditure using full-information maximum likelihood.

6.1 Calibration

The model is specified at the quarterly frequency and calibrated in steady state. Table 5 reports the resulting parameter values with the associated calibration targets. We assume a CRRA consumption-utility, $u(c) = \left(c^{1-\gamma} - 1\right)/(1-\gamma)$, and set the RRA parameter and the subjective discount factor to the standard values of $\gamma = 1$ (log-preferences) and $\rho = 0.99$, respectively. The steady state level of expenditure, $\bar{e}$, is normalized to 1.

To calibrate the exit rate of varieties δ, we take the year 2013 and the 4,266 households present in the KNCP continuously from 2004 though 2014 (11 years). We identify all varieties purchased in the first quarter of 2013 that were never purchased by the household in any of the previous 36 quarters. We interpret these varieties as newly added to the consideration set and compute the average quarterly share of expenditure on these varieties in any of the subsequent seven quarters, through the fourth quarter of 2014. In steady state this share, for $\tau = 1, 2, ...7$, is equal to

$$A^F(\tau) = \frac{(1-\delta)^\tau \bar{\Lambda}}{\bar{\mu}}\frac{\bar{e}-\bar{x}}{\bar{e}}, \tag{41}$$

which implies that $\delta = 1 - [A^F(7)/A^F(3)]^{1/4}$. We focus on the time horizon $\tau = 3$ and $\tau = 7$ to control for possible seasonal effects on expenditure. The data indicate that $A^F(3) = 0.0166$ and $A^F(7) = 0.0128$, which yields $\delta = 0.063$.

To calibrate the remaining parameters, first we estimate the share of adoption expenditure, $\bar{x}/\bar{e}$. For this purpose we calculate $A^R(\tau)$, equal to the average quarterly share

Table 5: Baseline calibration

Model		Data	
Parameter	Value	Moment	Value
$\bar{e}$	1	Steady state expenditure	1
ρ	0.01	Quarterly real interest rate	1%
γ	1	Elasticity of inter-temporal substitution	1
δ	0.063	Yearly attrition rate of adopted varieties, $A^F(7)/A^F(3)$	0.23
ψ	0.35	Yearly gross additions, $A^R(4)$ (rate)	0.30
$\bar{\lambda}$	0.713	Quarterly additions, $A^R(1)$ (rate)	0.49
κ	10.03	Robust additions, $A^R(36)$, on average (rate)	0.150
σ	5.50	Robust additions, $A^R(36)$, in the first quintile (rate)	0.172
α	6.00	Robust additions, $A^R(36)$ in median quintile (rate)	0.153
χ	0.165	Robust additions, $A^R(36)$ in the fifth quintile (rate)	0.125

of expenditure in 2013 on varieties never purchased in any of the previous $\tau = 1, 2, ...36$ quarters. $A^R(\tau)$ is plotted in Figure 3 as a solid blue line. In steady state, we have that

$$A^R(\tau) = \int_0^1 \sum_{v \in \Omega_{jt}} q_{\nu jt} \times \mathbb{I}\left(\sum_{i=1}^{\tau} q_{\nu jt-i} = 0\right) dj, \tag{42}$$

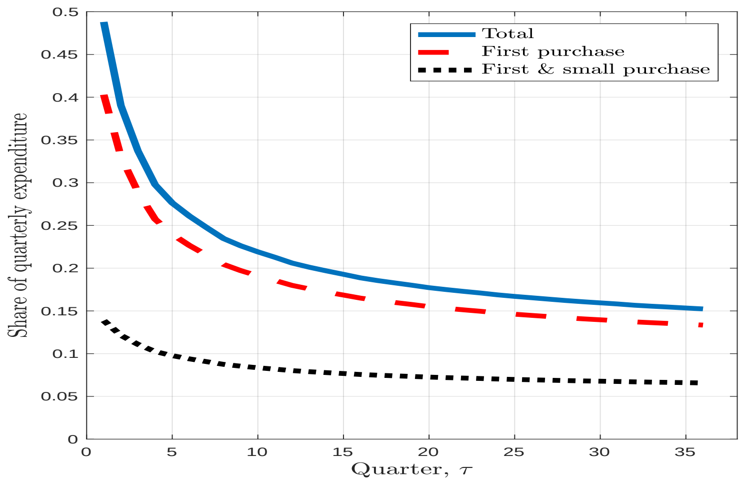
which is decreasing in τ and converges to

$$\lim_{\tau \to \infty} A^R(\tau) = \frac{\bar{x} + \delta(\bar{e} - \bar{x})}{\bar{e}}, \tag{43}$$

equal to the sum of adoption expenditure (the first term) and true additions (the second term). Using $\bar{e} = 1$, our estimate of δ, and $\lim_{\tau \to \infty} A^R(\tau) \approx 0.15$ we infer $\bar{x} = 0.093$.[12]

[12] As a validation, in Figure 3 we report two more refined versions of $A^R(\tau)$. In the first we consider only first purchases of the variety, dropping all subsequent purchases in the quarter (dashed red line). In the second we further require that the first purchase be for the minimum quantity available in the market (dotted black line). These two statistics are less contaminated by true additions and measure $\bar{x}/\bar{e}$ more directly. Since the minimum quantity required to experiment with a variety might be larger than the minimum available in the market, the black line provides a lower bound estimate for $\bar{x}/\bar{e}$. Since some first purchases might not reflect true experimentation, the dashed red line is an upper bound estimate for $\bar{x}/\bar{e}$. The resulting range for $\bar{x}/\bar{e}$ is 7-13%, with our estimate falling exactly in the middle.

Figure 3: Robust additions for different time windows, $A^R(\tau)$



The solid blue line plots the share of expenditure on additions of varieties never purchased in any of the previous τ quarters, $A^R(\tau)$, with τ on the x-axis. $A^R(\tau)$ is calculated as the average over the 4 quarters in 2013 using the sample of households continuously present in the KNPC since 2004. The dashed red line calculates $A^R(\tau)$ by considering only first purchases of the variety, dropping all subsequent purchases in the quarter. The dotted black line calculates $A^R(\tau)$ by further requiring that the first purchase be for the minimum quantity available in the market, defined as smaller than or equal to the bottom decile of the quantities of the variety purchased in 2013.

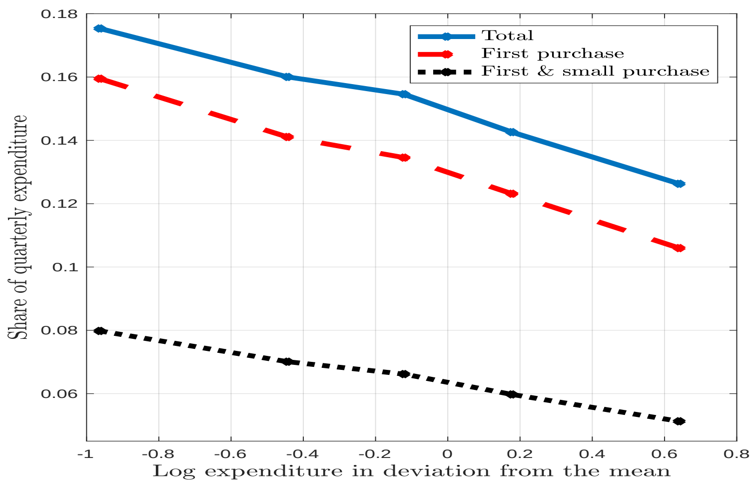
The parameter governing the persistence of preference shocks ψ is calibrated jointly with the average number of varieties in the consideration set of a sector $\bar{\mu}$. We target quarterly additions, $A^R(1) = 0.48$, and $A^R(4) = 0.3$ (see Figure 3), which yield a system of two equations in the two unknowns ψ and $\bar{\mu}$: the rate of decay of $A^R(\tau)$ identifies ψ, while $A^R(1)$ identifies $\bar{\mu}$, since a higher $\bar{\mu}$ implies more false additions and hence more additions, see (38). Solving the system we obtain $\psi = 0.35$ and $\bar{\mu} = 3$.

We assume that the Poisson arrival rate $\Lambda_t(x)$ has the following functional form

$$\Lambda_t(x) = e^{\lambda_t} x \left[1 - \frac{1}{1+\alpha} \left(\frac{x}{\chi} \right)^{\alpha} \right], \tag{44}$$

where λ_t characterizes the efficiency of the household's adoption technology, equal to $\bar{\lambda}$ in steady state, $\alpha \geq 0$ determines possible decreasing returns to adoption expenditure and $\chi \geq 0$ is the maximum efficient level of adoption expenditure—i.e. $\Lambda_t(x)$ reaches its maximum at $x = \chi$. The parameters α and χ determine how the elasticity of $\Lambda_t(x)$ to x varies as a function of x: a larger α (or a smaller χ) makes the elasticity decrease faster as x increases. The elasticity of $\Lambda_t(x)$ to x enters (33), and together with the Fréchet parameter κ and the parameter governing the elasticity of substitution across sectors σ, it determines how fast the ratio $\bar{x}/\bar{e}$ falls when steady state expenditure $\bar{e}$ increases. To obtain variation in $\bar{e}$ we consider households in different quintiles of the distribution of total expenditure in 2013 and evaluate $A^R(36)$ at each quintile, which indirectly measures the corresponding $\bar{x}/\bar{e}$ ratio, see (43). The solid blue line in Figure 4 plots the value of $A^R(36)$ for the five groups of households with their corresponding (logged) expenditure on the x-axis.[13] As the model predicts, $A^R(36)$ is decreasing in expenditure $\bar{e}$, indicating that wealthier households devote a smaller share of their expenditure to adoption. We calibrate $\bar{\lambda}$, α, χ, κ and σ to match $\bar{\Lambda} = \delta\,\bar{\mu} = 0.189$, which follows from (25) evaluated in steady state, and the values of $A^R(36)$ corresponding to the mean, bottom, median, and top quintiles of the distribution of household expenditure. For the average household, the resulting elasticity of $\Lambda_t(x)$ with respect to x is close to 1 (97 percent).

Figure 4: Adoption over total expenditure as a function of total expenditure



The solid blue line plots $A^R(36)$ for households in different quintiles of the distribution of total expenditure in 2013 as a function of their logged average expenditure, in deviation from the logged average expenditure in the sample. The dashed red line corresponds to $A^R(36)$ calculated summing only the first purchases by the household in the reference quarter. The dotted black line corresponds to $A^R(36)$ summing only first purchases for the minimum quantity available in the market.

6.2 Recovering adoption expenditure

The household chooses adoption expenditure x_t conditional on total expenditure e_t, which makes it possible to recover the in-sample profile of x_t using full information maximum likelihood estimation. The estimation is robust to the nature of the aggregate shocks that drive total expenditure and to changes in firms' mark-ups. We assume that the household's adoption technology λ_t in (44) evolves as an AR(1) process: $\lambda_t = \bar{\lambda} + \varrho_\lambda \left(\lambda_{t-1} - \bar{\lambda}\right) +$

[13]Figure 4 also plots the value of $A^R(36)$ obtained summing only first purchases (i.e. excluding all subsequent purchases in the quarter) as a dashed red line, and first purchases that are for the minimum quantity available in the market as a dotted black line. As observed in footnote 12, the two lines yield an upper and a lower bound estimate for the corresponding $\bar{x}/\bar{e}$ ratio.

ϵ_t^λ. Logged total expenditure generally 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. 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 endogenously, the shocks ϵ_t^e and ϵ_t^λ have correlation $\vartheta_{e\,\lambda}$ possibly different from zero. We log-linearize (31), (35), (38) and (39) and then use the Kalman filter to evaluate the likelihood function of quarterly net additions and logged total expenditure over the sample period 2007:Q1-2014:Q4 (see the Appendix for details). We convert the series into real value using the personal consumption price deflator from Bureau of Economic Analysis (BEA) and correct for the negative bias in the trend of expenditure relative to the BEA data.[14] In writing the likelihood function we take net additions as four-quarter moving averages. Based on an Akaike information criterion, we model (logged) expenditure as an AR(1) process with serial correlation ϱ_e. Given the parameter values of Table 5, we maximize the likelihood function with respect to both 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 6 reports the estimated parameters with the associated standard errors.[15] The

Table 6: Parameter estimates

	ϱ_e	ϑ_e	ϱ_λ	ϑ_λ	$\vartheta_{e\,\lambda}$
ML estimates	0.80	0.013	0.20	0.010	-0.02
Standard errors	0.08	0.002	0.24	0.0019	0.22

The table reports the Maximum Likelihood estimates and standard errors of the parameters $\{\varrho_e, \vartheta_e, \varrho_\lambda, \vartheta_\lambda, \vartheta_{e\,\lambda}\}$ for the stochastic processes of (logged) total expenditure, $\ln e_t$, and the adoption technology, λ_t. The likelihood function is calculated using the Kalman filter. The sample period is 2007:Q1-2014:Q4. Observables are net additions, N_t, and logged expenditure, $\ln e_t$, both in real value, see the Appendix for details.

