

# Reconsidering the Microeconomic Foundations of Price-Setting Behavior

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## Abstract

Although the Dixit-Stiglitz aggregator is the workhorse specification of monopolistic competition, this framework and related variants are fundamentally inconsistent with a key stylized fact from empirical studies of consumer behavior and product marketing, namely, that the price elasticity of demand for a given brand is primarily determined by the *extensive margin* (i.e., changes in the number of customers purchasing that product) rather than the *intensive margin* (i.e., changes in the specific quantity purchased by each individual customer). In this paper, we analyze household scanner data to confirm the salient empirical results, and we then proceed to formulate a new dynamic general equilibrium framework that captures both the intensive and extensive margins of demand. Our theoretical framework involves a two-dimensional product space and incomplete household information, giving rise to an equilibrium price distribution with customer search. Assuming uniform distributions for the individual-specific search costs and for the firm-specific productivity shocks, we obtain analytical expressions for the equilibrium price distribution and the optimal price-setting behavior of each producer, and we show that the implications of the model are consistent with the key stylized facts. Finally, we discuss how this new approach holds substantial promise for future research on price-setting behavior, not only in enhancing the linkages between micro data and macro models but in building stronger connections to ongoing research in marketing and consumer behavior.

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*Keywords:* Customer Search; Product Differentiation; Extensive and Intensive Margin; Quasi-Kinked Demand Curve

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# 1 Introduction

Over the past several decades, monopolistic competition has played a crucial role in pushing out the frontiers of analytical and empirical work across a wide range of economic fields. In nearly all of those studies, monopolistic competition has been represented in terms of the household preference aggregator introduced by Dixit and Stiglitz (1977) or more recent variants.<sup>1</sup> In particular, the Dixit-Stiglitz aggregator has been a key building block in the development of New Keynesian economics; prominent examples include Rotemberg (1982), Blanchard and Kiyotaki (1987), Dornbusch (1987), Benhabib and Farmer (1994), Rotemberg and Woodford (1997, 1999), McCallum and Nelson (1999), and Khan, King, and Wolman (2003).<sup>2</sup> This specification has also been used in a number of seminal studies in international trade, endogenous growth, and economic geography; see Krugman (1980, 1991), Romer (1990), Grossman and Helpman (1991), Aghion and Howitt (1992), Jones (1995), Bernard et al. (2003), and Melitz (2003).

In recent years, the increased accessibility of highly disaggregated economic data has contributed to a growing interest in developing models of price-setting behavior that can provide closer links between the theory and the empirical evidence.<sup>3</sup> In macroeconomics, of course, that interest also reflects the ongoing quest to address the Lucas (1976) critique by building models with sufficiently deep micro foundations that are reasonably invariant to changes in the policy regime; moreover, the specific characteristics of the micro foundations can turn out to be crucial in determining the features of the welfare-maximizing policy and in assessing the welfare costs of alternative regimes.<sup>4</sup> Even in very recent studies, however, the Dixit-Stiglitz aggregator has continued to serve as the workhorse specification of monopolistic competition; see Broda and Weinstein (2006), Golosov and Lucas (2007), Klenow and Willis (2007), Gertler and Leahy (2008), and Mackowiack and Wiederholt (2008a,b).

Nevertheless, the Dixit-Stiglitz specification and related variants are fundamentally inconsistent with a key stylized fact from empirical studies of consumer behavior and product marketing, namely, that the price elasticity of demand for a given brand is primarily determined by the *extensive margin* (i.e., changes in the number of customers purchasing that

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<sup>1</sup>Such variants include the generalized preference aggregator introduced by Kimball (1995) and the deep habits formulation of Ravn, Schmitt-Grohe, and Uribe (2007).

<sup>2</sup>See also Yun (1996) and Erceg, Henderson, and Levin (2000).

<sup>3</sup>See Bils and Klenow (2003), Klenow and Kryvtsov (2008), Nakamura and Steinsson (2008), and Eichenbaum, Jaimovich, and Rebelo (2008).

