Price Search, Consumption Inequality, and Expenditure Inequality over the Life Cycle*

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Abstract

In this paper, we incorporate price search decision into an otherwise standard life-cycle model with incomplete markets and endogenous labor supply, and differentiate consumption from expenditure. In our model, consumers are allowed to allocate part of their time on searching for low prices which leads to an endogenous price dispersion. We analytically derive the conditions under which price search can generate a lower consumption inequality than expenditure inequality. A plausibly calibrated version of the model predicts that the life-cycle increase in the variance of consumption is around 40% lower than the increase in the variance of expenditure. Moreover, we show that price search provides an additional quantitatively significant partial insurance mechanism against adverse income shocks.

Keywords: Consumption inequality, price search, incomplete markets, life cycle models, partial insurance.

J.E.L. Classification: D10, D91, E21.

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1 Introduction

Most of the earlier literature regarding life cycle profiles of consumption inequality implicitly assume that consumption and expenditure are identical.[1] From the data (typically Consumer Expenditure Survey (CEX)) they estimate the life cycle profile of inequality, and conclude that it rises around 30 log points over the life cycle. However, another strand of literature has documented significant dispersion in prices paid for identical goods.[2] Motivated by the dispersion in prices documented in the empirical literature, this paper focuses on the role of price search in the age-inequality profiles of consumption and expenditure. We believe that filling this gap in the literature is important to understand the dynamics of consumption inequality over the life cycle. By using a quantitative model, we show that assuming expenditure to be equal to consumption potentially over estimates the rise in the consumption inequality by about 40 percent. In addition, we find that price search acts as a quantitatively important additional insurance mechanism against adverse income shocks.

To quantify the significance of price search, we use a standard life-cycle model with incomplete markets and endogenous labor supply. However, we also allow agents to search for cheaper prices in addition to the usual saving and labor supply channels for insurance against adverse shocks. As a result of idiosyncratic income shocks, people are ex-post heterogeneous in terms of their income realizations and wealth accumulation. If agents search more for cheaper prices, they pay less and consume more; however, they enjoy less leisure due to time constraints. Optimality implies that in equilibrium the marginal return and cost of price search should be equalized. The marginal return to price search comes from additional consumption, and it is smaller for agents who already have high consumption. That implies that agents with low wealth and bad income shocks search more and pay less.

We first analyze the determinants of price search decision. We analytically show that when labor supply is exogenous and risk aversion is large enough (higher than log case), price search is a decreasing function of wealth. We show that this relation can be reversed when risk aversion is sufficiently small (lower than log case). However, when labor supply is endogenous, price search becomes positively correlated with wealth. We also show that price search monotonically decreases with wage when risk aversion is higher than 1. We then analyze the effect of price search on expenditure inequality and consumption inequality. We analytically show that expenditure inequality is

[1] Some classic examples of this literature are Deaton and Paxson (1994), Blundell and Preston (1998), Gourinchas and Parker (2002), Storesletten et al (2004), Krueger and Perri (2006), Guvenen (2007), Blundell et al (2008), Kaplan and Violante (2010) and Heathcote et al (2014).

[2] Baye et al. (2006) provide a detailed survey on the dispersion in prices paid for identical goods. For instance, Aguiar and Hurst (2007) document that, in the U.S. data, richer people pay higher prices for identical goods. Also, they report that prices paid for identical goods change over the life cycle, which is a result of a change in price search due to a change in the cost of time. Using the U.S. data, Sorensen (2000) documents dispersion in prices paid for the same medicine. Dahlbay and West (1986) report price dispersion in automobile insurance companies in Canadian data. Pratt et al. (1979) document price dispersion in several categories of goods. Baye et al. (2004) document dispersion in prices for identical goods posted in the internet.

larger than consumption inequality when risk aversion is higher than 1 and when labor supply is exogenous. In the case of endogenous labor supply, this gap crucially depends on the covariance of consumption and wage. Given that empirically motivated quantitative life-cycle models generate a positive covariance between consumption and wage, we can show that expenditure inequality is higher than consumption inequality when labor supply is endogenous. We, next, calibrate our model, and quantify the magnitude of this gap for the U.S. economy. Our results show that the life-cycle increase in the variance of consumption is roughly 40% smaller than the life-cycle increase in the variance of expenditure.

In addition to its impact on consumption levels, price search channel enables consumers to insure themselves against stochastic income shocks. Following the formulation of Blundell et al (2008) and Kaplan and Violante (2010), we quantify the partial insurance role of price search by computing the consumption insurance coefficients with respect to transitory and persistent shocks. The computed insurance coefficient of consumption for persistent shocks is 8% higher in the model with price search compared to the one with no price search. The same coefficient is 15% higher for transitory shocks. The fact that price search has an insurance role for consumers requires paying attention to policies that might affect the potential benefits from price search. Size-dependent subsidy policies and opening-time restrictions are two examples which might affect the potential benefits from price search.

Among many other studies in the quantitative life-cycle literature, this paper is closely related to Guvenen (2007), Storesletten et al. (2004), and Karahan and Ozkan (2010). Those papers study the role of income processes on the age-inequality profile of consumption. Kaplan (2012) extends a similar model with unemployment risk to better match age-inequality profiles of consumption and labor allocations over the life cycle. There is a common implicit assumption in those models that says the price of a consumption good is unique, and therefore consumption is equal to expenditure. However, as we mentioned above, there is a large empirical literature that rejects this assumption. Our paper differs from the standard life-cycle studies in the sense that it differentiates consumption from expenditure. We show that this distinction plays a quantitatively significant role in the age-inequality profile of consumption.

The paper continues as follows. In section 2, we present the model. We explain the details of the calibration in section 3. In section 4, we report the results, finally we conclude in section 5.

2 Model

We extend a standard life-cycle consumption-saving problem with endogenous labor supply and a price search technology, which allows agents to search for cheaper prices and partially insure against adverse income shocks. We study the age-inequality profiles of consumption and expenditure. The asset markets are incomplete due to uninsurable idiosyncratic income shocks. The population consists of a continuum of agents who work for T periods and afterwards enjoy retirement until period T^*. The retirement is imposed exogenously at period T. Each component of the model is explained in detail below.

2.1 Households

At each period, agents have two decisions: one is the consumption/saving decision, and the other is the time allocation decision between labor supply and price search. Agents can enjoy more consumption by searching for cheaper prices; however, he/she enjoys less leisure or has lower labor supply in that case. They maximize life time expected value of discounted utility:

$$E\sum_{t=0}^{T^*}\beta^t u(c_t, s_t+n_t)$$

where, $u(\cdot)$ is period utility, β is the time discount factor, c_t is consumption, s_t the time spent on price search, and n_t is labor supply for the agent at period t. We use a utility function that is quite standard in the literature, and is specified as follows:

$$u(c_t, s_t+n_t) = \frac{c_t^{1-\sigma}}{1-\sigma} - \phi\frac{(s_t+n_t)^{1+\gamma}}{1+\gamma}$$

The parameter ϕ affects the disutility received from price search and labor supply. It could also be interpreted as the cost of the time the agent spends on price search and labor supply.

Upon realization of current wage, agents choose to allocate their time over price search and labor supply. The asset markets are incomplete. Agents can only borrow or save through a risk-free interest-bearing asset. Agents face the following budget constraint at time t:

$$p(s_t, c_t)c_t + a_{t+1} = w_t n_t + (1+r)a_t$$

where $p(\cdot)$ is the price of a consumption good which depends on the individual search time and consumption. Consumption and saving at the current period are denoted with c_t and a_{t+1}, respectively. Current period wage is denoted with w_t, and we follow the literature for the process governing the evolution of wages over the life-cycle. At each period, the agent is assumed to receive a persistent and a transitory labor income shock. The log wage follows:

$$\log(w_t) = \beta_0 + \beta_1 t + \beta_2 t^2 + z_t + \epsilon_t, \quad \text{with } \epsilon_t \sim (0, \sigma_\epsilon^2)$$

where β_0 is a scale parameter, β_1 is return to experience, t is the years of experience , z_t is the persistent wage shock and ϵ_t is the transitory wage shock. The persistent wage shocks follow an $AR(1)$ process:

$$z_t = \rho z_{t-1} + \nu_t, \quad \text{with} \quad z_0 = 0 \text{ and } \quad \nu_t \sim N(0, \sigma_\nu^2)$$

We also assume that households face a borrowing limit, which is a constant fraction ($\underline{a}$) of the natural borrowing limit at each period.

Price Search Technology: Following Aguiar and Hurst (2007), we assume a log linear form for the price function:

$$\log(p_t) = \theta_0 + \theta_1 \log(s_t) + \theta_2 \log(c_t) \tag{1}$$

where θ_1 is the return to search on prices conditional on the amount of goods consumed. In the log linear form, doubling search decreases prices by $100 * \theta_1$ percent. We also allow that the amount of goods consumed to affect the prices as estimated in Aguiar and Hurst (2007). Consistent with the estimates in the literature we assume the following restrictions for the parameters:

Assumption 1 $\theta_1 < 0$ *and* $\theta_2 \geq 0$.

$\theta_1 < 0$ ensures that the return to price search is positive, i.e. higher search is associated with lower prices. $\theta_2 \geq 0$ implies that higher consumption implies a non-negative increase in the prices paid.