[14]In the model net additions and expenditure are in real value (measured in units of varieties). The series in the data are converted into real value using the household personal consumption deflator for expenditure on food and beverages from BEA (Mnemonic DFXARG3Q086SBEA). To account for the negative bias in the average growth rate of expenditure in the KNCP, we rescale its growth rate by a constant factor so as to match the overall increase of personal consumption expenditure from BEA (Mnemonic DFXARC1Q027SBEA) over the corresponding period. 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 (see the Appendix for details).

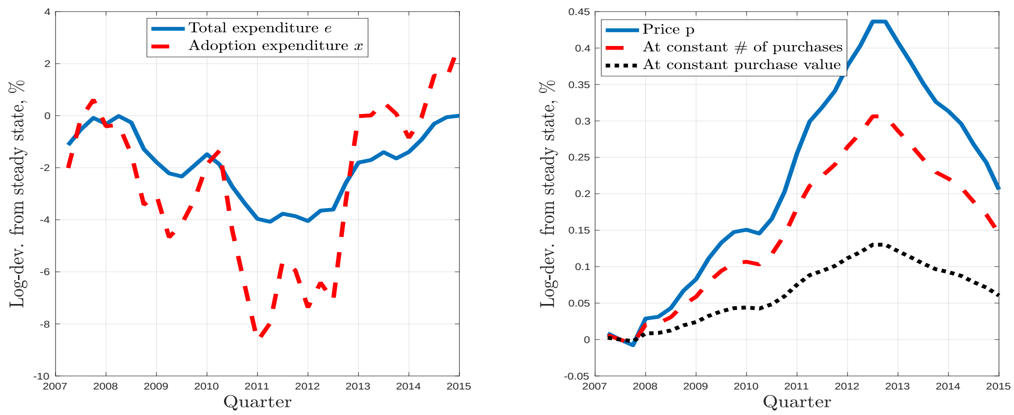
[15]The initial unobserved states of the system are not statistically different from their steady state value; for brevity, they are not reported here.

correlation between total expenditure and the adoption technology, $\vartheta_{e\lambda}$, is estimated to be slightly negative in line with the thesis that households' search intensity is countercyclical (Coibion et al. 2015, Nevo and Wong 2019, and Kaplan and Menzio 2016). In-sample (logged) adoption expenditures are recovered using a standard Kalman smoothing algorithm. The resulting time series for $\ln x_t$ corresponds to the dashed red line in panel (a) of Figure 5, which also plots (logged) total expenditure $\ln e_t$ (solid blue line). The two series have a positive correlation of 91 percent. Adoption expenditure is around two-and-a-half times as volatile as total expenditure (see also Table 8). 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 40 basis points relative to its steady state value (see the solid blue line in panel (b) of Figure 5). Changes in p_t are not reflected in the official aggregate inflation statistics, which therefore tend to underpredict true welfare-relevant inflation by around 15 basis points per year in the period of the Great Recession. To see what drives this inflation bias, we use (23) to write

$$\ln p_t - \ln \bar{p} = -\frac{1}{\sigma - 1} \ln\left(1 - f(0; \mu_t)\right) - \frac{1}{\sigma - 1} \ln\left(E\left[n^{\frac{\sigma-1}{\kappa}} | n > 0\right]\right).$$

The first term on the right-hand side (dotted black line in panel (b) of Figure 5) measures fluctuations in p_t due to changes in the number of varieties purchased by the household. The second term (dashed red line) measures the average value of each purchase. Around two thirds of the increase in p_t is due to changes in the average value of a purchase.

Figure 5: Adoption expenditure and the household price index



(a) Adoption vs total expenditure **(b) Household price index**

7 Empirical properties of the model

Here we analyze how well the model matches the response of consumption expenditure to the 2008 ESP, as observed in Section 3. We then compare the cyclical properties of net and gross additions in the model with those reported in Section 2.

7.1 Response to the ESP

In the household's problem in (30), we take the response of total expenditure to the ESP as given and compare the model responses of net, gross and persistent additions with the estimates given in Tables 3 and 4. ESP is modeled as an unexpected one-period increase of 4.72% in logged total expenditure, equivalent to the simple average of β_{-1}, β_0 and β_1 in column 1 of Table 3. The household's problem in (30) is solved using global (non-linear) methods with the parameter values of Table 5. We simulate the consumption histories of 10,000 households, initially in a steady state with constant expenditure, over six years (24 quarters). 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 7 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. In response to the increase in

Table 7: 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
Model	4.72	2.91	1.81	2.06	1.07

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. 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.

expenditure, adoption expenditure x_t increases first because varieties are generally more valuable (due to a scale effect) and secondly because the increase in x_t persistently reduces the household price index p_t (which enables the household to smooth consumption better). Consequently, net, gross, and persistent additions all increase on impact, roughly in line with the data. The model slightly underpredicts the response of net and gross additions at 1.81% and 2.06%, as against 1.92% and 2.51%, respectively, in the data.

7.2 Business cycle properties

After estimating the model over the cycle, we apply the Kalman smoothing algorithm to recover the in-sample profile of the adoption technology 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 series are logged and expressed in real value. Table 8 reports standard deviations and correlations with total expenditure e_t (again in logs). The third row also reports the fraction of the variance of the corresponding variable that is explained by fluctuations in expenditure alone; that is after setting all shocks to the adoption technology to zero, $\epsilon_t^\lambda = 0, \forall t$. As noted, x_t is strongly pro-cyclical and three times as volatile as e_t. As a result, $\Lambda_t(x_t)$ and μ_t are also pro-cyclical, implying that $p_t = p(\mu_t)$ is counter-cyclical. Since households use adoption expenditure to smooth consumption, c_t is 4 percent less volatile than e_t. The adoption technology λ_t is counter-cyclical, consistent with households' search intensity being counter-cyclical, but its volatility is low. This is confirmed by the fact that fluctuations in total expenditure e_t account for most of the volatility of the variables, with λ_t attenuating the fluctuations of x_t, c_t, p_t, and μ_t only marginally.

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	0.31	3.19	1.30	0.13	1.08	3.09
Correlation with e_t	1.00	-0.23	0.91	0.98	-0.53	0.53	0.90
Standard Deviation if $\lambda_t = \bar{\lambda}$	1.37	0.00	3.22	1.33	0.15	1.24	3.13

Variables in columns are obtained as in-sample estimates (period 2007:Q1-2014:Q4) using the Kalman smoothing algorithm discussed in Section 6.2. They are in logs, expressed in real value, and calculated as 4-quarter moving averages. Standard deviations are expressed in percentage units.

We calculate the intensive margin I_t, net additions N_t, and gross additions A_t using (38)-(40). The series are then converted into nominal value using the consumption price deflator from BEA and expressed as 4-quarter moving averages. Table 9 reports their standard deviations and t β-coefficients, which are the model's counterparts of the empirical estimates in panel (b) of Table 1. The model matches the cyclical properties of the data on net and gross additions reasonably well. The contributions of net and gross additions to changes in expenditure are respectively 56 and 51 percent in the model, compared with 57 and 58 percent in the data. Fluctuations in adoption expenditure contribute substantially to the relatively good fit of the model. This can be seen in columns 3-6 in Table 9, which report the standard deviations and β-coefficients of the three terms that represent additions A_t in (38): adoption expenditure, true additions, and false additions. The sum of adoption expenditure and true additions, which are driven by fluctuations in adoption expenditure, accounts for more than a third of the overall contribution of additions to the cyclical volatility of total expenditure.

Table 9: Cyclical contribution of additions and removals

	I_t	N_t	A_t	$A_t^{adoption}$	A_t^{true}	A_t^{false}
Standard deviation (%)	0.29	0.36	0.39	0.19	0.18	0.33
β-Decomposition, β_X	0.44	0.56	0.51	0.09	0.10	0.32

Variables in columns are obtained as in-sample estimates (period 2007:Q1-2014:Q4) using the Kalman smoothing algorithm discussed in Section 6.2. They are 4-quarter moving averages converted into nominal value using the deflator of household personal consumption expenditure from BEA (Mnemonic DFXARG3Q086SBEA); see the Appendix for details. "β-Decomposition" is the OLS estimated coefficient β_X from regressing the variable in column, $X_t = I_t, N_t, A_t, A_t^{adoption}, A_t^{true}, A_t^{false}$, against the percentage change in (nominal) expenditure ΔE_t: $X_t = \alpha_X + \beta_X \, \Delta E_t + \epsilon$.

8 General equilibrium

We now assume that the household is representative of the economy, which consists of a measure 1 of households who have identical financial wealth b_t, are subject to the same factor prices w_t and ι_t, have 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 embed the representative household in a general equilibrium model with endogenous innovation and quantify the contribution of fluctuations in adoption expenditure to the volatility of the demand for new varieties. Then we study the implications for policies of aggregate demand stabilization. Table 10 gives the values of the additional parameters introduced in the analysis.

8.1 The demand for new varieties

We assume that discovering a new variety costs $\xi > 0$, that a variety discovered at t is first on sale at $t + 1$ and that in every period thereafter the variety exits the market with probability δ_f. Due to the existence of a competitive fringe of producers, firms set a limit price equal to a constant markup $1/\phi$ over the marginal cost of production with $\phi \in (0, 1)$. Given our choice for the numeraire (i.e. the price of a variety is 1), ϕ is equal to the

Table 10: **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, $d = wl_d$, over total expenditure, e	0.05
ϕ	0.93	Mass of varieties at initial steady state, $\bar{v}$	1
ϵ_0	1	Steady state expenditure, e	1
ϵ_1	1/3	Frisch elasticity of labor supply	3
ω	0.91	Micro estimates of firm R&D spill-overs	0.91
$\bar{g}$	0.63	Government expenditure as a share of GDP	0.37

marginal cost. Under free entry in the R&D sector it must be that

$$\Pi_t = \xi, \tag{45}$$

where Π_t is the expected present value of profits from a new variety at t, equal to

$$\Pi_t = (1-\phi)\,\mathbb{E}_t\left[\sum_{j=1}^{\infty}(1-\delta_f)^{j-1}\rho_{t,t+j}\left(\frac{e_{t+j}-x_{t+j}}{\mu_{t+j}}m_{t,t+j}+\frac{x_{t+j}}{v_{t+j-1}}\right)\right]. \tag{46}$$

In the expression, $1-\phi$ are the profits per unit of the variety sold, while

$$\rho_{t,t+j} = \rho^j \frac{p_t}{p_{t+j}}\frac{u'(c_{t+j})}{u'(c_t)} \tag{47}$$

is the household's discount factor for income in period $t+j$, which materializes with probability $(1-\delta_f)^{j-1}$. The last parenthesis of (46) expresses the (gross) income from the variety at time $t+j$ as 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 spend $(e_{t+j}-x_{t+j})/\mu_{t+i}$ on it (in expected value). Second, the variety earns x_{t+j}/v_{t+i-1} as the result of household experimentation. The customers of the variety at $t+j$ are equal to

$$m_{t,t+j} = \sum_{i=1}^{j}(1-\delta_p)^{j-i}\frac{\Lambda_{t+i}(x_{t+i})}{v_{t-1+i}}, \quad \forall j \geq 1 \tag{48}$$

since at each time $t+i$, $\forall i \leq j$, the firm obtains $\Lambda_{t+i}(x_{t+i})/v_{t+i-1}$ new customers, increasing the number of customers at $t+j$ in proportion $(1-\delta_p)^{j-i}$.