<sup>4</sup>See Levin et al. (2005), Schmitt-Grohe and Uribe (2005), Levin, Lopez-Salido and Yun (2007), and Levin et al. (2008).

product) rather than the *intensive margin* (i.e., changes in the specific quantity purchased by each individual customer). Indeed, the extensive margin is completely absent from the Dixit-Stiglitz framework, which assumes that every household purchases output from *every* producer and hence that the elasticity of demand faced by the firm is identical to the own-price demand elasticity of households.

Moreover, the Dixit-Stiglitz framework imposes a very tight link between the steady-state demand elasticity and the markup of price over marginal cost; thus, given the available evidence that average price markups generally fall in the range of 5 to 25 percent, this specification is typically calibrated using a demand elasticity of about -5 to -20. In contrast, the empirical literature on consumer demand, including seminal studies by Stone (1954), Theil (1965), and Deaton and Muellbauer (1980), has consistently obtained very low estimates (around unity or below) for households own-price elasticity of demand, even for extremely narrow product categories. At the same time, the empirical marketing literature has documented the extent to which the elasticity of demand for a firm's product mainly depends on consumers choice of brand within that product category.

In this paper, we analyze household scanner data to confirm the key set of stylized facts, and we then proceed to formulate a new dynamic general equilibrium framework that captures both the intensive and extensive margins of demand. Our empirical analysis documents that consumers typically only purchase a single brand within each narrow product category. We also document that the own-price elasticity of household demand is quite low compared with the demand elasticity for each individual brand within that product category.

Our theoretical framework involves a two-dimensional product space and incomplete household information, giving rise to an equilibrium price distribution with customer search. The first dimension of the product space represents the set of narrow categories of consumer goods and services—such as bathsoap, breakfast cereal, toothpaste, haircuts, and automotive repairs—and the second dimension represents the set of nearly-identical producers within each category. Moreover, consistent with the typical pattern observed in the micro data, we assume that each household purchases items from only a single producer within each product category. To motivate an equilibrium with customer search over a non-trivial distribution of prices, the firms within each category are assumed to face idiosyncratic productivity shocks; the households are assumed to have full knowledge of this distribution but do not have any *ex ante* knowledge of the characteristics of individual producers and hence have an intrinsic search motive. There is a continuum of households,

and each household is comprised of many individual members; each member is responsible for searching across the producers within a single product category, and the fixed cost per search is assumed to vary randomly across the members of the household.

By assuming uniform distributions for the individual-specific search costs and for the firm-specific productivity shocks, we obtain analytical expressions for the equilibrium price distribution and the optimal price-setting behavior of each producer. We show that each firm faces a continuous downward-sloping demand curve, where the steady-state elasticity of demand can be represented as the sum of the elasticity at the intensive margin (which is determined by the households own-price elasticity of demand for that product category) and the elasticity at the extensive margin (which is determined by the distribution of search costs).

Using an empirical reasonable calibration, our framework can readily match the low elasticity of demand on the part of households along with the relatively high demand elasticity faced by each producer. Furthermore, the extensive margin of demand implies that each producer faces a *quasi-kinked* demand curve, where the degree of curvature is roughly consistent with the mode of the distribution of recent estimates from firm-level scanner data; cf. Dossche et al. (2006). Finally, we discuss how this new approach holds substantial promise for future research on price-setting behavior, not only in enhancing the linkages between micro data and macro models but in building stronger connections to ongoing research in marketing and consumer behavior.<sup>5</sup>

Although the analysis of customer search has been relatively quiescent in recent years, our investigation builds directly on the earlier work of MacMinn (1980), who analyzed sequential search in a partial-equilibrium setting with firm-specific idiosyncratic shocks, heterogeneous search costs, and completely inelastic demand by each consumer (and hence no intensive margin). Moreover, the role of customer search in generating a kinked or quasi-kinked demand curve for each firm was emphasized by Stiglitz (1979, 1987). Finally, a large but now-dormant literature studied the incidence of relative price dispersion in search models with nominal rigidities.<sup>6</sup>

Our analysis is also reminiscent of the burgeoning literature on the role of search in labor markets, although that literature has mainly focused on the extensive margin of demand. In the case of customer search, of course, there are no direct parallels to the incidence of unfilled job vacancies or of workers who remain unemployed while searching for

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<sup>5</sup>The need for such connections has recently been emphasized by Rotemberg (2008).