3 Theoretical Results

In the model, while consumption and saving choices are dynamic, labor supply and price search are static choices. So, we can separate the problem into a static and a dynamic problem. In the static problem, the individual chooses the optimal level of labor supply and price search given the current wealth and next period saving choice. In the dynamic problem, the individual chooses the optimal saving level for the next period given the static choices. We, now, focus on the static problem.

3.1 Static Problem

The static problem can be summarized as the maximization of the periodic utility function given the state variables and choice of next period saving. Denoting w as the current period wage rate and y as the current wealth net of saving, we can formulate the static problem as follows:

$$\max_{c,s,n} u\left(c, s+n\right)$$

s. to

$$p(s,c)\,c = wn + y \tag{2}$$

Given the functional form for the utility function and price technology, the first order conditions (FOC) with respect to labor supply and price search of the static problem can be written as:

$$\varphi(s+n)^{\gamma} = w\frac{c^{-\sigma}}{p(1+\theta_2)} \tag{3}$$

$$\varphi(s+n)^{\gamma} = -\theta_1\frac{pc}{s}\frac{c^{-\sigma}}{p(1+\theta_2)} \tag{4}$$

These equations are easy to interpret. Equation (3) shows that the marginal cost of additional labor (left hand side - LHS) should be equal to the marginal benefit of additional labor, w, multiplied by the marginal utility of consumption. Equation (4) shows a similar trade-off for price search. Again the LHS is the marginal cost of additional search effort, and the RHS is the marginal benefit of search, which is $-\theta_1\frac{pc}{s}$, multiplied with the marginal utility of consumption.

No Labor Supply: We first analyze the case when $n = 0$ which can be generated either by sufficiently large wealth retirement.[3] In this case, we have the following result:

Lemma 1 *Given Assumption 1, if labor supply is exogenous or zero, then price search is independent of wealth if* $\sigma = 1$*, and it is decreasing in wealth if* $\sigma > 1$*. That is,*

$$\frac{ds}{dy}\begin{Bmatrix} = 0 & \textit{if } \sigma = 1 \\ < 0 & \textit{if } \sigma > 1 \end{Bmatrix}$$

Without labor supply choice marginal cost of price search is independent of wealth. Wealth can only affect price search through its effect on the marginal benefit. As wealth increases, income effect decreases the marginal benefit of search whereas substitution effect increases it. When $\sigma = 1$, these two effects cancel out, and we have no change in price search. Price search becomes $\log s = \frac{\log\left(\frac{-\theta_1/\varphi}{1+\theta_2}\right)}{1+\gamma}$. However, when $\sigma > 1$ income effect dominates, and marginal benefit of search decreases as wealth increases. Thus, price search decreases.

Positive Labor Supply: Now, we turn to the case where labor supply is positive. In this case, the following lemma characterizes the price search as a function of wealth and wage.

[3] The following argument is also true when labor supply is exogenous.

Lemma 2 *When labor supply is endogenous and positive, the equation characterizing price search becomes:*

$$A \log s + \gamma \log \left(Bs - \frac{y}{w} \right) = C + D \log w \tag{5}$$

where $A = 1 - \frac{(1-\sigma)(1-\theta_1)}{1+\theta_2}$, $B = \frac{\theta_1 - 1}{\theta_1}$, $C = \log \left(\frac{-\theta_1/\varphi}{1+\theta_2} \right) + \frac{(\sigma-1)(\log(-\theta_1)+\theta_0)}{1+\theta_2}$, *and* $D = \frac{1-\sigma}{1+\theta_2}$.

Although, we can not derive an explicit equation for price search, it is possible to make comparative statics with respect to wealth and wage on price search using equation (5). The following proposition shows that when the curvature of the utility function on consumption is sufficiently high, price search increases as wealth increases.

Lemma 3 *When labor supply is endogenous and positive, price search increases as wealth increases if* $\sigma \geq 1$, *i.e.* $\frac{ds}{dy} > 0$.

The intuition is as follows. As net wealth increases, consumption and leisure should increase, i.e. the sum of labor supply and price search decreases. Equation (3) suggests that as wealth increases consumption increases, and this, in turn, decreases marginal benefit of additional labor supply due to pure income effect captured by the term $\frac{c^{-\sigma}}{p(1+\theta_2)}$. This results the labor supply to decrease. Equation (4) suggests that as wealth increases the marginal benefit of price search may increase or decrease. On the one hand, as wealth increases, due to income effect, marginal benefit of price search decreases, which is captured by the term $\frac{c^{-\sigma}}{p(1+\theta_2)}$. On the other hand, there is also the substitution effect. As wealth increases consumption increases, and the return to price search increases, which is captured by the term $-\theta_1 \frac{pc}{s}$. If $\sigma > 1$, then substitution effect dominates and marginal benefit of search increases as wealth increases. Moreover, a decrease in the labor supply generated by decreases the marginal cost. Thus, price search increases.

Lemma 4 *When labor supply is endogenous and positive, price search is decreasing in wage if* $\sigma \geq 1$. *That is,* $\frac{ds}{dw} < 0$ *if* $\sigma \geq 1$.

An increase in wage may increase or decrease the labor supply depending the magnitude of substitution and income effects. However an increase in wage generates an income effect for price search decision. Higher wage is associated with higher consumption, which decreases the marginal benefit of search if $\sigma > 1$. This effect unambiguously decreases price search.

An immediate implication of above Lemmas is that price search is a non-monotone function of wealth. When wealth is low labor supply is positive, and price search increases as wealth increases. However, when wealth is sufficiently large, wealth effect dominates, labor supply becomes zero. At that point, price search becomes a decreasing function of wealth. So, as wealth increases, the price paid for goods initially decreases, but then after some wealth level, it starts to increase. This is consistent with the results of several studies which documents potential non-monotonicity in prices paid as a function of income.[4]

3.2 Expenditure vs Consumption Inequality

After deriving the optimality conditions for price search, we can now discuss the effect of price search on consumption and expenditure inequality. Our ultimate goal is to understand the effect of price search on the wedge between consumption and expenditure inequality. Since expenditure is equal to price times consumption, we can express the connection between expenditure and consumption inequality as follows:

$$Var\left(\log e\right) = Var\left(\log c\right) + Var\left(\log p\right) + 2Covar\left(\log p, \log c\right)$$

So, the difference between expenditure inequality and consumption inequality depends on the variance of log prices paid and covariance of log prices and log consumption. We next analyze these terms in the case of exogenous labor supply and endogenous labor supply.

Exogenous Labor Supply: In the case of exogenous labor supply, we can derive an analytical expression defining the relation between expenditure and consumption inequality. Expenditure inequality, defined by the variance of log expenditures, becomes a constant proportion of consumption inequality, defined by the variance of log consumption. The following lemma summarizes this result:

Lemma 5 *When labor supply is exogenous, the relation between variance of log expenditures and variance of log consumption is characterized by the following equation:*

$$Var\left(\log e\right) = \left(\theta_1 \frac{1-\sigma}{1+\gamma} + 1 + \theta_2\right)^2 Var\left(\log c\right) \tag{6}$$

Corollary 1 *When labor supply is exogenous, variance of log expenditure is equal to variance of log consumption if $\sigma = 1$, and variance of log expenditure is higher than variance of log consumption if $\sigma > 1$, i.e.*

$$Var\left(\log e\right) \begin{Bmatrix} = Var\left(\log c\right) & \text{if } \sigma = 1 \\ > Var\left(\log c\right) & \text{if } \sigma > 1 \end{Bmatrix}$$

This result is an immediate consequence of equation (6). As we know from the static problem, price search does not depend on consumption if $\sigma = 1$. Then, we have $Var\left(\log p\right) = 0 =$

[4] See survey by Kaufman et al. (1997).

$Covar(\log p, \log c)$. Hence, variance of log expenditures and variance of log consumption are the same. Again from the static problem we know that price search is negatively correlated to consumption when $\sigma > 1$. This means price and consumption are positively correlated since search decreases price paid. So, we have $Var(\log p) > 0$ and $Covar(\log p, \log c) > 0$. Thus, variance of log expenditures becomes higher than variance of log consumption.

Endogenous Labor Supply:

Lemma 6 *If labor supply is endogenous, the relation between consumption and expenditure inequality is as follows:*

$$Var(\log e) = \left(\frac{1+\theta_2}{1-\theta_1}\right)^2 Var(\log c) + \left(\frac{\theta_1}{1-\theta_1}\right)^2 Var(\log w) - 2\frac{\theta_1(1+\theta_2)}{(1-\theta_1)^2} Cov(\log c, \log w) \quad (7)$$

$Var(\log w)$ is an increasing function over the life-cycle. Moreover, $Cov(\log c, \log w)$ is positive and also slightly increasing over the life-cycle both in the model and the data. So, using the above equation, we can conclude that the difference between $Var(\log e)$ and $Var(\log c)$ is positive and increasing over the life-cycle.