Let $\mathbf{h_t} = \{h_0, h_1, ...h_{t-1}, h_t, \mathbb{E}_t(h_{t+1}), \mathbb{E}_t(h_{t+2}) .....\}$ (written in bold) denote the past and future expected history of variable $h = e, \rho, \lambda, x$ (in logs) given the information available at time t. We normalize the steady state number of varieties to one, log-linearize the free-entry condition in (45) and invert it to obtain the following expression for the logged number of varieties in the market at $t+1$

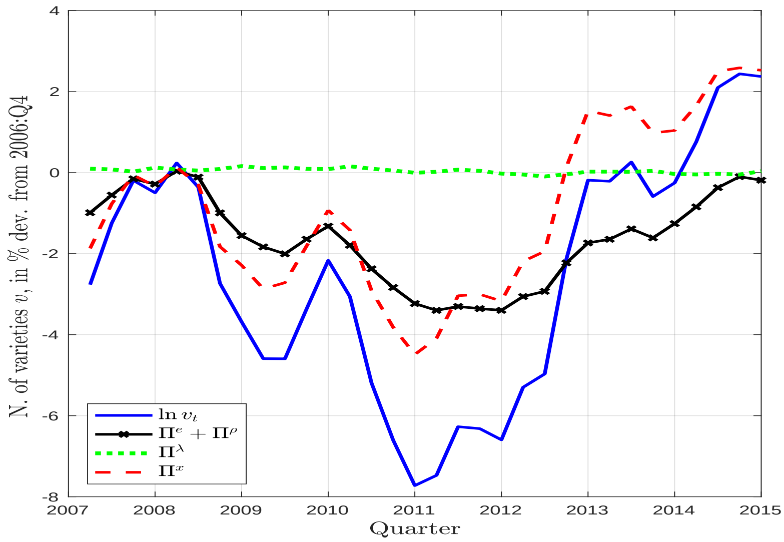
$$\ln v_t = \Pi^e(\mathbf{e_t}) + \Pi^\rho(\boldsymbol{\rho}_\mathbf{t}) + \Pi^\lambda(\boldsymbol{\lambda}_\mathbf{t}) + \Pi^x(\mathbf{x_t}), \tag{49}$$

where the functions $\Pi^h(\mathbf{h_t})\ \forall\ h = e, \rho, \lambda, x$, formally defined in the Appendix, are independent of the firm's cost ξ and the firm's mark-up ϕ. Intuitively, the right-hand side of (49) characterizes *household demand for new varieties*: how the present value of the income produced by a new variety at t is affected by the entire expected history of the household's total expenditure $\mathbf{e_t}$, household's discount factor, $\boldsymbol{\rho}_\mathbf{t}$, household's adoption technology $\boldsymbol{\lambda}_\mathbf{t}$, and household's adoption expenditure $\mathbf{x_t}$. Given an increase in the value of a new variety, v_t increases to make the free entry condition in (45) identically satisfied. The value of a new variety may increase for four reasons. First, it could follow from an increase in total expenditure $\mathbf{e}_t$, which is a scale effect measured by $\Pi^e(\mathbf{e_t})$. Second, it could reflect a reduction in the opportunity cost of the R&D investment, which is measured by $\Pi^\rho(\boldsymbol{\rho}_\mathbf{t})$. Third, it could be due to an improvement in the adoption technology λ_t, enabling the firm to accumulate customers $m_{t,t+j}$ more rapidly but also heightening competition, since with higher λ households ultimately have more varieties in their consideration set (μ_t increases), whose combined effect is measured by $\Pi^\lambda(\boldsymbol{\lambda}_\mathbf{t})$. And fourth, adoption expenditure $\mathbf{x_t}$ increases the value of a new variety through three channels: one is the direct impact on income through household experimentation, the other two are analogous to those resulting from changes in λ_t—with higher x the firm obtains customers more rapidly but at the same time μ_t also increases, which intensifies the competition for customers. The combined effect of these three channels is measured by $\Pi^x(\mathbf{x_t})$.

We set $\delta_f = 0.05$ (corresponding to the average attrition rate of varieties in the KNPC) and $\delta_p = 1 - (1-\delta)/(1-\delta_f)$, keeping all the other parameters values as in Table 5. For each t over the period 2007:Q1-2014:Q4 and for each $h = e, \rho, \lambda, x$, we calculate the sequence $\mathbf{h_t}$ using the state space representation of the household's problem previously estimated. Given the sequence $\mathbf{h_t}$ we calculate $\Pi^h(\mathbf{h_t})$. Figure 6 plots the in-sample time series profile of $\Pi^h(\mathbf{h_t})\ \forall\ h = e, \rho, \lambda, x$. For convenience we group together the components due to $\mathbf{e_t}$ and $\boldsymbol{\rho}_\mathbf{t}$ (solid black line), which are the typical determinants of household demand in models that ignore household adoption of varieties. Households' demand for new varieties was 7.7%

lower in 2010 than in 2006. This compares well with the observed fall in the number of varieties available in the market in 2010, which according to the Kilts Nielsen retail scanner (KNRS) data was 8 percent below its linear trend. The standard deviation of additions on newly introduced varieties into the market is about 23 percent of its mean compared with 20 percent in the data. The model overpredicts by three percentage points the contribution of additions on newly introduced varieties to fluctuations in expenditure, as measured by the corresponding β-coefficient. Fluctuations in adoption expenditure (dashed red line) account for more than half of the fluctuation in household demand for new varieties. This is because, if they are to sell their products, new firms need customers, who can be acquired only if households are willing to bring new varieties into their consumption basket.

Figure 6: Determinants of the demand for new products



To quantify the relevance of the different components more formally, we regress (using OLS) $\Pi^h(\mathbf{h_t})$ against $\ln v_t$. This β-coefficient measures the contribution of variable $h = e, \rho, \lambda, x$ to the fluctuation in household demand for new varieties. According to this metric, fluctuations in adoption expenditure account for 67 percent of the volatility of household demand. Changes in the household discount factor ρ account for 24 percent, and fluctuations in total expenditure for the remaining 9 percent. The effect of changes in the adoption technology is negative but negligible (less than 0.5 percent).

8.2 Stabilization policies

We now solve for the general equilibrium of the model by specifying the production side of the economy, which determines households' wealth b_t, income w_t and ι_t and, through (26) and (27), total expenditure e_t, leaving the household's problem in (30) unchanged. The model is specified so that the free-entry condition in (45) remains satisfied with Π_t as in (46).

The output amount of variety $(j, v) \in \mathcal{V}_t$ satisfies

$$q_{\nu jt} = \zeta_t \, v_{t-1}^{\omega} \, l_{\nu jt}, \tag{50}$$

where $l_{\nu jt}$ is labor input, while ζ_t is a technology shock evolving as $\ln \zeta_t = \varrho_\zeta \ln \zeta_{t-1} + \epsilon_t^{\zeta}$.[16] Labor productivity in (50) increases with the number of varieties v_{t-1}, with $\omega \in [0, 1]$, which builds on Romer (1990) where v_{t-1} enhances labor productivity by allowing greater division of labor.[17] Since the labor market is competitive, (50) implies that

$$w_t = \phi \, \zeta_t \, v_{t-1}^{\omega}. \tag{51}$$

As in Romer (1990) and Bilbiie et al. (2012), R&D is labor intensive: l_{dt} labor units in R&D yield $\frac{\phi}{\xi} \zeta_t \, v_{t-1}^{\omega} \, l_{dt}$ new varieties. Given (51), $\xi > 0$ is the cost of a new variety, which justifies the free-entry condition in (45). The number of varieties evolves according to

$$v_t = (1 - \delta_f) \, v_{t-1} + \frac{d_t}{\xi}, \tag{52}$$

where $d_t = w_t l_{dt}$ denotes R&D expenditure. Financial markets are modeled as a mutual fund that owns all firms in the economy and issues one-period assets whose return is such that the fund breaks even $\forall t$.[18] Clearing of the financial markets implies that $\forall t$

$$\iota_t b_t - b_{t+1} = (1 - \phi) \, e_t - d_t, \tag{53}$$

which equates the fund's time-t disbursements to firms' realized profits. Labor market clearing implies that the aggregate labor supply is given by ℓ_t in (28), evaluated at w_t in (51). The aggregate resource constraint equates net output to its uses

$$\zeta_t \, v_{t-1}^{\omega} \, (\ell_t - l_{dt}) = e_t + g_t,$$

where g_t denotes government purchases of goods, which we assume are fully wasted and allocated uniformly to all the varieties in the market at t. The government budget is always

[16] The technology shock ζ_t plays no role in the analysis below. It is introduced simply in order to allow for some exogenous variation in total expenditure.

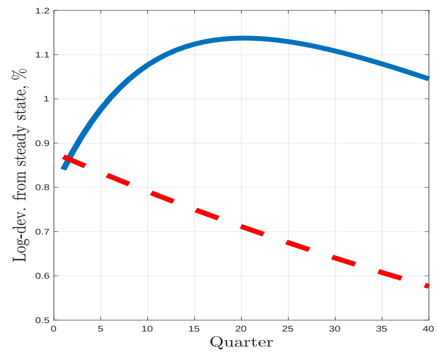
[17] Greater product variety could also allow firms to offer a more specialized product to existing customers, which would increase quality adjusted output. Under this alternative interpretation, the quality adjusted unit price of a variety would also increase.

[18] This is without loss of generality: there are no financial frictions in the economy, so the Modigliani-Miller theorem implies that the value of the fund is independent of how it is financed.

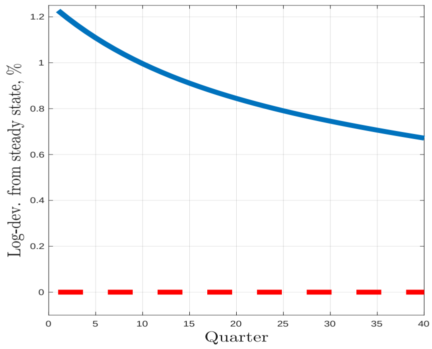
balanced, and to guarantee that (46) and (53) hold we posit a value added tax of $1-\phi$ on firms selling products to the government, which implies that τ_t in (26) is such that $\tau_t = \phi\, g_t$.

We study the response of the economy, initially in a steady state with $\bar{e} = 1$, to a tax rebate shock modeled as an unexpected one-period reduction in τ_t needed to finance an increase in g_t from its steady state value $\overline{g}$. 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 cost of a new variety ξ matches a ratio of R&D expenditure to total expenditure of 5 percent, while ϕ is such that (45) is satisfied in steady state with $v = 1$. To calibrate R&D spillovers we use the evidence presented in Table 5 of Colino (2017) to set $\omega = 0.91$. The tax rebate shock is $\epsilon_t^g = 0.045$ in line with the calibration of the ESP in Section 7.1; $\overline{g}$ is equal to 37% of net output. The solid blue lines in Figure 7 show the responses to the tax rebate shock of consumption $\ln c_t$ (panel a), adoption expenditure $\ln x_t$ (panel b), the price index $\ln p_t$ (panel c) and the mass of varieties $\ln v_t$ (panel d). The dashed red lines correspond to the responses in a counterfactual economy

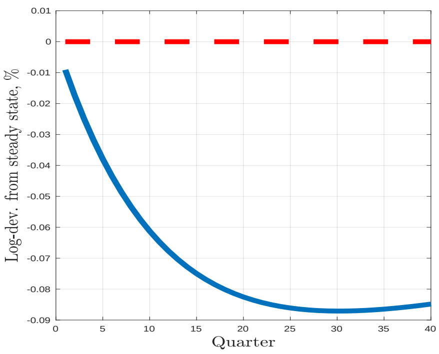
Figure 7: Economy response to a tax transfer



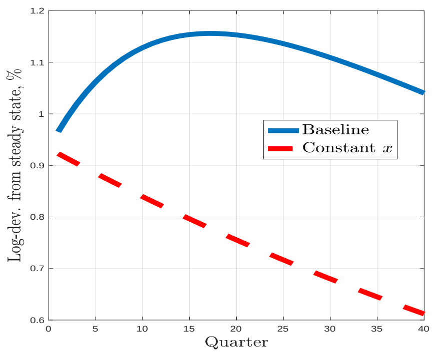
(a) Consumption



(b) Adoption expenditure



(c) Household price index



(d) Number of varieties

Impulse responses to a one-period tax transfer τ_t corresponding to 4.5% of steady state expenditure. The solid blue lines correspond to the model, the dashed red lines to the counterfactual with constant adoption expenditure.

where adoption expenditure remain unchanged at the steady state value. The cumulated increase of consumption in response to the tax rebate is around twice as great in our model as in the counterfactual economy with exogenously fixed adoption expenditure. This amplification has two causes. First, more adoption expenditure lowers the welfare-relevant household price (p_t falls), which increases consumption for a given volume of expenditure. Second, the increase in adoption expenditure pushes up the value of a new product Π_t in (46), which stimulates innovation, causing an increase in v_t almost two times larger in our model than in the counterfactual. This suggests that household adoption of varieties is a powerful amplification mechanism of shocks, especially when evaluating their long-run welfare effects.