<sup>6</sup>See Ball and Romer (1990), Benabou (1988, 1992), Diamond (1994), Fishman (1992, 1996), and Tommasi (1994).

a new job; hence, specifying an aggregate matching function for customers and firms might provide a useful approximation for analyzing inflation dynamics, as in Hall (2008), but might not be as useful for interpreting micro evidence on price-setting behavior. Finally, while the assumption of an exogenous separation rate may be useful for interpreting U.S. labor market data over the past couple of decades, specifications that incorporate on-the-job search and endogenous separation may well have greater potential for cross-fertilization with the analysis of customer search.<sup>7</sup>

The remainder of this paper is organized as follows. In sections 2 and 3, we analyze the disaggregated household scanner data and the aggregate data for peanut butter to document empirical evidence on extensive and intensive margins of demand, respectively. Section 4 specifies our analytical framework. In section 5, we briefly summarize the implications of this framework for demand analysis. Section 6 contains implications for monetary policy. Section 7 concludes.

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<sup>7</sup>For recent analysis of labor market separation patterns, see Shimer (2005), Hall (2006), and Davis et al. (2006).

## 2 Empirical Evidence on the Extensive Margin of Demand

In this section, we confirm the key stylized fact that the price elasticity of demand for a given brand is primarily determined by changes in the number of customers rather than changes in the specific quantity purchased by each individual.

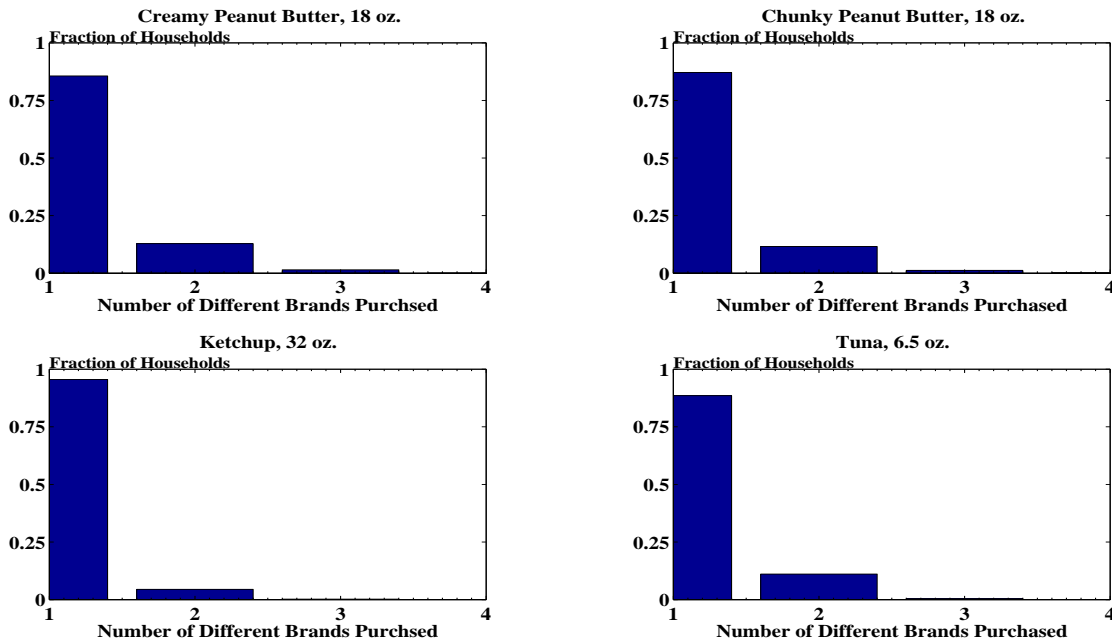
The ERIM data set tracks information for each UPC at several stores in two markets (Sioux Falls, South Dakota and Springfield, Missouri) between January 1985 and June 1987 for narrowly defined product categories such as ketchup, canned tuna, peanut butter, stick margarine and toilet tissue.<sup>8</sup> Using this data, we document the following stylized facts regarding the extensive margin of demand:

- Each consumer faces a multiplicity of producers (brands) of each specific good/service, but typically purchases the item from a single producer (e.g., haircuts, toothpaste).
- Firms face relatively high demand elasticities (consistent with low markups), reflecting the dominant role of the extensive margin (number of customers) rather than the intensive margin (quantity purchased by each customer).