4 Quantitative Results

As we analyzed in the theoretical section, the presence of price search can potentially generate a difference between consumption and expenditure inequality. Moreover, price search can alter the asset accumulation of households since it serves as an additional insurance mechanism for adverse shocks in addition to the standard insurance mechanisms like saving and labor supply. However, the presence of dynamic choices and uncertainty prevents us to derive analytical results for the evolution of consumption, expenditure and wealth inequality over the life-cycle. So, in this section, we quantitatively evaluate the significance of price search in an otherwise standard life-cycle model with incomplete markets and endogenous labor supply. We first start with the calibration of the model.

4.1 Calibration

We calibrate the model in two stages. In the first stage, we directly use the values of some parameters that are well established in the related literature. This gives us the opportunity to understand the role of price search in the standard life cycle models. A model period is set to one year, and each agent starts working at age 21 and retires at 65. Each agent starts working life with an asset and income level drawn from a log-normal distribution with mean $\mu_{a/y}$ and variance $\sigma_{a/y}$. The values for these parameters are directly taken from Gourinchas and Parker (2003), which estimate $\mu_{a/y}$ to be -2.79 and $\sigma_{a/y}$ to be 1.78. We set $r = 0.03$, which is roughly equal to return on risk-free investment in the U.S. The value of the relative risk-aversion parameter for consumption, σ, is set to a very standard value in the literature, 2.[5] The value of parameter γ, which pins down intertemporal elasticity of substitution for leisure, is usually set greater than the value of σin the literature. Therefore, we set the value of γ to 2.5.[6] The parameters of income process - β_0, β_1, β_2, ρ, σ_ε^2 and σ_v^2 - are borrowed from the literature.[7] In the benchmark model, we set θ_2 equal to 0.21, which is consistent with the estimates of Aguiar and Hurst (2005).

For the pension process, we follow Guvenen (2007), which mimics the U.S. Social Security system. After retirement, the pension of each agent is determined by the ratio of his wage in the last working period to the average wage in the last working period, $\frac{w_T}{\bar{w}}$. The pension function, $\Gamma(\frac{w_T}{\bar{w}})$ is as follows:

$$= \bar{w} \times \bar{n} \times \begin{cases} 0.9\frac{w_T}{\bar{w}}, & \text{if } \frac{w_T}{\bar{w}} < 0.3 \\ 0.27 + 0.32(\frac{w_T}{\bar{w}} - 0.3), & \text{if } 0.3 < \frac{w_T}{\bar{w}} < 2 \\ 0.81 + 0.15(\frac{w_T}{\bar{w}} - 2), & \text{if } 2 < \frac{w_T}{\bar{w}} < 4.1 \\ 1.1 & \text{if } 4.1 < \frac{w_T}{\bar{w}}. \end{cases}$$

where $\bar{w}$ is the average wage paid in the economy and $\bar{n}$ is the average hours worked.

In the second stage, we estimate the remaining parameters to match chosen moments in the data. For the quantitative performance of the model, we also assume that the return to price search follows a linear trend over the working period. We impose this assumption to better match the life-cycle evolution of prices paid we observe in the data.[8] So, we assume that $\theta_1(t) = \theta_1^0 + \theta_1^1 t$ before retirement, i.e. when $t \leq T$, and $\theta_1(t) = \theta_1(T)$ after retirement, i.e. when $t > T$.

Together with these two parameters for the return to price search, the other estimated parameters are the discount factor, β, relative weight of work disutility in the utility function, ϕ, borrowing limit coefficient, $\underline{a}$, and the constant in the price function, θ_0. In total, we jointly estimate six parameters, β, θ_0, θ_1^0, θ_1^1, ϕ, $\underline{a}$ to match the following moments: wealth-to-income ratio

[5] This number is very standard in both real business cycle literature and heterogeneous agents literature. An acceptable range for the value of σ is usually takes from 1 to 10.

[6] Storesletten et al. 2004, Chang and Kim 2007, Kaplan 2012 use similar numbers

[7] Guvenen (2009), Storesletten et al. (2004) are some examples which estimate similar values to the ones used in this paper.

[8] This assumption can be rationalized due to several factors like experience, access to better technologies, higher time endowment due to marriage, etc. Moreover, we find almost no effect of such a linear trend assumption on the evolution of consumption and expenditure inequality over the life-cycle. The model with constant returns to price search produces almost identical results for the evolution of consumption and expenditure inequality, but generates an increasing price paid over the life-cycle. The increasing price over the life-cycle is due to increasing consumption over the life-cycle. As higher consumption increases prices paid, life-cycle price is increasing with age without any trend in the returns to price search.

Table 1: Benchmark Model Parameters

Parameter	Explanation	Value
	Externally Set	
r	risk-free interest rate (U.S. data)	0.03
σ	intertemporal elasticity of substitution for consumption (various sources)	2
γ	intertemporal elasticity of substitution for leisure (various sources)	2.5
ρ	persistence of earning shocks (various sources)	0.96
σ_{ε}^2	variance of transitory earning shocks (various sources)	0.062
σ_v^2	variance of persistent earning shocks (various sources)	0.015
$\mu_{a/y}$	mean of initial asset/income dist (Gourinchas and Parker 2003)	-2.79
$\sigma_{a/y}$	variance of initial asset/income dist (Gourinchas and Parker 2003)	1.78
β_0	constant of the wage process	0.4
β_1	return to experience	0.032
β_2	return to experience-squared	-0.00035
	Internally Calibrated	
β	discount factor	0.956
θ_0	constant in price function	0.76
ϕ	weight of disutility of work in utility	27.9
$\underline{a}$	fraction of borrowers	0.40
θ_1^0	constant of returns to price search trend	-0.22
θ_1^1	slope of returns to price search trend	0.003

Table 2: Benchmark Model-Moments

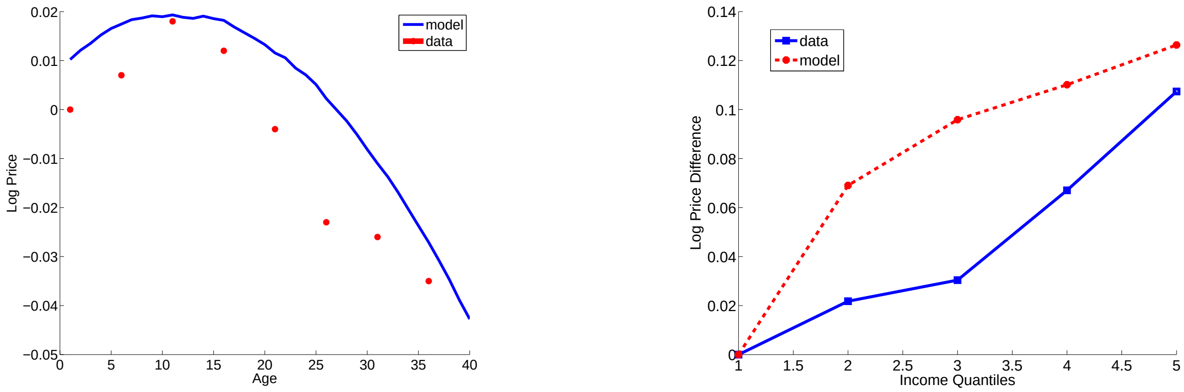
Moment	Data	Model
Wealth-income ratio	3.5	3.5
Mean hours worked	0.33	0.32
Fraction of borrowers	0.17	0.17
Average price paid	1.0	1.0

(3.5) as documented in Heathcote et al (2010), mean hours worked (0.33), fraction of borrowers (0.17) as estimated from Survey of Consumer Finance, average price paid (1.0) as normalization, and life-cycle profile of average prices paid as documented in Aguiar and Hurst (2007).

4.2 Results

Table 2 presents the model generated moments against the data counterparts. Not surprisingly, the model matches all the targeted moments quite well. Moreover, Figure 1(a) shows the life-cycle profile of average prices paid by households generated by the model. The pattern is consistent with the estimates of Aguiar and Hurst (2007) and Kaplan and Menzio (2014).

Figure 1(b) compares the model with data in terms of average prices paid by income quintiles. In the model, average price paid by the highest earning quintile is 10% higher than that of the



(a) Life-Cycle

(b) Income

Figure 1: **Average Price Paid - Model vs Data:** The figure on the left panel plots the life-cycle profile of average prices paid over the life-cycle both in the model and the data. It shows the deviation of prices paid from age 0, which corresponds to age 25 in the data. The figure on the right panel plots the average price paid for different income quintiles in the model versus the data. Empirical relationship between the level of earnings and prices is calculated using the data set of Aguiar and Hurst (2007). The sample is divided into quintiles in terms of labor income levels. We calculate the mean log price for each good and income group across shopping trips. We then average over goods by weighting with the number of shopping trips. In the model, we divided population into quintiles in terms of labor income, calculate average price paid by each quintile, and draw the log deviations from the 1st quintile.

lowest earning quintile. The corresponding number is 11% in the data.[9]

Figure 4.2 shows the life-cycle profile of average hours worked both in the model and the data. Although the model does not target the life-cycle profile of hours worked, it matches the pattern in the data quite well apart from the time prior to retirement. In the data hours worked decreases substantially before retirement. Although the model also generates a decreasing pattern of hours worked, it cannot generate the size of the decline right before retirement. Factors like early retirement, added-worker effect, age-dependent unemployment shocks can help to reconcile the model and the data.