9 Conclusions

We have shown that household adoption of new varieties in the consumption basket is procyclical. 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. Fluctuations in household adoption are a prime determinant of the aggregate demand for innovation and amplify the long-run welfare effect of shocks, including aggregate demand stabilization measures. Our model can be extended along several dimensions. 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 the Appendix, 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. Let us briefly discuss a few of them here. 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. In our view, some effort should also be devoted to understanding the welfare consequences of stabilization policies. Barlevy (2007) has emphasized that R&D tends to be inefficiently low in recessions, because the market value of new products is strongly pro-cyclical, while its social value, given intertemporal technological spill-overs, is relatively acyclical. The strong pro-cyclicality of household adoption expenditure is likely to exacerbate the disparity between social and private value in recessions, which might provide an alternative to sticky price models in justifying aggregate demand stabilization policies. The optimal design of these policies might also depend on how households' propensity to adopt new varieties responds to income shocks. Household adoption might also have interesting implications for growth models and the study of cross-country income disparities. So far the growth literature has focused on firms' incentive to innovate and somewhat neglected the aggregate demand for innovation, which is powerfully affected by household adoption of new product varieties. There could well be international differences in households' propensity to adopt new varieties, helping to explain some cross-country differences in welfare-relevant measures of GDP.

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APPENDIX

A Proofs

This section contains the proofs of all results stated in the paper.

Proof of Proposition 1. Let

$$\hat{z}_{jt} \equiv \max_{i \in \Omega_{jt}} \{z_{\nu jt}\} \tag{A1}$$

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

$$q_{jt} = c_t \left(\hat{z}_{jt}\right)^{\sigma-1} \theta_t{}^{-\sigma}, \tag{A2}$$

where θ_t is the Lagrange multiplier on the budget constraint (22). By integrating (A2) over j and after using (22), we obtain

$$\theta_t^{\sigma} = \frac{c_t}{v_t} \int_0^1 (\hat{z}_{jt})^{\sigma-1} dj, \tag{A3}$$

which can be substituted into (A2). The resulting expression is then substituted in (21) to yield:

$$c_t = v_t \left[\int_0^1 \left(\hat{z}_{jt}\right)^{\sigma-1} \, dj \right]^{\frac{1}{\sigma-1}}. \tag{A4}$$

Since the price index p_t should necessarily satisfy the identity $p_t c_t = s_t$, (A4) immediately implies that

$$p_t = \left(\int_0^1 \left(\hat{z}_{jt}\right)^{\sigma-1} \, dj \right)^{-\frac{1}{\sigma-1}}. \tag{A5}$$

To calculate (A5), 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

$$p_t = \left\{ \sum_{n=0}^{\infty} E[(\hat{z}_{jt})^{\sigma-1} \Big| \, n_{jt} = n] f(n;\mu_t) \right\}^{-\frac{1}{\sigma-1}}. \tag{A6}$$

To evaluate (A6), notice that the $z_{\nu jt}$'s in (A1) 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

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

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

$$E[(\hat{z}_{jt})^{\sigma-1} \Big| n_{jt} = n] = n^{\frac{\sigma-1}{\kappa}} \Gamma\left(1 - \frac{\sigma-1}{\kappa}\right), \tag{A7}$$

which can be substituted into (A6) to yield (23).

After substituting (A3) into (A2), 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 (A7). ■

Proof of Lemma 1. We prove that the number of varieties in the consideration set of the household 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 λx_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 of the household. 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 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

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

which concludes the proof. ■

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

$$W(\boldsymbol{\omega}, b, \mu_{-1}) = \max_{\{e,b',x\}} \left\{ u\left(\frac{e-x}{p(\mu)}\right) - \varepsilon\left(\ell\right) + \rho \mathbb{E}_{\boldsymbol{\omega}}\left[W(\boldsymbol{\omega'}, b', \mu)\right] \right\} \tag{A8}$$

s.t.

$$e + b' = w\,\ell + \iota\, b_t - \tau, \tag{A9}$$

$$\mu = (1-\delta)\,\mu_{-1} + \lambda x, \tag{A10}$$

$$p(\mu) = \left[\Gamma\left(1 - \frac{\sigma-1}{\kappa}\right) \sum_{n=0}^{\infty} n^{\frac{\sigma-1}{\kappa}} \frac{\mu^n e^{-\mu}}{n!}\right]^{-\frac{1}{\sigma-1}}. \tag{A11}$$

where the function $p(\mu)$ in (32) is obtained by combining (23) with Lemma (1), while the law of motion of the average number of varieties in the household consideration set, μ_t, in (31) comes from (25). The first order condition with respect to x in (A76) reads as follows:

$$-\frac{u'\left(c\right)}{p(\mu)} - \frac{u'(c)c}{\left[p(\mu)\right]^2} p'(\mu)\Lambda_t'(x) + \rho\Lambda_t'(x)\mathbb{E}_{\mathbf{e}}\left[W_3(\boldsymbol{\omega'}, b', \mu)\right] = 0$$

which can be rearranged to obtain

$$\frac{u'\left(c_t\right)}{p(\mu_t)} = \left\{ -\frac{u'(c_t)c_t p'(\mu_t)}{\left[p(\mu_t)\right]^2} + \rho\mathbb{E}_t\left[W_3(\boldsymbol{\omega}_{t+1}, b_{t+1}, \mu_t)\right] \right\} \Lambda_t'(x_t) \tag{A12}$$

where we adopted the notation $\mathbb{E}_t \equiv \mathbb{E}_{\mathbf{e}_t}$. The envelope condition with respect to u_{-1} yields

$$W_3(\boldsymbol{\omega}_t, b_t, \mu_{t-1}) = \left\{ -\frac{u'(c_t)c_t p'(\mu_t)}{\left[p(\mu_t)\right]^2} + \rho\mathbb{E}_t\left[W_3(\boldsymbol{\omega}_{t+1}, b_{t+1}, \mu_t)\right] \right\} (1-\delta),$$

which after using (A17) can be expressed as follows:

$$W_3(\boldsymbol{\omega}_t, b_t, \mu_{t-1}) = \frac{u'\left(c_t\right)}{p(\mu_t)} \frac{(1-\delta)}{\Lambda_t'(x_t)} \tag{A13}$$

After substituting (A13) into (A17) we obtain

$$\frac{u'\left(c_t\right)}{p(\mu_t)} = \left\{-\frac{u'(c_t)c_t p'(\mu_t)}{[p(\mu_t)]^2} + \rho\mathbb{E}_t\left[\frac{u'\left(c_{t+1}\right)}{p(\mu_{t+1})}\frac{(1-\delta)}{\Lambda'_{t+1}(x_{t+1})}\right]\right\}\Lambda'_t(x_t)$$

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

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

which eventually yields

$$1 = \frac{c_t\eta(\mu_t)}{\mu_t}\Lambda'_t(x_t) + (1-\delta)\mathbb{E}_t\left[\rho_{t,t+1}\frac{\Lambda'_t(x_t)}{\Lambda'_{t+1}(x_{t+1})}\right] \tag{A14}$$

where

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

and

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

(A14) corresponds to (33) in the main text. Finally the problem in (A76) is characterized by the first ordercondition for labor supply

$$\varepsilon'\left(\ell_t\right) = u'\left(c_t\right)w_t \tag{A15}$$

and the Euler Equation for consumption

$$\frac{u'\left(c_t\right)}{p(\mu_t)} = \rho\mathbb{E}_t\left[\iota_t\frac{u'\left(c_{t+1}\right)}{p(\mu_{t+1})}\right] \tag{A16}$$

which makes use of the envelope condition with respect to b. ■

Derivation of (35). The first order condition of (30) with respect to x_t reads as:

$$-u'\left(\frac{e-x}{p(\mu)}\right)\frac{1}{p(\mu)}\left[1+\Lambda'(x)\frac{(e-x)}{p(\mu)}\cdot\frac{dp(\mu)}{d\mu}\right] + \rho\Lambda'(x)\mathbb{E}_{\mathbf{e}}\left[\frac{\partial V(\mathbf{e}',\mu)}{\partial\mu}\right] = 0. \tag{A17}$$

The envelope condition implies that

$$\frac{\partial V(\mathbf{e},\mu_{-1})}{\partial\mu_{-1}} = \frac{1-\delta}{\Lambda'(x)}u'\left(\frac{e-x}{p(\mu)}\right)\frac{1}{p(\mu)} \tag{A18}$$

which substituted into (A17) and after dividing the left and right-hand side by $u'\left(\frac{e_t-x_t}{p(\mu_t)}\right)\frac{1}{p(\mu_t)}$ immediately yields (35). ■

Proof of Proposition 2. We first prove that the derivative of the function $\eta(\mu)$ in (35) is negative:

$$\eta'(\mu) = \frac{1}{\sigma-1}\left\{\frac{E(n^{u+2})\,E(n^u) - [E(n^{u+1})]^2}{[E(n^u)]^2\,E(n)} - 1\right\}$$
$$= \left[\frac{E(n^{u+2})}{E(n^{u+1})E(n)} - \frac{E(n^{u+1})}{E(n^u)E(n)}\right]\frac{E(n^{u+1})}{E(n^u)} - \frac{1}{\sigma-1} < 0 \tag{A19}$$

where we used the notation

$$E(n^u) \equiv \sum_{n=0}^{\infty} n^u\, f(n;\bar{\mu}) \tag{A20}$$

with $u = \frac{\sigma-1}{\kappa} \in (0,1]$. The inequality in (A19) follows from the fact that the term in square brackets in (A19) is negative. To see this notice that $f(n;\bar{\mu}) = \frac{(\bar{\mu})^n e^{-\bar{\mu}}}{n!}$ implies that

$$E(n^{u+1}) = E(n)E[(n+1)^u] \tag{A21}$$

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 (A19) is negative.

By taking derivatives in (36) we obtain that

$$\frac{d\bar{x}}{d\rho} = \frac{(1-\delta)\bar{x}}{1-(1-\delta)\rho + \delta\eta(\bar{\mu}) - \eta'(\bar{\mu})\delta(\bar{e}-\bar{x})} > 0, \tag{A22}$$

and that

$$\frac{d\ln\bar{x}}{d\ln\bar{e}} = \frac{1-(1-\delta)\rho + \delta\eta(\bar{\mu})}{1-(1-\delta)\rho + \delta\eta(\bar{\mu}) - \eta'(\bar{\mu})\delta(\bar{e}-\bar{x})} \in (0,1), \tag{A23}$$

where the inequality in (A22) and the range of variation in (A23) follows immediately from the fact that η' in (A19) is negative. ■

Analytical expression for $\tilde{e}^0_{t-1}$ in Section 5.4. $\tilde{e}^0_t$ denotes the fraction of total expenditure at $t-1$ in varieties that are purchased also at t, equal to

$$\tilde{e}^0_{t-1} = \left[\sum_{n=1}^{\infty} \kappa^r_{nt} \, f\left(n; \mu_{t-1}\right) \right] \frac{1}{e_{t-1}}, \tag{A24}$$

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

$$\kappa^r_{nt} = s_{nt-1} \left(1-\delta\right) \sum_{m=0}^{\infty} f\left(m; \Lambda_t(x_t)\right) \left[(1-\psi) \frac{n}{m+n} + \psi \sum_{u=0}^{n-1} b\left(u; 1-\delta, n-1\right) \frac{1}{m+u+1} \right] \tag{A25}$$

where

$$b(u; 1-\delta, n) = \binom{n}{u} \left(1-\delta\right)^u \delta^{n-u}, \qquad u = 0, 1...n \tag{A26}$$

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 (A25) 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 (A25) notice that the index m refers to the number of new varieties added to the consideration set of the household 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 of the household 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 by separately considering the case when preference shocks are not redrawn at t (probability $1-\psi$) from the case when they are (probability ψ). In the former case, the variety consumed at $t-1$—which is the one preferred among the n varieties in the consideration set at $t-1$—is still consumed at time t, provided that it is *not* dominated by any of the m varieties newly added to the consideration set. Due to symmetry in preference shocks, this happens with probability $n/(m+n)$—equal to the probability that a variety has maximum value over $m+n$ varieties given that it is maximum value over n varieties. If 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 of the household at time t; and it remains preferred to the $u \leq n-1$ other old varieties inherited from the consideration set of the household 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 (A25), 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 5.4. $\tilde{e}_t^1$ 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

$$\tilde{e}_t^1 = \left[\sum_{n=1}^{\infty} \kappa_{nt}^a f(n; \mu_t)\right] \frac{1}{e_{t-1}}, \tag{A27}$$

where κ_{nt}^a denotes the (expected) expenditure at time t in varieties that (i) were already in the consideration set of the household 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