### 2.1 Selection of Brands

In order to see the first stylized fact, we investigate how frequently a typical household changes producers each month for narrow product categories. It is the case in the A.C. Nielsen ERIM data (Chicago GSB) that a wide diversity of brands exist in narrow product categories. For example, creamy peanut butter includes a variety of brands such as Arrowhead, Peter Pan, Billy Boy, Robb Ross, Elam's, Skippy, Hallam's, Smucker's, Home Brand, Sun Gold, JIF, Superman, and 26 chain-specific "private label" brands. Nevertheless, as shown in Figure 1, more than 90 percent of households who purchased creamy and chunky peanut butters 18 oz. buy the item from a single producer. We also see essentially the same brand choice behavior of households for ketchup 32 oz. and tuna 6.5 oz. as well.

Figure 1: Consumer Choices in Narrow Product Categories



Note: this figure shows how many different brands households on average each month between January 1985 and June 1987.

## 2.2 The Price Elasticity of Demand at the Extensive Margin

The ERIM data suggest that firms face relatively high demand elasticities, consistent with low markups. In order to show this, we follow the approach of Hausman, Leonard and Zona (1994) that takes account of a three stage demand system in estimating demand for differentiated products. For example, the top level correspond to overall demand for the product such beer. The middle level corresponds different segments for the product. The bottom level of the demand system corresponds to competition among brands in a given segment.

We begin with the bottom level of the demand system. The demand specification for

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<sup>8</sup>The household data were collected from a panel of households that were issued magnetic ID cards to be presented at the checkout counter in participating stores. Purchases made by households were scanned along with their ID numbers. Sales from the participating stores were collected for all universal product code (UPC) products through scanners at the stores' checkout counters.

each product within a market segment is given by

$$s_{int} = \alpha_i + \omega_{in}d_{nt} + \beta_i \log(y_{Gnt}/P_{nt}) + \sum_{j=1}^J \gamma_{ij} \log p_{jnt} + \epsilon_{int} \quad (1)$$

where  $s_{int}$  is the revenues share of total segment expenditure of the  $i$ th brand in city  $n$  in period  $t$ ,  $d_{nt}$  is the dummy variable for city  $n$ ,  $y_{Gnt}$  is overall segment expenditure,  $P_{nt}$  is the price index and  $p_{jnt}$  is the  $j$ th brand in city  $n$ .

It is worthwhile to mention the identification of coefficients for individual prices in the demand equation specified above because prices are likely to be correlated with error terms. Following the work of Hausman and Taylor (1981), Hausman et al. (1994) use prices of one city as instrument variables for prices of another city.<sup>9</sup> The idea is that prices in one city (after elimination of city and brand effects) are driven by underlying costs that can be used as instrument variables. Specifically, they assume that the price for a brand  $i$  in city  $n$  at time  $t$  is determined by the following equation:

$$\log p_{jnt} = \delta_j \log c_{jt} + \alpha_{jn} + w_{jnt}$$

where  $p_{jnt}$  is the  $j$ th brand in city  $n$  and  $\alpha_{jn}$  is a city specific brand differential that accounts for transportation costs or local wage differentials. In addition, they assume that a mean zeros stochastic disturbance  $w_{jnt}$  is uncorrelated with  $\epsilon_{imt}$  if  $n \neq m$ .

In the analysis of peanut butter data, we consider two distinct segments of the peanut butter market, known as “creamy” and “chunky”.<sup>10</sup> Although there are a large number of competing brands of peanut butter, three national brands have a dominant share of the market; thus, in our empirical analysis, we compute weighted averages for all of the regional and store-specific brands and treat this group as a single brand (commonly referred to as the “control” brand).

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<sup>9</sup>Alternatively one can use factor price instruments such as wages and prices materials that do not affect unobserved demand shocks. It is also possible to construct a time-series of dummies that can be used as an instrument variable if the aggregate price index of a particular product shifts independent of demand shocks.