Given the success of the model to match some important features of the data, we next present the statistics of our interest for this paper. We first start with the determinants of price search decision. Section 3 predicts that in our model price search should be negatively correlated with wage, and non-monotone in wealth. More specifically, when labor supply is positive which happens when wealth is not very high, price search increases with wealth. However, when labor supply becomes zero which happens when wealth is sufficiently large, price search becomes negatively correlated with wealth.

Figure 3(a) and 3(b) confirm these results. Figure 3(a) shows that as wealth increases price search initially increases, consistent with the predictions of Lemma 3. However, after sufficiently

[9]We borrowed the data set (A.C. Nielsen Homescan data) of Aguiar and Hurst (2007) for this analysis.

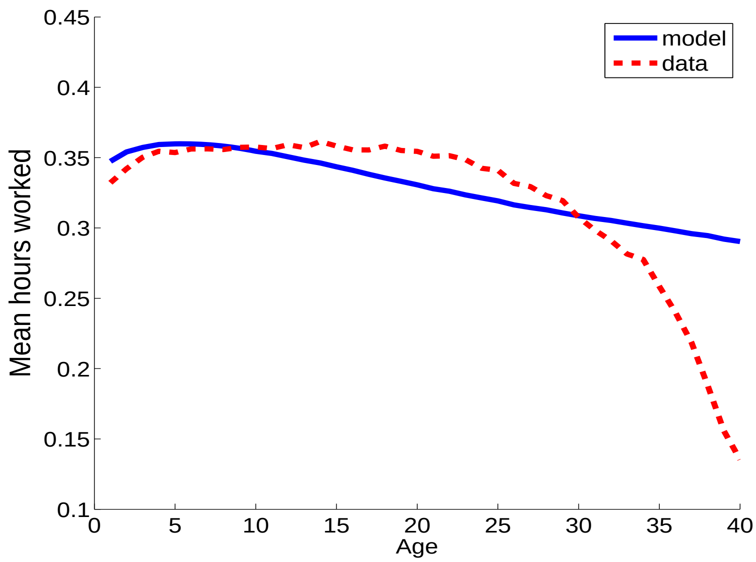


Figure 2: **Average Hours Worked - Model vs Data:** The figure plots life-cycle profile of average hours worked in the model and the data.

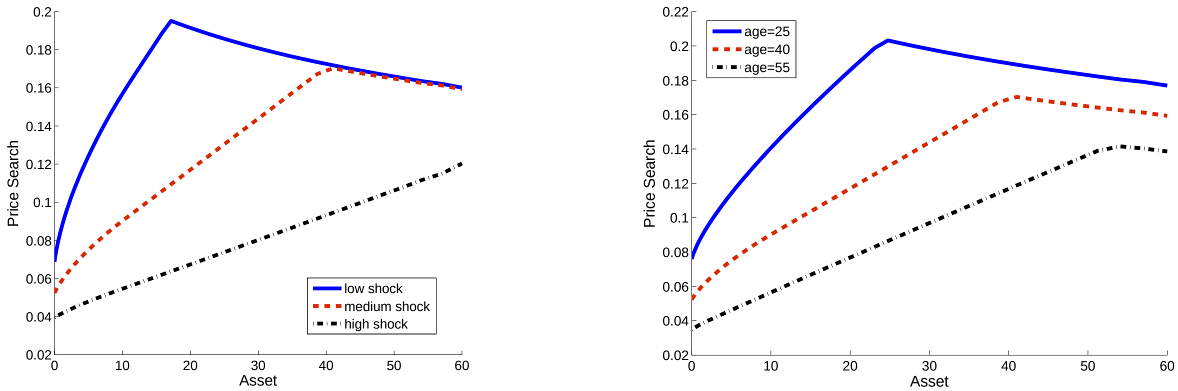
large wealth, it starts to decrease as predicted by Lemma 1. The turning point coincides with the wealth level when labor supply becomes zero. The same figure also shows the effect of wage on price search.[10] Higher wage implies higher labor supply and lower price search as stated in Lemma 4. Figure 3(b) also shows that as household ages, price search decreases. This is due to two effects. First, wage increases as household ages, and this decreases the price search. Second, thanks to our calibration, returns to price search decreases as household ages. So, this effect mechanically decreases price search over the life-cycle.

Given these determinants of price search, we now analyze the quantitative effect of price search on expenditure and consumption inequality. We measure inequality by the variance of log of the variables.

4.2.1 Age-Inequality Profiles of Consumption and Expenditure

In the earlier studies, consumption was assumed to be equal to expenditure, which implied exactly equal age-inequality profiles for consumption and expenditure. In this paper, we differentiate consumption from expenditure by introducing price search into the model. Our model predicts a substantially lower consumption inequality than expenditure inequality throughout the life cycle. As Figure 4(a) shows cross-sectional variance of log expenditure increases by almost 30 log points

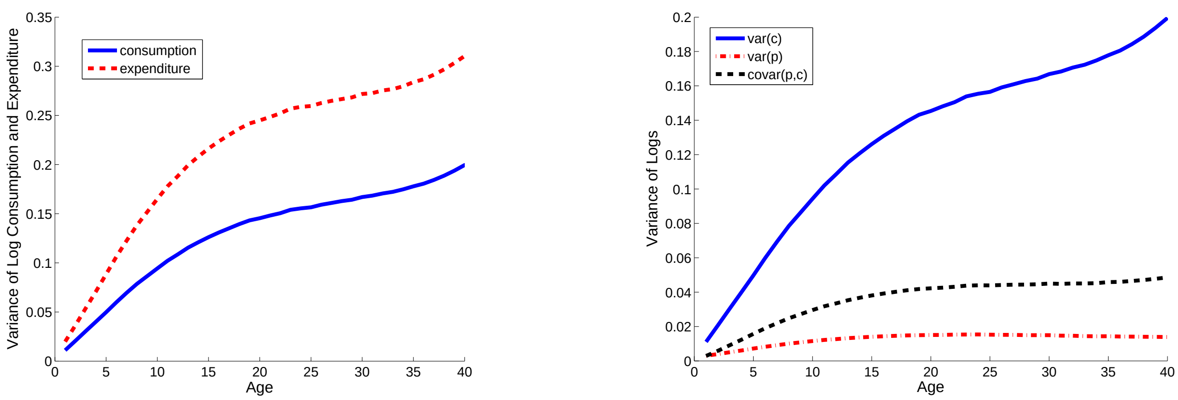
[10]Wages correspond to different levels of persistent shock. The plot with transitory shocks generate the same qualitative results.



(a) Wage (b) Age

Figure 3: **Determinants of Price Search:** The figure shows model generated price search decision as a function of wealth, wage and age. The price search decisions are shown for a household at the age 40 with median level of both persistent and transitory shocks.

over the life cycle whereas variance of log consumption increases by only 19 log points. This is almost 40% reduction in the increase of inequality over the life-cycle.[11]



(a) Expenditure vs Consumption Inequality (b) Decomposition of Expenditure Inequality

Figure 4: **Expenditure and Consumption Inequality:** The figure on the left plots the life-cycle profile of consumption and expenditure inequality measured by the variance of log of the variables. The figure on the right decomposes the expenditure inequality into its components: variance of consumption, variance of prices and covariance between consumption and prices.

In order to understand the gap between the consumption variance and the expenditure variance

[11]The age-inequality profile of expenditures in our model is consistent with Deaton and Paxson 1994 and Guvenen 2007. However, our main result - the % difference between age-inequality profiles of consumption and expenditure - is robust to flatter age-inequality profiles of expenditure. We tested this by imposing lower persistent earnings shocks to the model.

throughout the life cycle, we decompose the expenditure variance:

$$var(\log e) = var(\log c) + var(\log p) + 2cov(\log c, \log p)$$

We calculate each component of $var(\log e)$ from the model-generated data. As can be seen from 4(b), around 63% of the increase is due to the increase in the variance of log consumption, around 34% of the increase is due to the increase in the covariance between consumption and price, and the rest 3% is due to the increase in the variance of prices paid.

Price and consumption over the life-cycle are positively correlated. We can see this by analyzing the covariance term. We can rewrite the covariance between consumption and price using the equation 1 as follows:

$$Covar(\log p, \log c) = \theta_1 Covar(\log s, \log c) + \theta_2^2 Var(\log c)$$

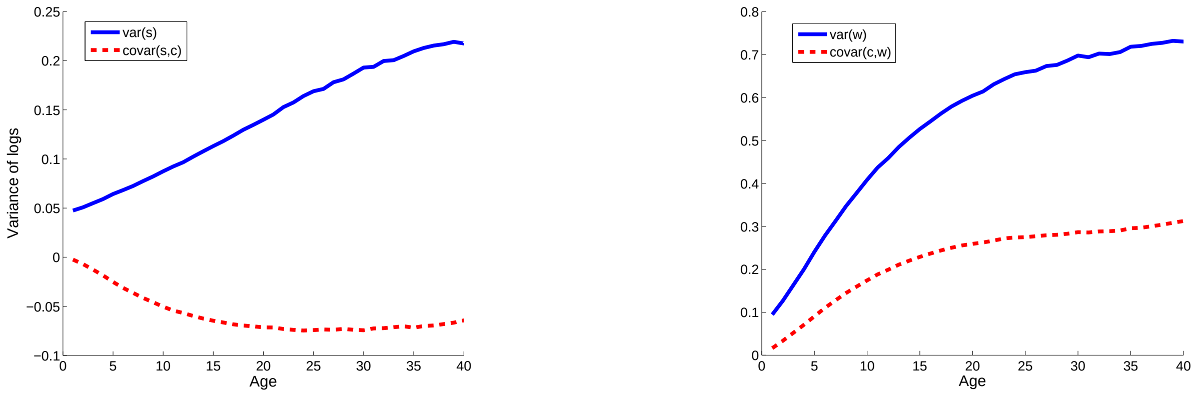
Since $\theta_1 < 0$ and the second term is positive, it is clear from above equation that as long as $Covar(\log s, \log c) < 0$, we have positive correlation between consumption and price. Equation 4 shows that since $\sigma > 1$, we have negative correlation between price search and consumption. Intuitively, higher consumption creates income effect for the household, and this forces the household to decrease the price search. Figure 5(a) plots the life-cycle profile of the covariance between consumption and price search. As expected it is negative. Moreover, it becomes more negative as the household ages. This is because, as the household ages, wealth increases and labor supply responds less to the changes in wealth, and price search becomes the important insurance mechanism. From the theoretical section, we know that when this happens, price search and consumption becomes negatively correlated thanks to the fact that $\sigma > 1$, i.e. income effect is larger.