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

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 of the household 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:

$$\kappa_{nt}^a = \sum_{k=0}^{\infty} \sum_{u=1}^{n} \sum_{j=0}^{n-u} \left\{ \begin{array}{c} f(k; \delta\mu_{t-1})\, h\left(u, j; \frac{(1-\delta)^2 \mu_{t-2}}{\mu_t}, \frac{(1-\delta)\Lambda_{t-1}(x_{t-1})}{\mu_t}, n\right) \\ \times \frac{u}{k+u+j} \left[(1-\psi) \frac{k+u+j}{n+k} s_{n+kt} + \psi \frac{1}{n} s_{nt}\right] \end{array} \right\}. \tag{A28}$$

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 (A28) calculates the expected expenditure at time t in the variety, by considering separately the case when preferences are not redrawn at time t (probability $1-\psi$) from the case when they are redrawn at time t (probability ψ). Notice that the variety consumed at time $t-1$ was preferred to all the $k+u+j$ varieties present in the consideration set at time $t-1$. Then, without redrawing of preferences and given the symmetry in preference shocks, the variety consumed at $t-1$ is also consumed at time t with probability $\frac{k+u+j}{n+k}$ (this is the probability that a variety has maximum value over $n+k$ varieties given that it is the maximum value over $k+u+j$ varieties), and, conditional on consumption, expenditure is equal to s_{n+kt}, since yesterday the variety was preferred to all the $k+u+j$ varieties present in the consideration set and today it is also preferred to all the $n-u-j$ varieties newly added to the consideration set at time t. This explains the first term in square brackets of (A28). The second term considers the case when there is a redrawing of preferences. In this case the variety consumed at $t-1$ is chosen 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 (A28) 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

$$\kappa^a_{nt}=\sum_{k=0}^{\infty}\left\{f(k;\delta\mu_{t-1})\left[\frac{(1-\psi)n}{n+k}\cdot\frac{(1-\delta)^2\mu_{t\text{-}2}}{\mu_t}\cdot s_{n+kt}+\psi\frac{1}{n}s_{nt}\vartheta_{n,k,t}\right]\right\} \tag{A29}$$

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 (40) in Section 5.4. Given the definition of $\tilde{e}^0_t$ and $\tilde{e}^1_t$ 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

$$\sum_{m=0}^{n} b\left(m; \frac{(1-\delta)\Lambda_{t-1}(x_{t-1})}{\mu_t}, n\right)\frac{m}{n} = \frac{(1-\delta)\Lambda_{t-1}(x_{t-1})}{\mu_t}, \tag{A30}$$

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

$$\sum_{n=1}^{\infty} s_{nt}\frac{\Lambda_t(x_t)}{\mu_t} f(n;\mu_t) = \frac{(1-\delta)\Lambda_{t-1}(x_{t-1})}{\mu_t} s_t. \tag{A31}$$

To calculate the probability in (A30) 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 of the household 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 of the household at time $t-2$ (which is a Poisson random variable with mean $(1-\delta)^2\mu_{t-2}$). The last equality in (A30) follows from the property of the mean of a binomial random variable. ■

Derivation of (38) in Section 5.4. We now prove that the expression for total additions in (38) holds true by deriving its second and third term.

Derivation of second term The second term of (38) 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

$$\sum_{m=0}^{n} b\left(m; \frac{\Lambda_t(x_t)}{\mu_t}, n\right)\frac{m}{n} = \frac{\Lambda_t(x_t)}{\mu_t}, \tag{A32}$$

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

$$\sum_{n=1}^{\infty} s_{nt}\frac{\Lambda_t(x_t)}{\mu_t} f(n;\mu_t) = \frac{\Lambda_t(x_t)}{\mu_t} s_t. \tag{A33}$$

To calculate the probability in (A32) we used the previously mentioned result—used to derive (A30)— 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 of the household 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 λx_t) and of the old varieties inherited from the consideration set of the household at time $t-1$ (a Poisson random variable with mean $(1-\delta)\mu_{t-1}$). The last equality in (A32) 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 (A27) corresponds to the expenditure at time t in all varieties which were already in the consideration set of the household at time $t-2$, which can be obtained using a logic analogous to the one used to derive (A33). ■

Derivation of (39) in Section 5.4. The proof is analogous to the one used to prove (38). ■

B Maximum likelihood estimation

First, we log-linearize the key equations of the household 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.

B.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 a 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, 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 (33), (25) 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

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

We notice that 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)).

B.2 State space representation

We now write the household problem in state space format (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 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 while Ω is the observation covariance. The observable variables are logged total expenditure and net additions:

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

The vector of structural shock 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, $\quad j = e,\ \lambda$. 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 (38)-(39 9to construct the following two functions for additions and removals

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

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

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:

$$\underset{11\times 2}{B} = \begin{bmatrix} \underset{11\times 1}{B_1} & \underset{11\times 1}{B_2} \end{bmatrix}.$$

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

$$\underset{2\times 11}{C} = \begin{bmatrix} C_1' = \underset{1\times 11}{\begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}} \\ \underset{1\times 11}{C_2'} \end{bmatrix}$$

Our vector of observables is given by

$$y_t^a = \begin{bmatrix} \hat{e}_t^a \\ n_t^a \end{bmatrix} \tag{A42}$$

rather than by

$$y_t = \begin{bmatrix} \hat{e}_t \\ n_t \end{bmatrix}$$

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

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

$\mathbf{s}_t$ 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:

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

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

$$\underset{20\times 20}{D^a} = \begin{bmatrix}
\underset{11\times 11}{D} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} \\
\underset{1\times 11}{\begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} \\
\underset{1\times 11}{0} & \underset{1\times 1}{1} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} \\
\underset{1\times 11}{C_2'} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} \\
\underset{1\times 11}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{1} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} \\
\underset{1\times 11}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{1} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} \\
\underset{1\times 11}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} \\
\underset{1\times 11}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{1} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} \\
\underset{1\times 11}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{1} & \underset{1\times 1}{0} & \underset{1\times 1}{0} \\
\underset{1\times 11}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{1} & \underset{1\times 1}{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:

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

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

$$\underset{2\times 20}{C^a} = \begin{bmatrix} \underset{1\times 11}{\left[.25\ .25\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\right]} & \underset{1\times 1}{.25} & \underset{1\times 1}{.25} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{0} \\ \underset{1\times 11}{.25C_2'} & \underset{1\times 1}{0} & \underset{1\times 1}{0} & \underset{1\times 1}{.25} & \underset{1\times 1}{.25} & \underset{1\times 1}{.25} & \underset{1\times 1}{.25} & \underset{1\times 1}{.25} & \underset{1\times 1}{.25} & \underset{1\times 1}{.25} \end{bmatrix} \tag{A50}$$

B.3 Likelihood function

We maximize the likelihood function with respect 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

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

B.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. To correct for this, we rescale the growth rate of expenditure in the 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 in the quantitative analysis 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 $\widetilde{P}_{dt}$ denote the price deflator from BEA. Nominal expenditure is converted into real expenditure as follows: $E_{rt} = \frac{E_t}{\widetilde{P}_{dt}}$. The growth rate of real expenditure is equal to

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

Additions are converted into real value by writing

$$A_{rt} = \frac{\widetilde{P}_{dt-1}}{\widetilde{P}_{dt}} A_t$$

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

$$a_{hrt} = \sum_{\nu \in \mathcal{V}} \frac{\frac{e_{\nu ht}}{\widetilde{P}_{dt}}}{\frac{e_{ht-1}}{\widetilde{P}_{dt-1}}} \times \mathbb{I}(e_{\nu ht-1} = 0) \times \mathbb{I}(e_{\nu ht} > 0), \tag{A53}$$

to yield

$$A_{rt} = \sum_{h \in \mathcal{H}} a_{hrt} \times \frac{e_{hrt-1}}{E_{rt-1}} = \frac{\widetilde{P}_{dt-1}}{\widetilde{P}_{dt}} A_t, \tag{A54}$$

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

$$I_{rt} = \Delta E_{rt} - (A_{rt} - R_{rt}).$$

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

C Derivation of the decomposition in (49)

The present value of the revenue of a new variety at time t is equal to the ratio between Π_t in (46) and $1-\phi$, equal to

$$\Pi_{Rt} = \frac{\Pi_t}{1-\phi} = \mathbb{E}_t\left[\sum_{j=1}^{\infty}(1-\delta_f)^{j-1}\rho_{t,t+j}\left(\frac{e_{t+j}-x_{t+j}}{\mu_{t+j}}m_{t,t+j}+\frac{x_{t+j}}{v_{t+j-1}}\right)\right] \tag{A55}$$

where

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

Notice that Π_{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

$$m_j = \Lambda\sum_{i=1}^{j}(1-\delta_p)^{i-1} = \frac{\Lambda}{\delta_p}\left[1-(1-\delta_p)^j\right] \tag{A56}$$

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

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

We adopt the notation:

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

Let

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

denote the firm discount factor in steady state. After log-linearizing (A55) and after using (A102) we obtain that in an equilibrium with free-entry:

$$\widetilde{\Pi}_t^e + \widetilde{\Pi}_t^\mu + \widetilde{\Pi}_t^x + \widetilde{\Pi}_t^m + \widetilde{\Pi}_t^v + \widetilde{\Pi}_t^\rho = 0 \tag{A57}$$

where

$$\widetilde{\Pi}_t^e = \frac{\rho e}{\mu \Pi_R} \sum_{j=1}^{\infty} \widehat{\beta}^{j-1} m_j \mathbb{E}_t \left(\widehat{e}_{t+j}\right) \tag{A58}$$

$$\widetilde{\Pi}_t^\mu = -\frac{\rho \left(e-x\right)}{\mu \Pi_R} \sum_{j=1}^{\infty} \widehat{\beta}^{j-1} m_j \mathbb{E}_t \left(\widehat{\mu}_{t+j}\right) \tag{A59}$$

$$\widetilde{\Pi}_t^x = \frac{\rho x}{\Pi_R} \sum_{j=1}^{\infty} \widehat{\beta}^{j-1} \left(1 - \frac{m_j}{\mu}\right) \mathbb{E}_t \left(\widehat{x}_{t+j}\right) \tag{A60}$$

$$\widetilde{\Pi}_t^m = \frac{\rho \left(e-x\right)}{\mu \Pi_R} \sum_{j=1}^{\infty} \widehat{\beta}^{j-1} \mathbb{E}_t \left(\widehat{m}_{t,j}\right) \tag{A61}$$

$$\widetilde{\Pi}_t^v = -\frac{\rho x}{\Pi_R} \sum_{j=1}^{\infty} \widehat{\beta}^{j-1} \mathbb{E}_t \left(\widehat{v}_{t+j-1}\right) \tag{A62}$$

$$\widetilde{\Pi}_t^\rho = \frac{\rho}{\Pi_R} \sum_{j=1}^{\infty} \widehat{\beta}^{j-1} \left[\frac{e-x}{\mu} m_j + x\right] \mathbb{E}_t \left(\widehat{\rho}_{t,j}\right) \tag{A63}$$

where $\widehat{\mu}_{t+j}$ is calculated using (25) to obtain

$$\widehat{\mu}_t = \left(1-\delta\right)^{t+1} \widehat{\mu}_{-1} + \delta \sum_{i=0}^{t} \left(1-\delta\right)^{t-i} \left[\zeta_{\Lambda,\lambda} \mathbb{E}_t \left(\widehat{\lambda}_i\right) + \zeta_{\Lambda,x} \mathbb{E}_t \left(\hat{x}_i\right)\right], \tag{A64}$$

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

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

while $\widehat{m}_{t,j}$ is calculated using (48) 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 $\widetilde{\Pi}_t^m$ in (A61) can be rewritten as follows

$$\begin{aligned}
\widetilde{\Pi}_t^m &= \frac{\rho \left(e-x\right)}{\Pi_R[1-\rho(1-\delta)]} \frac{\Lambda}{\mu} \sum_{i=1}^{\infty} \widehat{\beta}^{i-1} \mathbb{E}_t \left[\zeta_{\Lambda,\lambda} \widehat{\lambda}_{t+i} + \zeta_{\Lambda,x} \hat{x}_{t+i} - \widehat{v}_{t+i-1}\right] \\
&= \frac{\delta(e-x)}{\Pi_R(r+\delta)} \sum_{i=1}^{\infty} \widehat{\beta}^{i-1} \mathbb{E}_t \left[\zeta_{\Lambda,\lambda} \widehat{\lambda}_{t+i} + \zeta_{\Lambda,x} \hat{x}_{t+i} - \widehat{v}_{t+i-1}\right]
\end{aligned} \tag{A65}$$

where $r = 1/\rho - 1$. We then define

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

The condition (A57) can then be written as follows:

$$\widehat{\alpha}\mathbb{E}_t\left(H_t\right) - \frac{\mathbb{E}_t\left(\hat{v}_t\right)}{1-\widehat{\beta}F} = 0 \tag{A66}$$

where F denotes the forward operator and

$$\widehat{\alpha} = \frac{\left(r+\delta\right)\Pi_R}{\delta\left(e-x\right)+\rho\left(r+\delta\right)x}$$