<sup>10</sup>A brief explanation for non-afficianados of peanut butter: the “creamy” label indicates that the peanut butter is completely smooth and homogeneous, whereas the “chunky” label indicates that small fragments of roasted peanuts are mixed in with the butter.



Table 1: The Demand for Competing Brands of Peanut Butter

	<i>Creamy, 18 oz.</i>			<i>Chunky, 18 oz.</i>		
	Jif	PPan	Skippy	Jif	PPan	Skippy
Constant	-0.02 (0.22)	0.34 (0.29)	0.80 (0.31)	0.21 (0.16)	0.40 (0.32)	0.63 (0.34)
$\log(Y/P)$	0.05 (0.02)	-0.01 (0.03)	-0.06 (0.03)	0.004 (0.022)	-0.06 (0.04)	-0.02 (0.04)
$\log(P_{\text{Jif}})$	-0.93 (0.31)	0.74 (0.40)	0.27 (0.43)	-0.92 (0.24)	1.21 (0.43)	0.01 (0.48)
$\log(P_{\text{PPan}})$	0.22 (0.14)	-0.81 (0.19)	0.42 (0.20)	0.54 (0.16)	-0.97 (0.30)	0.40 (0.33)
$\log(P_{\text{Skippy}})$	0.63 (0.22)	0.26 (0.27)	-1.13 (0.30)	0.50 (0.15)	0.36 (0.28)	-1.20 (0.32)
$\log(P_{\text{cntrl}})$	0.20 (0.17)	-0.30 (0.22)	0.33 (0.24)	-0.20 (0.16)	-0.35 (0.32)	0.36 (0.32)
City Dummy	0.01 (0.02)	-0.006 (0.03)	-0.02 (0.03)	0.04 (0.02)	0.07 (0.04)	-0.02 (0.04)
$R^2$	0.26	0.40	0.37	0.44	0.33	0.30

Note: For each column, the dependent variable is the share of the specified national brand (Jif, Peter Pan, or Skippy) as a fraction of total expenditures in that product category (creamy or chunky, 18 oz. container), and the explanatory variables include a constant, the logarithm of real expenditures,  $\log(Y/P)$ , the price of each national brand, and the average price of all other regional and store-specific brands. Standard errors are given in parentheses.

Table 2: The Extensive Margin of Demand for Peanut Butter  
*(Conditional Own-Price Elasticities of National Brands)*

<i>Brand Name</i>	<i>Creamy, 18 oz.</i>	<i>Chunky, 18 oz.</i>
Jif	-5.2 (1.4)	-5.8 (1.2)
Peter Pan	-3.2 (0.5)	-3.7 (0.8)
Skippy	-7.0 (1.6)	-6.1 (1.4)

Note: The regression equation for each brand share implies that the own-price elasticity ( $=\epsilon_i$ ) and the own-price coefficient ( $\beta_i$ ) in the regression equation for brand  $i$  should satisfy  $\epsilon_i = \beta_i((1/T) \sum_{t=1}^T s_{it}^{-1}) - 1$ , where  $s_{it}$  is the expenditure share of brand  $i$  at period  $t$ . Standard errors are given in parentheses.

Furthermore, as for many retail items, each manufacturer typically makes its products in a variety of different sizes that are appealing to distinct groups of consumers. In the ERIM dataset, for example, each national brand of peanut butter is available in three sizes: 18 ounces, 28 ounces and 40 ounces. Although not shown here, we have documented that most households purchase a single size of peanut butter and that choice of size does not vary significantly over time; that is, the household typically continues to purchase the same size container even when switching to a different brand. In effect, each size of peanut butter should be viewed as a distinct product category.<sup>11</sup> For simplicity of presentation, the empirical analysis reported here is focused on the 18-ounce size, which accounts for the largest share of total spending on peanut butter; it should be noted, however, that we have performed some preliminary analysis for other sizes and obtained results that are broadly similar to those reported here.