Lastly, as in Lemma 6, the variance of log expenditure can be decomposed into variance of log consumption, variance of log wages, and covariance of log wages and log consumption:

$$Var(\log e) = \left(\frac{1+\theta_2}{1-\theta_1}\right)^2 Var(\log c) + \left(\frac{\theta_1}{1-\theta_1}\right)^2 Var(\log w) - 2\frac{\theta_1(1+\theta_2)}{(1-\theta_1)^2} Cov(\log c, \log w)$$

Figure 5(b) shows the evolution of wage inequality and covariance of wages and consumption over the life-cycle. Wage inequality substantially increases over the life-cycle as a result of parametrization. However, the covariance of wages and consumption is also positive and increases significantly over the life-cycle. Our calibration reveals that especially the covariance of consumption and wages is quite effective in the gap between consumption and expenditure inequality.[12]

[12] Notice that we assume $\theta_1 < 0$ and it is substantially smaller than 1. So, it is clear that the coefficient of covariance between consumption and wages is substantially larger than the coefficient of variance of wages in equation 7.



(a) Price Search and Consumption Inequality

(b) Wage and Consumption Inequality

Figure 5: **Decomposition of Expenditure Inequality:** The figure on the left plots the life-cycle profile of the variance of log price search and covariance of log of price search and log of consumption. The figure on the right plots the life-cycle profile of the variance of log of wage and covariance of log of wage and log of consumption.

4.2.2 Measuring the Partial Insurance Role of Price Search

In this section, we compute the amount of partial insurance gained through price search. In order to quantify the partial insurance role of price search, we resolve the model without price search. To separate the effect of price search we recalibrate the discount factor, β, borrowing limit, $\bar{a}$, and disutility of work, ϕ, to match the same statistics for wealth-income ratio, mean hours worked and fraction of households with debt. This calibration results $\beta = 0.95$, $\phi = 51.4$ and $\bar{a} = 0.43$ generating wealth-income ratio of 3.5, mean hours worked as 33% and fraction of borrowers as 17%.

Following Blundell et al. (2008) and Kaplan and Violante (2010), we calculate the insurance coefficients:

$$\phi^{\epsilon} = 1 - \frac{cov(\Delta c_{it}, \epsilon_{it})}{var(\epsilon_{it})} \tag{8}$$

where insurance coefficient of shock ϵ is denoted with ϕ^{ϵ}. In the complete markets framework, $\phi^{\epsilon} = 1$ due to the fact that idiosyncratic shocks do not affect consumption, that is $cov(\Delta c_{it}, \epsilon_{it}) = 0$. In an autarky environment, consumption is one-to-one mapped to idiosyncratic shocks, therefore $\phi^{\epsilon} = 0$. Under incomplete markets, one would expect insurance coefficients between 0 and 1.

Using U.S. micro-level consumption data, Blundell et al. (2008) estimate insurance coefficients as 0.36 and 0.95 for permanent and transitory shocks, respectively.[13] Kaplan and Violante (2010) generate similar coefficients in a simulated economy using a life cycle model with incomplete asset markets, inelastic labor supply and idiosyncratic income shocks where agents face natural borrowing

[13] They use the Panel Study of Income Dynamics (PSID) and Consumer Expenditure Survey (CEX) data. See Blundell et al. 2008 for details.

Table 3: Insurance Coefficients

	w/ Price Search		w/out Price Search	
	Expenditure	Consumption	Expenditure	Consumption
Transitory	.84	.98	.91	.91
Persistent	.56	.70	.61	.61

Notes: The insurance coefficients are calculated using equation (8). The coefficients are calculated for the entire population. See text for details.

limits.

Using equation (8), we compute the insurance coefficients for the entire population in our benchmark economy. As shown in Table 3, in the case of no price search, the computed insurance coefficients are 0.61 (persistent shock) and 0.91 (transitory shock) for both consumption and expenditure.[14] With price search, the corresponding insurance coefficient for consumption increases to 0.70 for the persistent shock and to 0.98 for the transitory shock.[15] The corresponding coefficients for expenditure are 0.56 and 0.84, respectively. In the model with price search, the consumption insurance coefficients of persistent and transitory shocks are improved by 0.09 (15%) and 0.07 (8%), respectively.

4.3 Robustness Analysis

In this section we provide several robustness analysis with respect to some important parameters of the model, specifically with respect to the parameters of the price function and the preference parameters. In all these counterfactuals, we recalibrate the discount factor (β), disutility of labor (ϕ), borrowing limit constant ($\bar{a}$), and price function constant (θ_0) to match wealth-income ratio, mean hours worked, fraction of borrowers, and mean price paid.

There are two important parameters of the price function. The first one is the return to price search, θ_1, which is assumed to be age dependent in the benchmark model to match the average price profile over the life-cycle. The second parameter for the search technology is θ_2, the effect of the size of consumption bundle on the price. We explore the effect of these two parameters on the evolution of consumption and expenditure inequality.

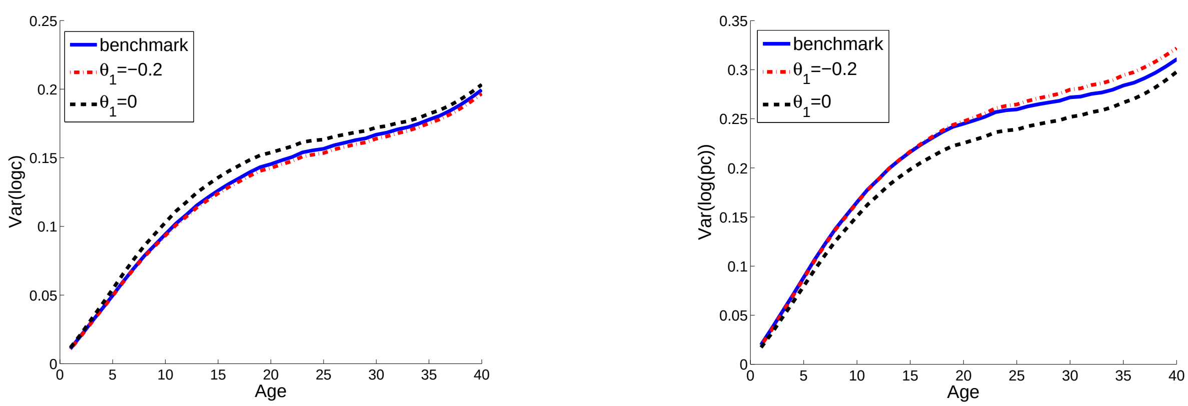
Returns to Price Search: From equation (7) we know that the difference between expenditure inequality and consumption inequality depends on the values of θ_1 and θ_2 together with the variance

[14] Note that consumption is equal to expenditure by definition in this case.

[15] Using natural borrowing limits, Kaplan and Violante 2010 compute insurance coefficients for consumption in the range of 0.30-0.52 (depending on the persistence of the shocks) for persistent shocks and 0.92-0.93 for transitory shocks.

of consumption, the variance of the log wages and covariance of log consumption and log wages. Wage inequality, by construction, is exogenous in the model. The only endogenous objects in equation (7) that can effect the difference between expenditure inequality and consumption inequality are the variance of consumption and the covariance of consumption and wages. So, changes in the parameters of the price function (specifically θ_1 and θ_2) affect the difference between expenditure and consumption inequality in two ways. First, they directly affect the importance of each object in equation (7). Second, they can also affect the level of the variance of the consumption and the covariance between consumption and wages, which, in turn affect the difference between expenditure and consumption inequality.

In Figures 6(a) and 6(b), we show quantitatively how a change in the return to price search affects the difference between expenditure inequality and consumption inequality over the life-cycle. In the benchmark model, θ_1 follows a linear trend over the life-cycle. It starts with a value of -0.22, and increases up to -0.09 by retirement. The average value of θ_1 is -0.15, which is within the range estimated by Aguiar and Hurst (2007). To analyze the effect of the return to price search, we solve the model by setting θ_1 to a constant value of over the life-cycle. In the benchmark model the maximum of the difference between expenditure and consumption inequality is around 11 log points. When θ_1 is set to -0.2 for every age, the difference increases to 12 log points, whereas when θ_1 is set to 0, then the difference decreases to 9 log points. So, the higher the return to price search, the higher the difference between expenditure inequality and consumption inequality over the life-cycle is.