After multiplying the left and right-hand side of (A66) by $1-\widehat{\beta}F$ and then solving for $\hat{v}_t$ we obtain that

$$\hat{v}_t = \widehat{\alpha}\left[\mathbb{E}_t\left(H_t\right) - \widehat{\beta}\mathbb{E}_t\left(H_{t+1}\right)\right] \tag{A67}$$

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 (A57) can be rewritten as follows:

$$\hat{v}_t = \Pi^e\left(\mathbf{e_t}\right) + \Pi^\rho\left(\boldsymbol{\rho}_\mathbf{t}\right) + \Pi^\lambda\left(\boldsymbol{\lambda}_\mathbf{t}\right) + \Pi^x\left(\mathbf{x_t}\right) \tag{A68}$$

where

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

and we defined

$$\widehat{\mu}^\lambda_t = \left(1-\delta\right)^{t+1}\widehat{\mu}^\lambda_{-1} + \delta\zeta_{\Lambda,\lambda}\sum_{i=0}^{t}\left(1-\delta\right)^{t-i}\mathbb{E}_t\left(\widehat{\lambda}_i\right), \tag{A69}$$

$$\widehat{\mu}^x_t = \left(1-\delta\right)^{t+1}\widehat{\mu}^x_{-1} + \delta\zeta_{\Lambda,x}\sum_{i=0}^{t}\left(1-\delta\right)^{t-i}\zeta_{\Lambda,x}\mathbb{E}_t\left(\hat{x}_i\right) \tag{A70}$$

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 (49). Notice that none of the terms in

(A68) depend on ξ or ϕ.

For each t the components of (A68) are calculated using the state space representation of the household problem used to estimate the model, as discussed in Section B. 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:

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

where we have defined

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

D Data and additional empirical results

Here we describe the construction of the sample starting from the KNCP. We also report results on several robustness checks discussed in the main text. Then we better relate our results to those by Broda and Weinstein (2010). Finally, we better characterize the process of adoption of new varieties by households.

D.1 Construction of sample and variables definition

Our analysis is based on the Kilts-Nielsen Consumer Panel (KNCP). The 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.

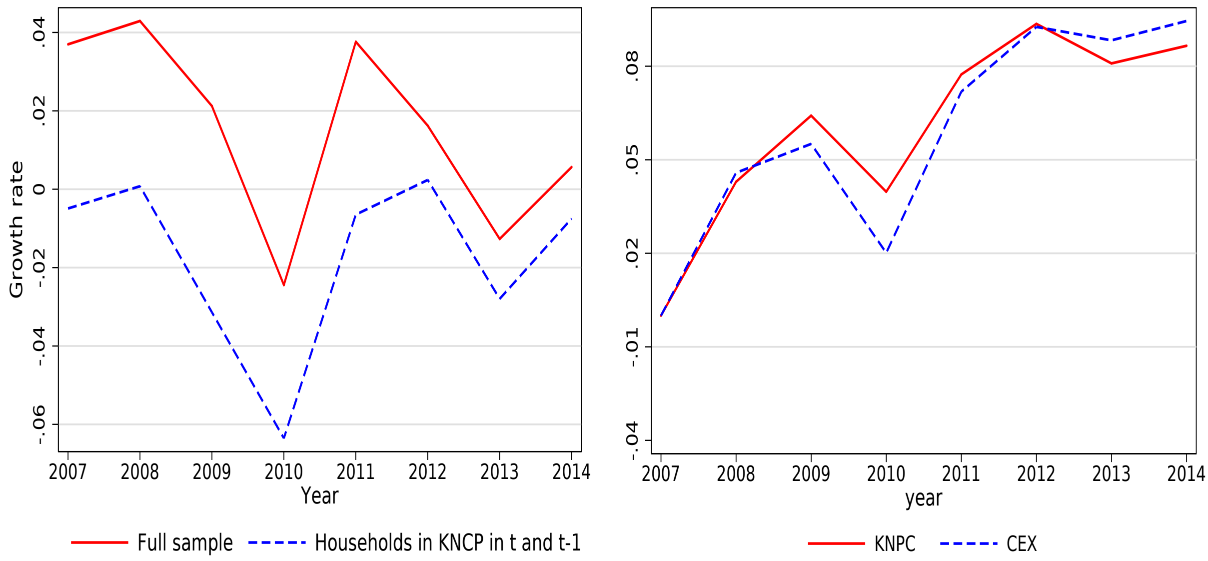
In 2006 the sample size of the KNCP increases from about 40,000 households to over 60,000 households. This sharp increase in sample size is also associated with an expansion in the product categories covered by the KNCP. For this reason we use the KNCP starting from 2006. The KNCP has an important panel 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. The KNCP also reports information on households characteristics such as household's size, composition, age, gender, ethnicity, income (in ranges), and education.

A product in the 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".

We restrict the sample to households who report positive expenditure in every month of a year. When calculating year-on-year growth rates, 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 the KNCP. Fresh products have no associated UPC and their purchases can only be tracked for a subsample of households in the KNCP ("Magnet households"). When running hedonic price regressions, we further discard product modules whose items do not have a homogeneous measure of unit size.

Panel (a) of Figure A1 plots as a red solid 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 calculated using all households who report some purchases in all months of the year. The blue dashed line is the analogous growth rates but where aggregate expenditure in year t is calculated using households present in the sample both in year t and in year $t-1$. The correlation between the two series is high (0.83), but the growth rate level is higher when considering the larger sample. Panel

Figure A1: Consumption expenditure per household: KNPC vs CEX data



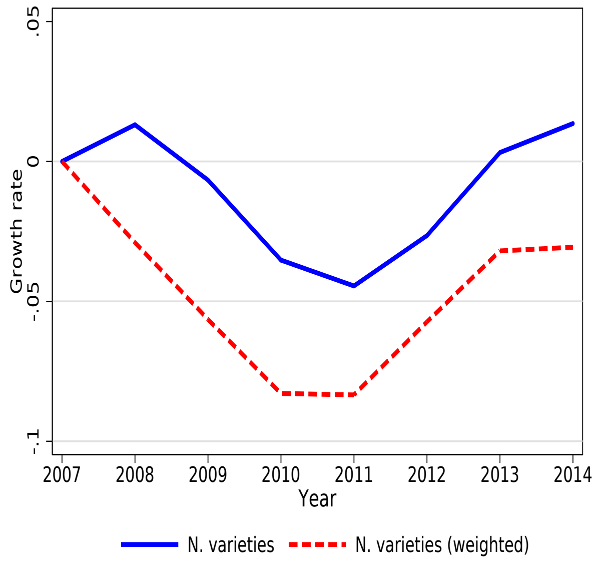
(a) Growth rates: full sample and subsample **(b) Level: KNPC vs CEX**

Panel (a) plots the yearly growth rate of aggregate expenditure. In the red solid line, aggregate expenditure are calculated using all households who report positive expenditure in every month of year t. In the blue dashed line aggregate expenditure is calculated using all households in the sample both in year t and in year $t-1$. Panel (b) plots the yearly level of aggregate expenditure per household from the KNCP (red solid line) and CEX (blue dashed 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).

(b) of Figure A1 plots the (log of) yearly aggregate expenditure per household from the KNPC (red solid line) and from the Consumer Expenditure Survey (CEX) prepared by the US Census Bureau for the Bureau of Labor Statistics (blue-dashed line). The CEX series is obtained by adding expenditures for the following categories intended to mimic the coverage of the KNCP: 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). 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.

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 the 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 the KNCP. To identify newly introduced or dismissed varieties by manufacturers, we use data from both the KNCP and the KNRS. The KNRS is a companion dataset to the 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. Figure A2 plots the evolution of the number of varieties available on sale in the US using the KNRS. The solid blue line corresponds to the logged number of varieties in deviation from a linear trend estimated over the years 2007-2014, the red dashed line sum varieties by weighting each of them according to their sales. Both series are normalized to zero in 2007. A variety is newly introduced in the market at time t if some households in

Figure A2: Number of varieties on sale in the US



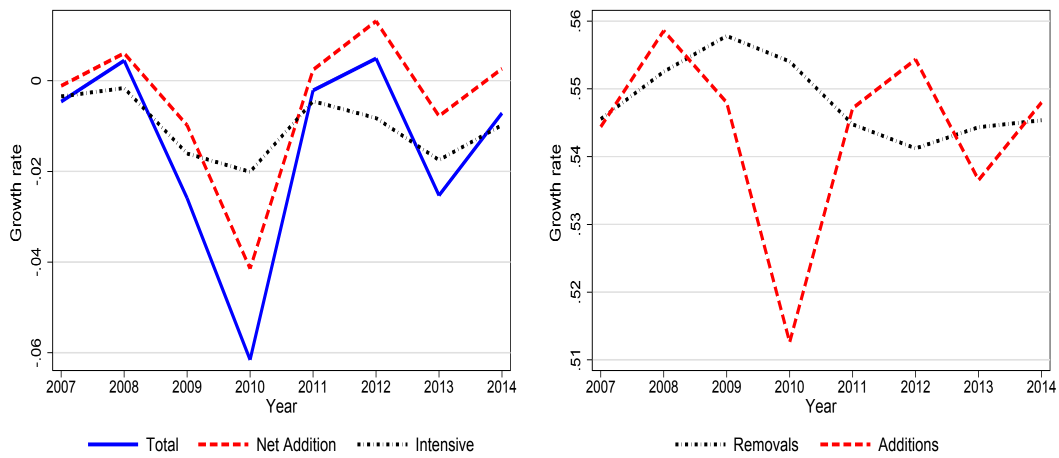
The figure plots the logged number of varieties on sale in the US as calcultaed using the KNRS in deviation from a linear trend estimated over the period 2007-2014. The solid blue line is a simple count of the number of varieties; whereas the red dashed line weight each variety using its sales. The definition of a variety is a brand-product module.

the KNCP report some positive expenditure for the variety at t, and no households in the KNCP and no firms in the KNRS data have ever reported positive expenditure on that variety before time t. A withdrawn variety is identified analogously. Due to the fact that introduction/dismissal of products is sometimes staggered across regions, we have also experimented with an alternative definition where market availability is defined at the local market level, using the 78 Scantrack markets constructed by Nielsen.

D.2 Robustness

Varieties as UPCs As a robustness check, we consider a different definition of variety. Instead of identifying a variety as a brand/product-module pair, we identify a a variety with its UPC-ver. This causes an increase in the number of varieties because different packages of the same brand are now counted as a different variety. Figure A3 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 A1 shows that the contribution of net additions, gross additions and removals to expenditure growth. substantially increase when we identify a variety with its UPC-ver. The contribution of net additions, gross additions and removals substantially increase when we identify a variety with its UPC-ver.

Figure A3: 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, ΔE_t, (blue solid line) together with the contribution of the intensive margin I_t (black dotted line) and net additions N_t (red dashed line). Panel (b) plots additions A_t (red dashed line) and removals R_t (black dotted line). The analysis is at the yearly frequency and a variety is defined as a UPC-ver in KNPC.

Constant prices So far we evaluated additions at the price of period t and removals at the prices of period $t-1$. 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 $u_{\nu ht}$ 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 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 A1.

Table A1: 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: $X_t = \alpha_X + \beta_X\,\Delta E_t + \epsilon_t$. 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 that are storable for different periods, using the index by Alessandria, Kaboski, and Midrigan (2010). 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 $t+1$.

Durability Panel C) of Table A1 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 as implied by the index described in Alessandria, Kaboski, and Midrigan (2010): less than 2 months of durability, between 2 and six months of durability, between 6 and 12 months, between 1 and two years, and above two years.

Quality substitution Over the cycle, households substitute across products of different quality (Jaimovich, Rebelo, and Wong 2019, Argente and Lee 2017). Quality substitution can occur along the intensive or the extensive margin. To measure the extent to which the cyclical patterns of net and gross additions reflect quality substitution, we construct a measure of quality for each variety $\nu \in \mathcal{V}$. First, we estimate separately for each product group a regression of the logarithm of the average quarterly price of variety ν in Designated Market Area (DMA) m in quarter t on a full set of brand and quarterly dummies:

$$\ln p_{\nu mt} = d_{\nu} + \tau_t + e_{\nu mt}, \tag{A71}$$

The average per-unit price of variety ν in DMA m in quarter t, $p_{\nu mt}$, is calculated using the KNRS which includes a larger set of varieties than the set covered by all varieties purchased by households in the KNCP. The average is calculated over all weeks in the same quarter and across all stores in the same DMA. For each UPC Nielsen reports its unit of measurement (fluid ounces, pounds, etc..), if available. In running the regression (A71), 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 their value of d_{ν}, 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 modules.