Turning to estimation results, Table 1 shows estimation results of brand share equations for Jif, Peter Pan and Skippy. The estimates of own-price coefficients are all significantly negative, which fall into a range of -0.8 to -1.2. These estimates indicate that the market share of each brand are likely to fall by around 1 percent as the logarithm of its price rises

<sup>11</sup>Accordingly, each segment amounts to a narrow product category that helps define a product customers might search for a seller who provides the lowest price or the best quality. It is important to have segments of products appropriately defined in this type of empirical analysis. For example, if the definition of a segment is too narrow, it incurs substantially high substitution between different segments.

Table 3: The Extensive Margin of Demand for Beer  
*(Estimates from Hausman et al., 1994)*

<i>Premium Brands</i>	<i>Conditional Elasticity</i>	<i>Popular Brands</i>	<i>Conditional Elasticity</i>
Budweiser	-3.5 (0.1)	Old Milwaukee	-4.8 (0.1)
Molson	-5.1 (0.2)	Genesee	-3.8 (0.1)
Labatts	-4.3 (0.3)	Milwaukee's Best	-5.8 (0.2)
Miller	-4.2 (0.3)	Busch	-5.7 (0.3)
Coors	-4.6 (0.2)	Piels	-4.0 (0.5)

Note: The estimates of conditional own-price elasticities for each brand of premium beer (left panel) and each brand of popular beer (right panel) are taken from Hausman et al.(1994). Although not shown in the table, their study also obtained corresponding estimates for five brands of light beer: Genesee Light, -3.2; Coors Light, -4.2; Lite Beer, -4.8; Molson Light, -5.7; and Old Milwaukee Light, -5.9.

by one percent. In addition, the adjusted  $R^2$  of brand share equations covers a range of 0.3 to 0.4.

To gauge the extensive margin of demand, we now use these regression results to compute the conditional own-price elasticity of demand. Using the multi-stage demand system, it is possible to allow for conditional own-price elasticities and total own-price elasticities depending on whether to include the effect of a change in a particular brand's price on the expenditure of the market segment that the brand belongs to. The conditional own-price elasticity is defined as the own-price elasticity holding constant the expenditure of market segment. For the creamy peanut butter, the conditional own elasticities are -3.2 to -7.0. For example, Jif has a conditional own elasticity of -5.2, Peter Pan is -3.2 and Skippy is - 7.0. Similarly, estimates of the chunky peanut butter covers a range of -3.7 and -6.1. As a result, the ERIM data indicate that firms face relatively high demand elasticities consistent with low markups. These estimates are comparable to those shown

in Hausman et al. (1994). For example, the conditional own-price elasticities are in the range of -3.5 to -5.0 for the premium beer.

### 3 Empirical Evidence on the Intensive Margin of Demand

We now consider the magnitude of the intensive margin of household demand for a given product category, which can be gauged in terms of the own-price elasticity of demand for that product. In particular, we analyze the intensive margin of demand for peanut butter, thereby facilitating comparison with our foregoing estimates regarding the extensive margin of demand.

#### 3.1 Estimation using Instrumental Variables

In estimating the slope of demand for a given product, of course, one faces the classic econometric challenge of identifying exogenous supply shocks that effectively trace out the shape of the demand curve. The standard approach—taken in Hausman et al. (1994) and numerous other studies—is to estimate the demand equation via two-stage least-squares (2SLS), using national time series data on average retail prices, consumption, and disposable income, with input prices of labor and raw materials serving as instruments.

For measuring the total volume of peanut butter consumption, there is no published data on retail sales or consumer spending. However, the National Agricultural Statistics Service does produce a regular publication titled “Peanut Stocks and Processing” which reports on the monthly volume of shelled peanut shipments (measured in thousands of pounds) from farms to peanut butter manufacturers.<sup>12</sup> Since roasted peanuts and a pinch of salt are the only ingredients used in producing peanut butter, this time series can serve as an excellent proxy for total U.S. peanut butter consumption.<sup>13</sup> As for the retail price of peanut butter, we use the national average unit price (measured in dollars per pound) published on a monthly basis by the Bureau of Labor Statistics.<sup>14</sup> Finally, our analysis

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<sup>12</sup>This series does not reflect the magnitude of imported peanuts, which was negligible prior to 1994, increased rapidly to a volume equivalent to about 4 percent of total U.S. farm production by 2001, and then faded away again after the enactment of the U.S. Farm Act of 2002; see figure 4 of Dohlman and Livezey (2005) and the accompanying discussion.