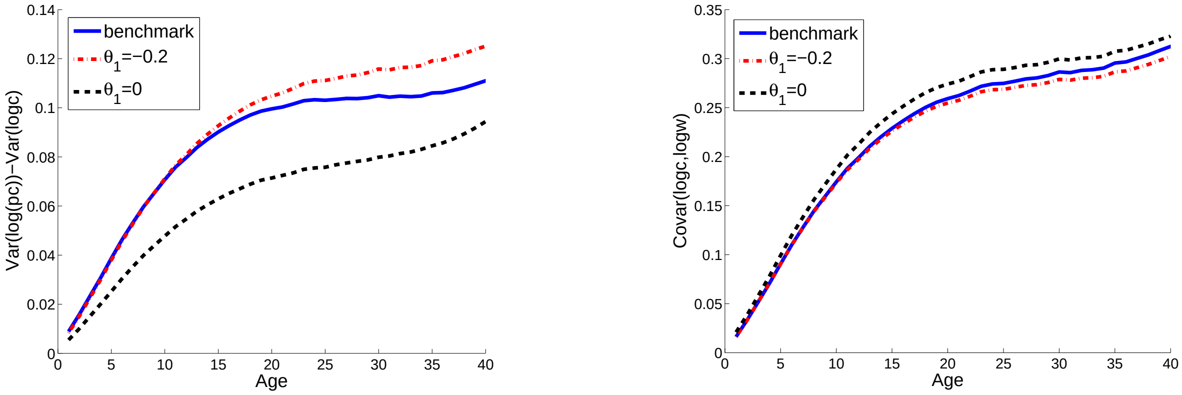


(a) Consumption

(b) Expenditure

Figure 6: **The Effect of Returns to Price Search:** The figure shows the effect of the return to price search on the variance of log expenditure and variance of log consumption.

Mechanically, an increase in θ_1, which means a decrease in the return to price search, decreases the significance of wage inequality and covariance of consumption and wages on the difference between expenditure and consumption inequality. Given that wage inequality is constant and as-



(a) Var(log(pc))-Var(logc)

(b) Covar(logc,logw)

Figure 7: **The Effect of Returns to Price Search:** The figure shows the effect of the return to price search on the difference between variance of log expenditure and variance of log consumption, and on the covariance between log consumption and log wages.

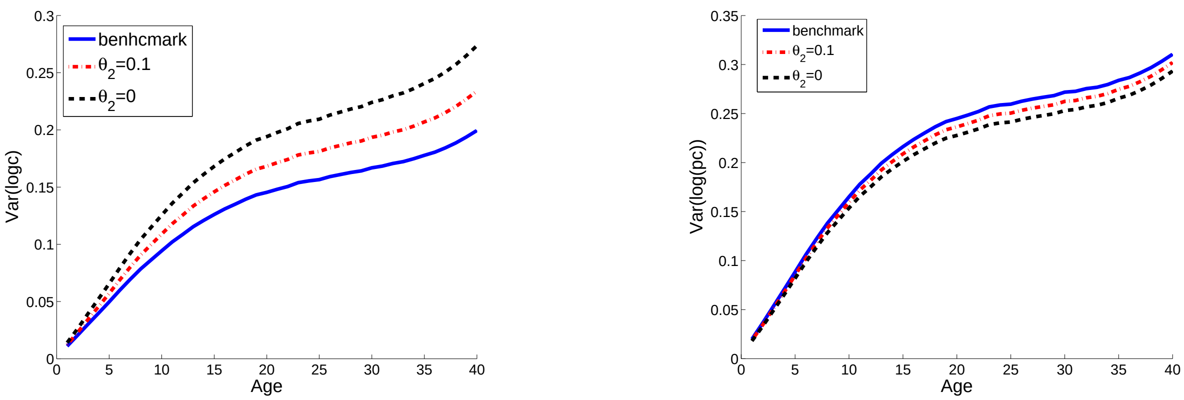
suming covariance of consumption and wage does not change, this effect should lower the difference between expenditure and consumption inequality. On the other hand, an increase in θ_1 increases the coefficient of the variance of log consumption in equation (7), and this effect should increase the difference between expenditure and consumption inequality. Lastly, an increase in θ_1 can change the level of the variance of log consumption and the covariance of consumption and wages. Since the insurance channel through price search is weakened due to a decrease in the return to price search, we expect that shocks to the wages are less likely to be insured and more likely to be translated into consumption. So, we should observe a higher variance of consumption and a higher covariance between consumption and wages as shown in Figures 6(a) and 7(b). Higher consumption inequality and higher covariance of consumption and wages should increase the difference between expenditure and consumption inequality. However, as shown in Figures 6(a) and 7(b), these changes are quantitatively small, and the first two effects dominate. So, an increase in θ_1 decreases the difference between expenditure and consumption inequality.

Intuitively, as the return to price search decreases, the insurance role of price search decreases, and we expect the gap between expenditure and consumption inequality to decrease. As Figures 6(a) and 6(b) suggest, lower return to price search results a lower increase in expenditure inequality but a higher increase in consumption inequality. Notice that when $\theta_1 = 0$, price search becomes zero, however, we still observe a substantial difference between expenditure and consumption inequality (around 9 log points). This is because of the differences in prices paid by households generated by the differences in consumption. In fact, when $\theta_1 = 0$, using equation (7), we can express the relation between expenditure inequality and consumption inequality as follows:

$$Var\left(\log e\right) = \left(1 + \theta_2\right)^2 Var\left(\log c\right)$$

So, expenditure inequality becomes a constant fraction of consumption inequality, which is dictated by the value of θ_2.

Size of Consumption Bundle: As a next robustness check, we explore the effect of θ_2, the effect of the size of consumption bundle on price paid. This effect is governed by the parameter θ_2. Using equation (7), we can see that an increase in θ_2 mechanically increases the coefficients of variance of log consumption and covariance of consumption and wages. So, these two effects should increase the difference between expenditure and consumption inequality. However, an increase in θ_2 also implies a higher price paid for the same amount of consumption and a higher variance for the prices paid. As a result variance of consumption and covariance between consumption and wages decrease. These two effects should decrease the difference between expenditure and consumption inequality.



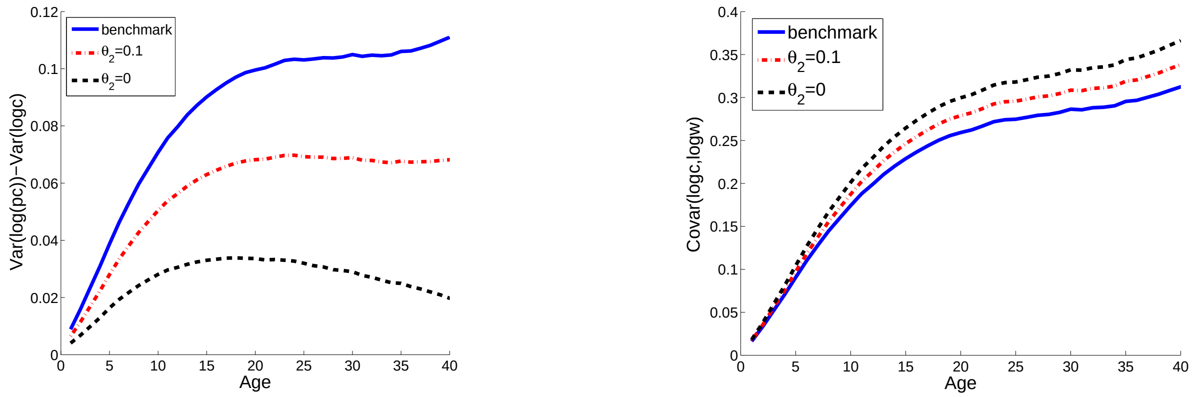
(a) Consumption

(b) Expenditure

Figure 8: **The Effect of the Size of Consumption Bundle:** The figure shows the effect of the return to the size of consumption bundle on the variance of log expenditure and variance of log consumption.

Confirming the results implied by equation (7), Figures 8(a) and 9(b) show that the variance of consumption and the covariance of consumption and wage decrease as θ_2 increases. However, an increase in θ_2 also increases the coefficients of these terms in equation (7). With current calibration, the second effect dominates and, as shown in Figure 9(a), the difference between expenditure and consumption inequality increases as θ_2 increases. Intuitively, higher θ_2 means that households who have lower consumption pay lower prices. This fact causes a relatively lower expenditure for the poor households. So, effectively, higher θ_2 increases the insurance role of price search. As a result, as θ_2 increases we expect consumption inequality to decrease and expenditure inequality to increase, which is the prediction of the model as shown in Figures 8(a) and 8(b).