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.

Newly introduced varieties: Relation with Broda and Weinstein (2010) Panel c) of Table 2 reports the contribution of varieties newly introduced in the market or dismissed 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. The estimates in Table 2 are obtained considering the years 2007-2015, identifying varieties as brand× product-module and aggregating expenditure across all product categories. Table 7 in Broda and Weinstein (2010) is obtained using quarterly data over the period 2000-2003, identifying varieties with their UPC and aggregating expenditure at the product group level. Table A2 investigates the source of the discrepancy between our results and those in Broda and Weinstein (2010). The first row in Table A2 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

Table A2: 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 are either additions in newly introduced varieties β_C, or removals due to varieties dismissed 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 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 definition of variety.

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 A2 reports the estimates obtained by running the same regression as in the second row but on our aggregate data at the quarterly frequency over the sample-period 2007-2015, but where we identify a variety with its UPC. In the last two rows of Table A2, 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 A2 indicates that the main reasons for why the results in Table 2 differ from those in Broda and Weinstein (2010) is due to the fact that we identify a variety using its brand/product-module pair, while they identify a variety using its UPC. Even when identifying a variety with its UPC, there is still a sizeable fraction (around fifty percent) of the cyclical volatility of additions and removals which is not driven by newly introduced or dismissed varieties.

Household heterogeneity Table A3 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 the 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.

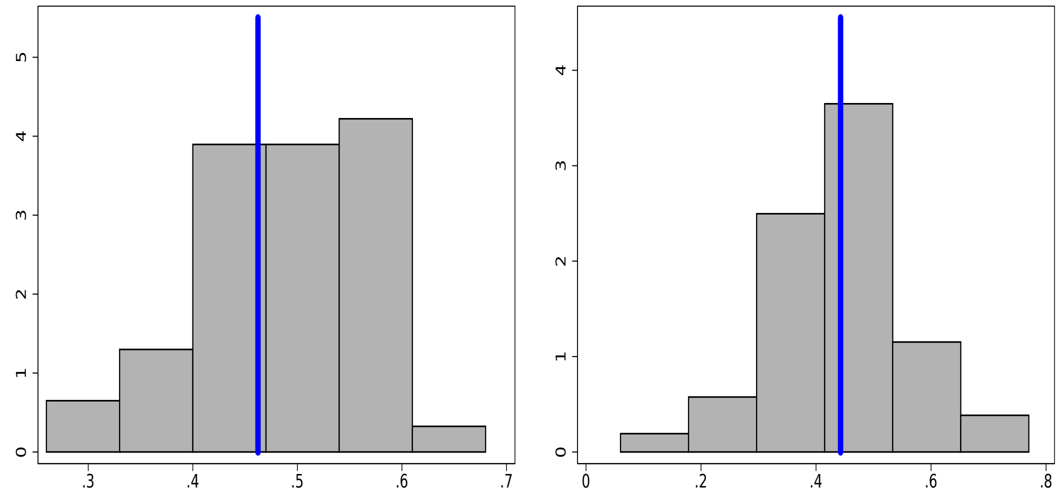
Table A3: Household heterogeneity by permanent income

	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 $t-1$.

Regional variation Figure A4 documents differences across Scantrack markets. Over the years 2007-2014 the 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.

Figure A4: 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.

Robust additions and removals Panel D) of Table A1 shows the results when considering a more stringent definitions of additions and removals. "Robust" additions are expenditures in varieties purchased in year t that were purchased neither in year $t-1$ nor in year $t-2$. "Robust" removals are defined as expenditures in products absent from the household basket at t that were purchased both at $t-1$ and at $t-2$. These statistics can be calculated only for households who remain in the KNCP for at least three years.

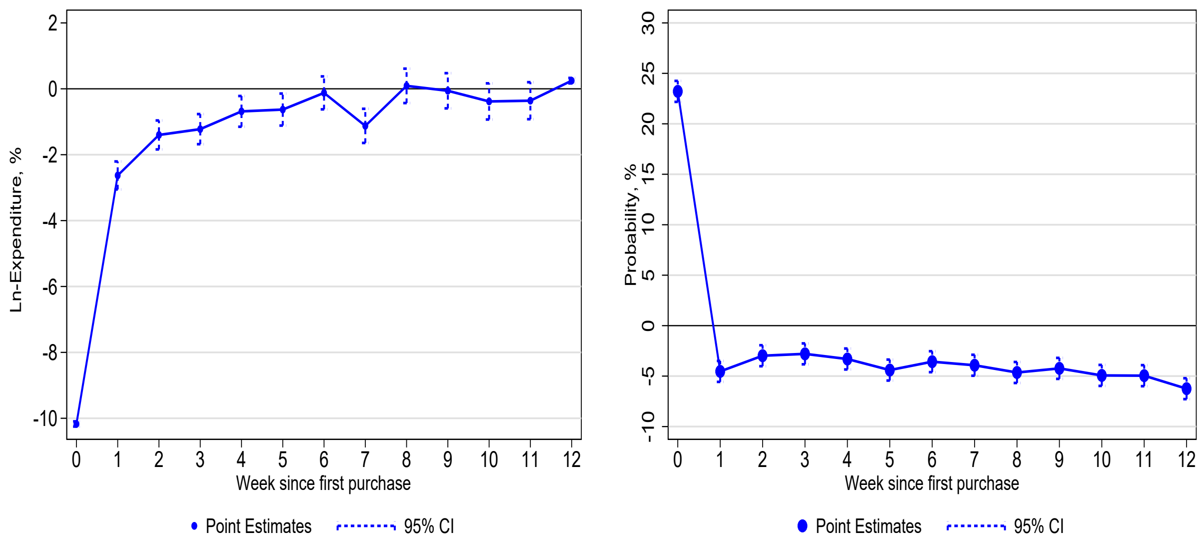
Persistent vs temporary additions and removals Panel E) of Table A1 reports results for "persistent" and "temporary" additions and removals. Persistent additions are expenditures in varieties added in year t that are also purchased in year $t+1$; persistent removals occur when a variety removed from the basket in year t is not purchased in year $t+1$. All additions and removals that are not persistent are defined as temporary. 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.

Adoption of varieties We characterize the evolution over time of the expenditures in varieties newly added to the consumption basket of household. We select all households continuously present in the KNCP since 2004, and focus on their expenditures in any week of year 2013. We are interested in comparing household 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:

$$z_{\nu ht} = \sum_{n=0}^{52} \beta_n^z F_{\nu ht-n} + \beta_X^z X_{\nu ht} + \epsilon_{\nu ht} \tag{A72}$$

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 first 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 A5 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

Figure A5: The time profile of newly added varieties

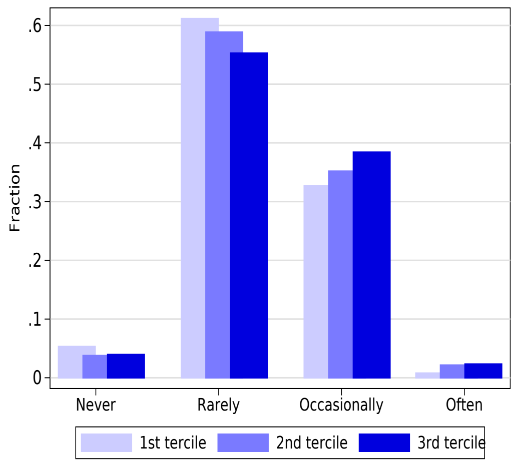


(a) Expenditure conditional on purchase, β_n^e **(b) Purchase probability in next 52 weeks, β_n^π**

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 A5 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 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 A6 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 A6: Robust and persistent additions



The histogram displays the share of respondent choosing each option to the survey question by their level of addition rate. The sample is 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 A4 we report the coefficient of an ordered probit whose dependent variable is the same as in Figure A6: 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, race, size, and employment status. 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 A4: 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 answer 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, age, 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 presents the results of a linear probability model where the dependent variable is a dummy that takes value 1 if the household reports to have experienced regret over past purchases either occasionally or often; and 0 otherwise. The regressors are the same included in the ordered probit in the first column (and the coefficients on the demographic controls are also omitted and available upon request).

E Growth model and balanced growth path

We now briefly discuss how our household 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.

E.1 Assumption and equilibrium conditions

In the economy at time t there are S_t sectors and in each of them there is a measure one of varieties. As a result at time 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 of the household. 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 of the household and the number of sectors in the consideration set of the household evolves as follows:

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

$$\mu_t = (1-\delta)\,\mu_{t-1} + \frac{\lambda x_t}{S_t} \tag{A73}$$

while s_t evolves as follows

$$s_t = s_{t-1} + (S_t - s_{t-1}) \left(1 - e^{-\frac{\lambda x_t}{S_t}}\right) \tag{A74}$$

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 time t of the first variety introduced in the market,

$$p_{0t} = 1, \forall t, \tag{A75}$$

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 μ_t, the number of sector she is aware 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 problem reads as follows:

$$\max_{\{c_t,i_t,x_t,l_t,\mu_t,s_t,k_{t+1}\}_{t\geq 0}} \sum_{t=0}^{\infty} \beta^t \left[\ln(c_t) - \psi_0 \frac{l_t^{1+\psi}}{1+\psi}\right] \tag{A76}$$

s.t.

$$p(s_t, \mu_t)(c_t + i_t) + x_t \leq r_t k_t + w_t l_t + \tau_t \tag{A77}$$

$$c_t = \left[\int_0^{s_t} \max_{q_{\nu j}\geq 0} \left(\sum_{\nu\in\Omega_{jt}} z_{\nu jt}\, q_{\nu j}\right)^{\frac{\sigma-1}{\sigma}} dj\right]^{\frac{\sigma}{\sigma-1}} \tag{A78}$$

$$p(s_t, \mu_t) = \left[\Gamma\left(1 - \frac{\sigma-1}{\alpha}\right) s_t \sum_{n=0}^{\infty} n^{\frac{\sigma-1}{\alpha}} f(n; \mu_t)\right]^{-\frac{1}{\sigma-1}} \tag{A79}$$

$$k_{t+1} = (1-\varkappa) k_t + i_t \tag{A80}$$

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

$$\mu_t = (1-\delta)\mu_{t-1} + \frac{\lambda x_t}{S_t} \tag{A81}$$

$$s_t = e^{-\frac{\lambda x_t}{S_t}} s_{t-1} + \left(1 - e^{-\frac{\lambda x_t}{S_t}}\right) S_t = s_{t-1} + \left(1 - e^{-\frac{\lambda x_t}{S_t}}\right)(S_t - s_{t-1}) \tag{A82}$$

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:

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

subject to the budget constraint in (A77) 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 (A80), (A81) and (A82), respectively.