The fact that elasticity of prices to search (θ) is quantitatively very important for the insurance role of price search requires paying attention to policies that might affect this elasticity. Guner et



(a) Var(log(pc))-Var(logc)

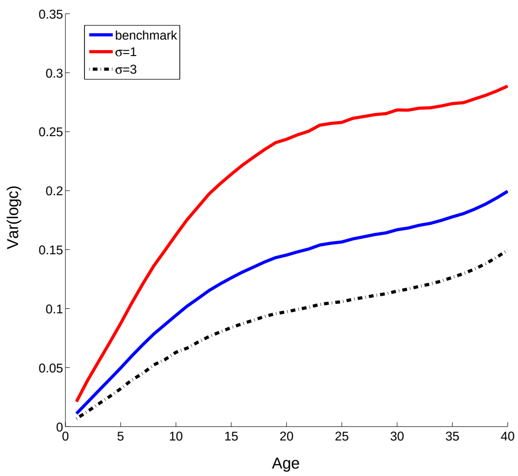
(b) Covar(logc,logw)

Figure 9: **The Effect of the Size of Consumption Bundle:** The figure shows the effect of the return to the size of consumption bundle on the difference between variance of log expenditure and variance of log consumption, and on the covariance between log consumption and log wages.

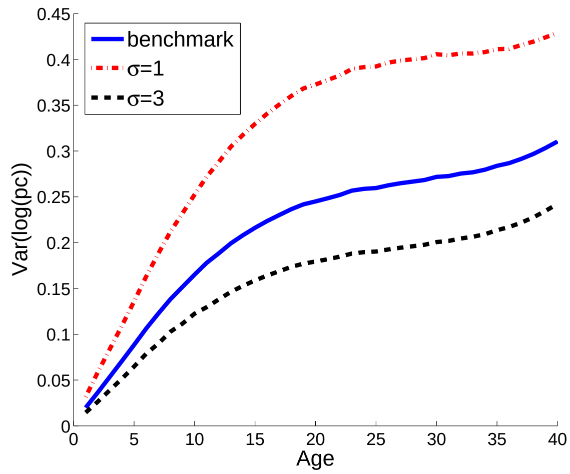
al. (2008) discuss size-dependent policies in favor of small firms. They argue that depending on the type of policy, the dispersion in the size distribution of firms might increase or decrease. The increased dispersion in firms' sizes might potentially increase the dispersion of prices across firms which would potentially improve the returns to search. That would lead to an improvement in insurance role of price search. A decrease in dispersion of firms' size-distribution would possibly create an opposite effect.

Opening-time restrictions might be consider another type of policy that might potentially affect the insurance role of price search. This kind of a restriction would potentially put a constraint to the shopping time flexibility of consumers, which would constrain the benefits of price search. For many people, cost of various time periods such as day-time, evening, weekday, and weekend are arguably different from each other. Opening-time restrictions for shops would lead to constraints while choosing the optimal time for shopping and reduce the potential benefits from price search.

Risk Aversion: In the models with incomplete markets, risk aversion is an important parameter which determines the desire for consumption smoothing. It is well known within these models that as risk aversion increases consumption inequality decreases. This fact is also confirmed by Figure 10(a) in our model. However, the same fact also decreases the expenditure inequality as confirmed in Figure 10(b). So, it is not clear what happens to the difference between expenditure and consumption inequality. However, equation (7) shows us that an increase in risk aversion only affects the difference between expenditure and consumption inequality through its effect on the variance of consumption and covariance of consumption and wages. We know that higher risk aversion, which implies higher desire for consumption smoothing, decreases both the variance of consumption and the covariance of consumption and wages as also shown in Figure 11(b). So, the difference between expenditure and consumption inequality decreases as risk aversion increases, which is also confirmed in Figure 11(a).



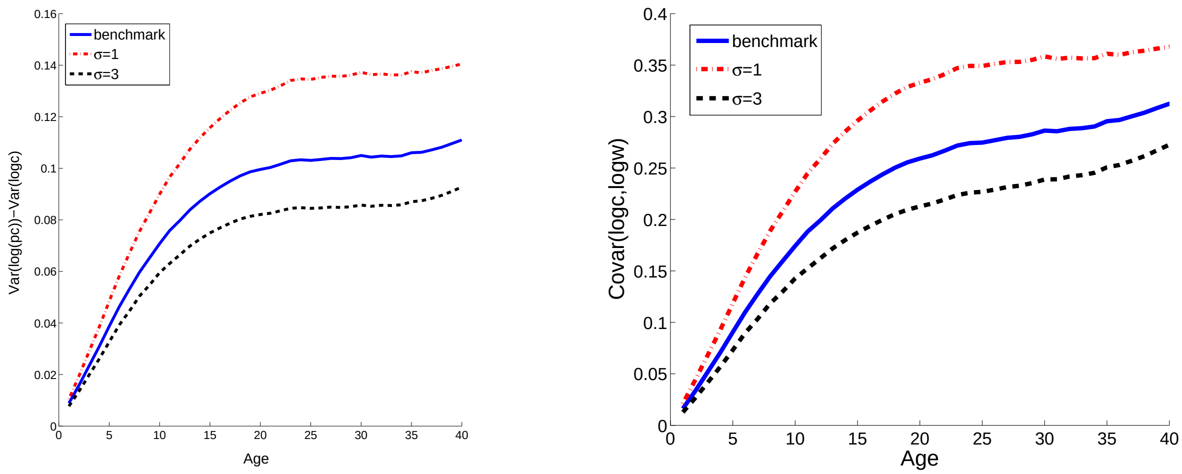
(a) Consumption



(b) Expenditure

Figure 10: **The Effect of Risk Aversion:** The figure shows the effect of risk aversion on the variance of log expenditure and variance of log consumption.

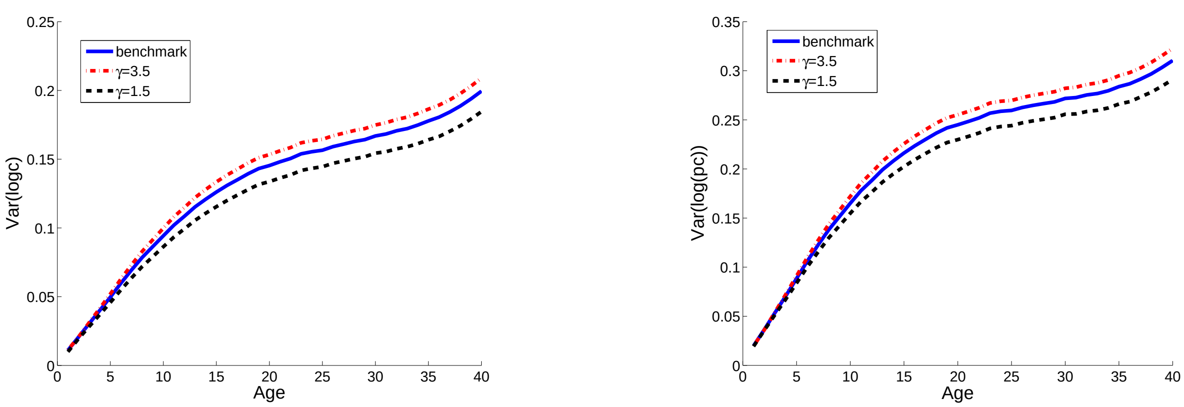
Frisch Elasticity: Frisch elasticity is an important parameter in our model, which effects the insurance role of labor supply to avoid the fluctuations in consumption generated by exogenous and stochastic movements in wages. In our model, Frisch elasticity is equal to $\frac{1}{\gamma}$. As Frisch elasticity increases, labor supply becomes more elastic, and labor supply can play a more significant role to insure against wage fluctuations. So, higher Frisch elasticity should imply lower consumption and expenditure inequality. This is confirmed by Figures 12(a) and 12(b) in our model. As these figures show, a decrease in γ, which translates into a higher Frisch elasticity, decreases both expenditure and consumption inequality. Although the net effect on the difference between expenditure and consumption inequality looks ambiguous, equation (7) shows that this difference depends on the variance of consumption and covariance of consumption and wages. A decrease in γ decreases both of these terms as also shown in Figures 12(a) and 13(b). So, we expect the difference between expenditure and consumption inequality to decrease as γ decreases, which is confirmed by Figure 13(a).



(a) Var(log(pc))-Var(logc)

(b) Covar(logc,logw)

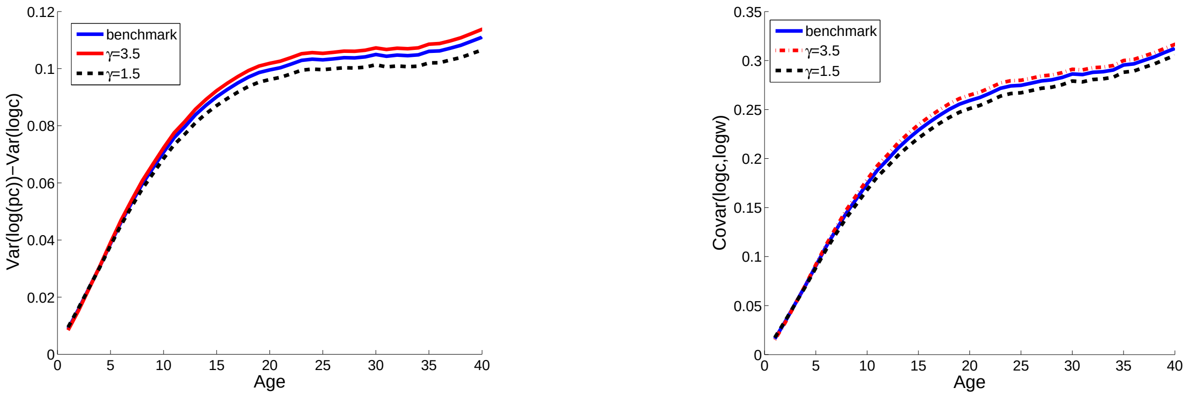
Figure 11: **The Effect of Risk Aversion:** The figure shows the effect of risk aversion on the difference between variance of log expenditure and variance of log consumption, and on the covariance between log consumption and log wages.



(a) Consumption

(b) Expenditure

Figure 12: **The Effect of Frisch Elasticity:** The figure shows the effect of Frisch Elasticity on the variance of log expenditure and variance of log consumption.



(a) Var(log(pc))-Var(logc)

(b) Covar(logc,logw)

Figure 13: **The Effect of Frisch Elasticity:** The figure shows the effect of Frisch Elasticity on the difference between variance of log expenditure and variance of log consumption, and on the covariance between log consumption and log wages.

5 Discussion and Conclusion

In this paper, we study the role of price search on the age-inequality profiles of consumption and expenditure. We introduce a price search decision into a life-cycle model, differentiate consumption from expenditure, and study the joint behavior of shopping strategies, individual prices, labor supply, and consumption/saving decisions. The model predicts an increasing age-inequality profile for consumption and expenditure. Our quantitative exercise - using an estimated income process and price search functions from the literature - predicts that consumption inequality is significantly lower than expenditure inequality when agents are allowed to search for prices. A plausibly calibrated version of our model predicts that the cross-sectional variance of log consumption is about 40% smaller than that of log expenditure throughout the life cycle. However, in the earlier studies, consumption inequality was implicitly assumed to be the same as expenditure inequality.[16]

Although we focused on age-inequality profiles, the model can be extended to explain further empirical observations. For instance, Aguiar and Hurst (2013) document different patterns in different expenditure categories. Price search could be helpful in explaining the different patterns because some categories might be more sensitive to price search than others. The life-cycle search profile may have different implications for the expenditure patterns of different categories due to their different sensitivities. Carroll and Summers (1989) document different expenditure patterns for different education groups. Again, price search together with conventional earning processes could be helpful to explain these expenditure patterns. Different price search technologies or time cost profiles for different education or occupation groups could be helpful in explaining the different

[16]For example; Storesletten et al. (2004), Krueger and Perri (2006), Guvenen (2007).

expenditure patterns. In this paper, we used a fixed cost of time (the coefficient of leisure in the utility function) for the same age groups. It is possible that the variance of the opportunity cost of time across ages and within ages might vary over the life cycle for different education and occupation groups. Potentially it might have important implications on inequality in general.

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NOT FOR PUBLICATION

Supplemental Appendix

Proofs

Proof. [**Lemma 1**] Without labor supply, the FOC with respect to price search becomes

$$\varphi s^{1+\gamma} = -\frac{\theta_1}{1+\theta_2} c^{1-\sigma}$$

Taking the log of both sides and substituting equations (1) and (2) into above equation, we get the following equation characterizing the price search:

$$\left(1+\gamma+\frac{(1-\sigma)\,\theta_1}{1+\theta_2}\right)\log s = \log\left(\frac{-\theta_1/\varphi}{1+\theta_2}\right) + \frac{(1-\sigma)\,(\log y - \theta_0)}{1+\theta_2}$$

Taking the total differentiation of both sides, we have

$$\frac{ds}{dy} = \frac{1-\sigma}{(1+\gamma)\,(1+\theta_2) + (1-\sigma)\,\theta_1}$$

The Lemma is an immediate consequence of this equation since $\theta_1 < 0$. ■

Proof. [**Lemma 2**] Rearranging the terms in (4), we get

$$s\,(s+n)^{\gamma} = \frac{-\theta_1/\varphi}{1+\theta_2} c^{1-\sigma}$$

Taking the logs of both sides, we have

$$\log s + \gamma \log (s+n) = \log\left(\frac{-\theta_1/\varphi}{1+\theta_2}\right) + (1-\sigma)\log c \tag{A1}$$

Using equations (3) and (4)we get

$$s = -\theta_1 \frac{pc}{w} \tag{A2}$$

Taking the logs of both sides results

$$\log s - \log c = \log(-\theta_1) + \log p - \log w$$

Substituting equation (1) into above equation, we arrive at

$$\log c = \frac{(1-\theta_1)\log s - \log(-\theta_1) - \theta_0 + \log w}{1+\theta_2} \tag{A3}$$

Substituting equation (2) into equation ($A2$) we get

$$s = -\theta_1 \frac{wn + y}{w} = -\theta_1 \left(n + \frac{y}{w} \right)$$

which implies

$$n = -\frac{s}{\theta_1} - \frac{y}{w} \tag{A4}$$

Substituting equations ($A4$) and ($A3$) into equation ($A1$), we have

$$A \log s + \gamma \log \left(Bs - \frac{y}{w} \right) = C + D \log w$$

where $A = 1 - \frac{(1-\sigma)(1-\theta_1)}{1+\theta_2}$, $B = \frac{\theta_1 - 1}{\theta_1}$, $C = \log \left(\frac{-\theta_1/\varphi}{1+\theta_2} \right) + \frac{(\sigma-1)(\log(-\theta_1)+\theta_0)}{1+\theta_2}$, and $D = \frac{1-\sigma}{1+\theta_2}$. ■

Proof. **[Lemma 3]** If $\sigma > 1$, we have $A > 0$ in equation (5). Moreover, since $\theta_1 < 0$ by Assumption 1 we also have $B > 0$. Then, it is easy to see that price search, s, should increase as wealth, y, increases. ■

Proof. **[Lemma 4]** This is again an immediate consequence of equation (5). When $\sigma \geq 1$, we have $A > 0$ and $D \leq 0$. We also have $B > 0$ since $\theta_1 < 0$. As a result, the RHS of equation (5) is nonincreasing in wage, and the LHS is strictly increasing in wage. So, as wage increases price search should decrease. ■

Proof. **[Lemma 5]** Expenditure is defined as

$$\begin{aligned} e &= pc \\ \log e &= \log p + \log c \end{aligned}$$

Substituting equation (1) into above we have

$$\log e = \theta_0 + \theta_1 \log s + (1 + \theta_2) \log c$$

Taking the variance of both sides, we get

$$Var(\log e) = \theta_1^2 var(\log s) + (1 + \theta_2)^2 var(\log c) + 2\theta_1 (1 + \theta_2) cov(\log s, \log c) \tag{A5}$$

Using equation (4) evaluated at $n = 0$, we have

$$(1 + \gamma) \log s = \log \left(\frac{-\theta_1/\varphi}{1 + \theta_2} \right) + (1 - \sigma) \log c$$

Using this equation, we can write the $Var\left(\log s\right)$ as

$$Var\left(\log s\right)=\left(\frac{1-\sigma}{1+\gamma}\right)^{2}var\left(\log c\right)$$

and $Covar\left(\log s,\log c\right)$ as

$$Covar\left(\log s,\log c\right)=\frac{1-\sigma}{1+\gamma}var\left(\log c\right)$$

Substituting these expressions into $(A5)$, we get

$$\begin{aligned}Var\left(\log e\right) &= \left(\left(\theta_{1}\frac{1-\sigma}{1+\gamma}\right)^{2}+\left(1+\theta_{2}\right)^{2}+2\theta_{1}\left(1+\theta_{2}\right)\frac{1-\sigma}{1+\gamma}\right)Var\left(\log c\right)\\ &= \left(\theta_{1}\frac{1-\sigma}{1+\gamma}+1+\theta_{2}\right)^{2}Var\left(\log c\right)\end{aligned}$$

■

Proof. **[Lemma 6]** Using the budget identity, we have

$$\begin{aligned}\log e &= \log p+\log c\\ \log e &= \theta_{0}+\theta_{1}\log s+\left(1+\theta_{2}\right)\log c\end{aligned}$$

Substituting the expression for $\log s$ from equation $(A3)$, we get

$$\begin{aligned}\log e &= \theta_{0}+\theta_{1}\frac{\theta_{0}+\log\left(-\theta_{1}\right)+\left(1+\theta_{2}\right)\log c-\log w}{1-\theta_{1}}+\left(1+\theta_{2}\right)\log c\\ &= \frac{\theta_{0}+\theta_{1}\log\left(-\theta_{1}\right)}{1-\theta_{1}}+\frac{1+\theta_{2}}{1-\theta_{1}}\log c-\frac{\theta_{1}}{1-\theta_{1}}\log w\end{aligned}$$

Taking the variance of both sides, we get

$$Var\left(\log e\right)=\left(\frac{1+\theta_{2}}{1-\theta_{1}}\right)^{2}Var\left(\log c\right)+\left(\frac{\theta_{1}}{1-\theta_{1}}\right)^{2}Var\left(\log w\right)-2\frac{\theta_{1}\left(1+\theta_{2}\right)}{\left(1-\theta_{1}\right)^{2}}Cov\left(\log c,\log w\right)$$

■