Solution to the household problem By writing the first order conditions of the problem in (A76) with respect to c_t, and i_t, and after using the envelope condition, we obtain that:

$$\frac{1}{c_t} = \beta\left[(1-\varkappa) + \frac{r_{t+1}}{p_{t+1}}\right]\frac{1}{c_{t+1}} \tag{A83}$$

$$\frac{\partial v_t}{\partial k_t} = \frac{1}{c_t}\left[(1-\varkappa) + \frac{r_t}{p_t}\right] \tag{A84}$$

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

$$\frac{1}{p_t c_t} = \left[\frac{1}{\sigma-1}\frac{1}{s_t}\frac{c_t+i_t}{c_t} + \beta\frac{\partial v_{t+1}}{\partial s_t}\right]\lambda\left(\frac{S_t - s_{t-1}}{S_t}\right)e^{-\frac{\lambda x_t}{S_t}} + \left[\frac{\eta(\mu_t)}{\sigma-1}\cdot\frac{c_t+i_t}{c_t} + \beta\frac{\partial v_{t+1}}{\partial \mu_t}\right]\frac{\lambda}{S_t} \tag{A85}$$

where from the envelope conditions we know that

$$\frac{\partial v_t}{\partial s_{t-1}} = e^{-\frac{\lambda x_t}{S_t}}\left[\frac{1}{\sigma-1}\frac{1}{s_t}\frac{c_t+i_t}{c_t} + \beta\frac{\partial v_{t+1}}{\partial s_t}\right] \tag{A86}$$

$$\frac{\partial v_t}{\partial \mu_{t-1}} = (1-\delta)\left[\frac{1}{\sigma-1}\eta(\mu_t)\frac{c_t+i_t}{c_t} + \beta\frac{\partial v_{t+1}}{\partial \mu_t}\right] \tag{A87}$$

The first order conditions for the choice of l_t yields

$$\psi_0\, l_t^{\psi} = \frac{w_t}{p_t c_t} \tag{A88}$$

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

$$q_{it} = (\sigma l_{it})^{\frac{1}{\sigma}}\left(\frac{\sigma k_{it}}{\sigma-1}\right)^{\frac{\sigma-1}{\sigma}} \tag{A89}$$

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

$$m_t = (w_t)^{\frac{1}{\sigma}}(r_t)^{1-\frac{1}{\sigma}}\,. \tag{A90}$$

The derivation of (A90) from first principles is at the end of this note. Cost minimization also implies that

$$l_{it} = \frac{m_t q_{it}}{\sigma w_t} = \frac{1}{\sigma}\left(\frac{r_t}{w_t}\right)^{1-\frac{1}{\sigma}} q_{it} \tag{A91}$$

$$k_{it} = \frac{(\sigma-1)\, m_t q_{it}}{r_t \sigma} = \left(1-\frac{1}{\sigma}\right)\left(\frac{w_t}{r_t}\right)^{\frac{1}{\sigma}} q_{it} \tag{A92}$$

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

$$p_t = 1 = \theta m_t \tag{A93}$$

which implies that marginal costs are constant and equal to

$$m_t = \frac{1}{\theta} \tag{A94}$$

Combining (A93) with (A90) yields

$$r_t = \frac{1}{\theta^{\frac{\sigma}{\sigma-1}} (w_t)^{\frac{1}{\sigma-1}}} \tag{A95}$$

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

$$\pi_t(\tau) = \left(1-\frac{1}{\theta}\right)\left[\frac{p_t\,(c_t+i_t)}{s_t}\left(1-e^{-\lambda\sum_{j=0}^{\tau}\frac{x_{t-j}}{S_{t-j}}}\right)+\frac{x_t}{S_t}\right] \tag{A96}$$

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

$$V_t(\tau) = \left(1-\frac{1}{\theta}\right)\left[\frac{p_t\,(c_t+i_t)}{s_t}\left(1-e^{-\lambda\sum_{j=0}^{\tau}\frac{x_{t-j}}{S_{t-j}}}\right)+\frac{x_t}{S_t}\right]+\beta E_t\left[\frac{p_t c_t}{p_{t+1}c_{t+1}}V_{t+1}(\tau+1)\right] \tag{A97}$$

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 (A77). The value upon entry of the firm at time t is equal to $V_t(0)$. Notice that $V_t(0)$ can be written recursively as follows:

$$V_t(0) = V_{1t} - e^{-\lambda\frac{x_t}{S_t}} V_{2t} \tag{A98}$$

where

$$V_{1t} = \left(1-\frac{1}{\theta}\right)\left[\frac{p_t\left(c_t+i_t\right)}{s_t}+\frac{x_t}{S_t}\right]+\beta E_t\left(\frac{p_t c_t}{p_{t+1}c_{t+1}}V_{1t+1}\right) \tag{A99}$$

$$V_{2t} = \left(1-\frac{1}{\theta}\right)\frac{p_t\left(c_t+i_t\right)}{s_t}+\beta E_t\left(\frac{e^{-\lambda\frac{x_{t+1}}{S_{t+1}}}p_t c_t}{p_{t+1}c_{t+1}}V_{2t+1}\right) \tag{A100}$$

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

$$\xi_t = \omega_0\left(\frac{w_t}{S_{t-1}}\right)^{\omega}(m_t)^{1-\omega} = \omega_0\left(\frac{w_t}{S_{t-1}}\right)^{\omega}\left(\frac{1}{\theta}\right)^{1-\omega} \tag{A101}$$

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:

$$V_t(0) = \xi_t. \tag{A102}$$

Aggregate profits Aggregate profits are equal to

$$\tau_t = \left[p_t\left(c_t+i_t\right)+x_t\right]\left(1-\frac{1}{\theta}\right)-(S_t-S_{t-1})\xi_t \tag{A103}$$

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

$$\begin{aligned} l_t &= \left[\frac{1}{\sigma}+(1-\frac{1}{\sigma})\omega\right]\frac{\xi_t}{w_t}\left(S_t-S_{t-1}\right)+\frac{p_t\left(c_t+i_t\right)+x_t}{w_t\sigma\theta} \\ &= \left[\frac{1}{\sigma}+(1-\frac{1}{\sigma})\omega\right]\left(\frac{S_{t-1}}{\theta w_t}\right)^{1-\omega}\left(\frac{S_t}{S_{t-1}}-1\right)+\frac{1}{\sigma}\frac{p_t\left(c_t+i_t\right)+x_t}{\theta w_t} \end{aligned} \tag{A104}$$

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

$$\begin{aligned} k_t &= \frac{\left(1-\frac{1}{\sigma}\right)(1-\omega)\xi_t}{r_t}(S_t - S_{t-1}) + \frac{\left(1-\frac{1}{\sigma}\right)\left[p_t\left(c_t+i_t\right)+x_t\right]}{\theta r_t} \\ &= \frac{1-\frac{1}{\sigma}}{r_t\theta^{1-\omega}}\left[(1-\omega)\,\omega_0\left(\frac{w_t}{S_{t-1}}\right)^{\omega}(S_t-S_{t-1}) + \frac{p_t\left(c_t+i_t\right)+x_t}{\theta^{\omega}}\right] \end{aligned} \tag{A105}$$

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

$$p_t\left(c_t+i_t\right)+x_t = \left\{\sigma\left[l_t - \left[\frac{1}{\sigma}+(1-\frac{1}{\sigma})\omega\right]\frac{\xi_t}{w_t}(S_t-S_{t-1})\right]\right\}^{\frac{1}{\sigma}}\left\{\frac{\left[k_t - \frac{(1-\frac{1}{\sigma})(1-\omega)\xi_t}{r_t}(S_t-S_{t-1})\right]}{1-\frac{1}{\sigma}}\right\}^{\frac{\sigma-1}{\sigma}} \tag{A106}$$

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

E.2 Equilibrium

An equilibrium is a tuple

$$\left(c_t, i_t, x_t, l_t, \frac{\partial v_t}{\partial k_t}, \frac{\partial v_t}{\partial s_{t-1}}, \frac{\partial v_t}{\partial \mu_{t-1}}, w_t, r_t, p_t, k_{t+1}, \mu_t, s_t, S_t, \xi_t, V_t(0)\right) \tag{A107}$$

such that

1. The optimal saving decision of households in (A84) holds:

$$\frac{1}{c_t} = \beta\left[(1-\varkappa) + \frac{r_{t+1}}{p_{t+1}}\right]\frac{1}{c_{t+1}} \tag{A108}$$

2. The optimal choice for experimentation of households in (A85) is satisfied

$$\frac{1}{p_t c_t} = \left[\frac{1}{\sigma-1}\frac{1}{s_t}\frac{c_t+i_t}{c_t} + \beta\frac{\partial v_{t+1}}{\partial s_t}\right]\lambda\left(\frac{S_t - s_{t-1}}{S_t}\right)e^{-\frac{\lambda x_t}{S_t}} + \left[\frac{\eta\left(\mu_t\right)}{\sigma-1}\frac{c_t+i_t}{c_t} + \beta\frac{\partial v_{t+1}}{\partial \mu_t}\right]\frac{\lambda}{S_t} \tag{A109}$$

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 (A88) holds:

$$\psi_0\, l_t^{\psi} = \frac{w_t}{p_t c_t} \tag{A110}$$

4. The marginal value of capital satisfies (A84):

$$\frac{\partial v_t}{\partial k_t} = \frac{1}{c_t}\left[(1-\varkappa) + \frac{r_t}{p_t}\right] \tag{A111}$$

5. The marginal value of a new sector in the consideration set evolves as in (A86):

$$\frac{\partial v_t}{\partial s_{t-1}} = e^{-\frac{\lambda x_t}{S_t}}\left[\frac{1}{\sigma-1}\frac{1}{s_t}\frac{c_t+i_t}{c_t} + \beta\frac{\partial v_{t+1}}{\partial s_t}\right] \tag{A112}$$

6. The marginal value of a new variety in the consideration set evolves as in (A87):

$$\frac{\partial v_t}{\partial \mu_{t-1}} = (1-\delta)\left[\frac{1}{\sigma-1}\eta\left(\mu_t\right)\frac{c_t+i_t}{c_t} + \beta\frac{\partial v_{t+1}}{\partial \mu_t}\right] \tag{A113}$$

7. The aggregate budget constraint of the economy in (A77) is satisfied:

$$\left[p_t\left(c_t+i_t\right)+x_t\right]\frac{1}{\theta} + (S_t - S_{t-1})\xi_t = r_t k_t + w_t L_t \tag{A114}$$

8. Aggregate prices satisfy (A79):

$$p_t = \left[\Gamma\left(1-\frac{\sigma-1}{\alpha}\right) s_t \sum_{n=0}^{\infty} n^{\frac{\sigma-1}{\alpha}} f(n;\mu_t)\right]^{-\frac{1}{\sigma-1}} \tag{A115}$$

with

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

9. The capital stock evolves as in (A80):

$$k_{t+1} = (1-\varkappa)\, k_t + i_t \tag{A116}$$

10. The average number of varieties in the consideration set of the household evolves as in (A81):

$$\mu_t = (1-\delta)\,\mu_{t-1} + \frac{\lambda x_t}{S_t} \tag{A117}$$

11. The number of sectors in the consideration set of the household evolve as in (A82):

$$s_t = e^{-\frac{\lambda x_t}{S_t}} s_{t-1} + \left(1-e^{-\frac{\lambda x_t}{S_t}}\right) S_t \tag{A118}$$

12. The value of an innovation satisfies (A98):

$$V_t(0) = V_{1t} - e^{-\lambda\frac{x_t}{S_t}} V_{2t} \tag{A119}$$

where

$$V_{1t} = \left(1-\frac{1}{\theta}\right)\left[\frac{p_t\left(c_t+i_t\right)}{s_t}+\frac{x_t}{S_t}\right]+\beta E_t\left(\frac{p_t c_t}{p_{t+1}c_{t+1}}V_{1t+1}\right) \quad \text{(A120)}$$

$$V_{2t} = \left(1-\frac{1}{\theta}\right)\frac{p_t\left(c_t+i_t\right)}{s_t}+\beta E_t\left(\frac{e^{-\lambda\frac{x_{t+1}}{S_{t+1}}}p_t c_t}{p_{t+1}c_{t+1}}V_{2t+1}\right) \quad \text{(A121)}$$

13. There is free entry in R&D so that (A102) holds true:

$$V_t(0)=\xi_t \quad \text{(A122)}$$

14. The marginal cost of an innovation is equal to (A101):

$$\xi_t=\omega_0\left(\frac{w_t}{S_{t-1}}\right)^{\omega}\left(\frac{1}{\theta}\right)^{1-\omega} \quad \text{(A123)}$$

15. The labor market clears so that (A104) holds true:

$$l_t=\left[\frac{1}{\sigma}+(1-\frac{1}{\sigma})\omega\right]\frac{\xi_t}{w_t}\left(S_t-S_{t-1}\right)+\frac{p_t\left(c_t+i_t\right)+x_t}{w_t\sigma\theta} \quad \text{(A124)}$$

16. The aggregate resource constrain in (A106) is satisfied:

$$p_t\left(c_t+i_t\right)+x_t = \left\{\sigma\left[l_t-\left[\frac{1}{\sigma}+(1-\frac{1}{\sigma})\omega\right]\frac{\xi_t}{w_t}\left(S_t-S_{t-1}\right)\right]\right\}^{\frac{1}{\sigma}} \left\{\frac{\left[k_t-\frac{1}{r_t}\left(1-\frac{1}{\sigma}\right)(1-\omega)\,\xi_t\left(S_t-S_{t-1}\right)\right]}{1-\frac{1}{\sigma}}\right\}^{1-\frac{1}{\sigma}} \quad \text{(A125)}$$

E.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 (A107) 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

$$\left(c, i, x, l, \frac{\partial v}{\partial k}, \frac{\partial v}{\partial s}, \frac{\partial v}{\partial \mu}, w, r, p, k, \mu, s, S_t, \xi, V(0)\right). \tag{A126}$$