<sup>13</sup>We assume that a two-month lag occurs between shipment of the raw peanuts and the retail sale of the resulting peanut butter; this timing assumption reflects the characteristics of the fairly brief production process, transportation lags, and the prevalence of just-in-time inventory management in this market.

<sup>14</sup>This series indicates the average unit price of creamy peanut butter across all U.S. cities for all container sizes. For our purposes, it would have been ideal to have retail price data for a specific size (namely, 18 ounces) for each type of peanut butter (creamy and chunky); however, the published BLS series is likely to be an excellent proxy, since our analysis of the ERIM dataset did not reveal any systematic deviations between the prices of creamy vs. chunky peanut butter nor any systematic time variation in the deviations

Table 4: The Elasticity of Demand at the Intensive Margin

<i>Product Category</i>	<i>Own-Price Elasticity</i>	<i>Source</i>
Peanut Butter	-1.0 (0.4)	This Paper
Beer	-1.4 (0.2)	Hausman et al. (1994)
Canned Tuna	-0.3 (0.7)	Babula and Corey (2004)
Butter	-0.4	Deaton & Muellbauer (1985)

uses two input prices as instruments: the unit price of raw peanuts (as reported by the U.S. Department of Agriculture), and the hourly compensation of employees in the nonfarm business sector. Each price series is deflated by chain-weighted price index for personal consumption expenditures.

Thus, using monthly data over the period January 1985 to June 2008, we obtain the following regression results via 2SLS:

$$\log C_t = -0.96 \log \tilde{P}_t + 1.47 \log Y_t - 18.5 \log N_t - 75.7 + 0.0004T + \epsilon_t \quad (2)$$

(0.41)            (0.70)            (2.8)            (55.1) (0.0001)

where  $C_t$  denotes the volume of peanut butter consumption,  $\tilde{P}_t$  is the relative price of peanut butter,  $Y_t$  denotes real disposable income,  $N_t$  is total U.S. population, and the standard error of each coefficient is shown in parentheses.<sup>15</sup> The value of  $R^2$  for this regression is 0.28.

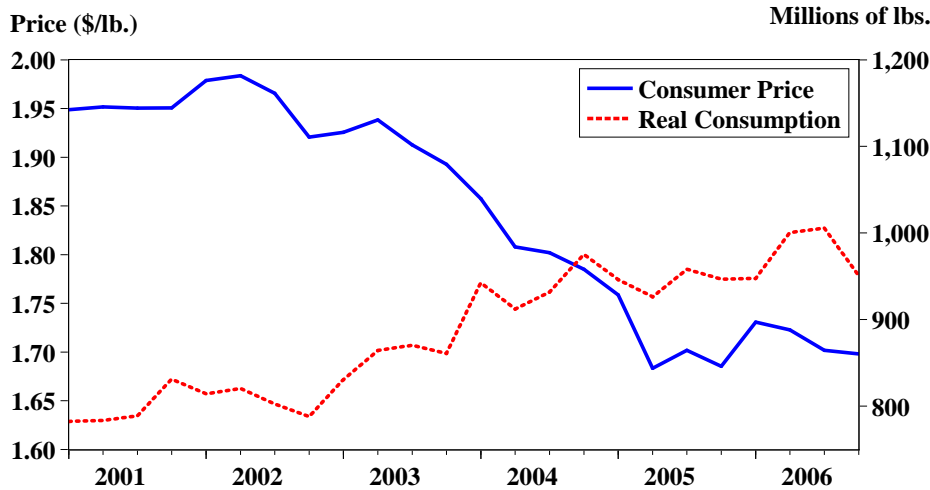
Evidently, the elasticity of peanut butter demand at the intensive margin is very close to unity. Of course, given the sampling uncertainty of the coefficient estimate, the magnitude of the true elasticity might well be nearly twice as large but could also be quite close to zero. In any case, the product-level elasticity is almost surely much smaller than any of the brand-specific elasticities reported above; that is, the elasticity of demand at the intensive

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between unit prices for different container sizes.

<sup>15</sup>Although not shown in equation 2, the regression also includes seasonal dummies, which are also specified as instruments along with the constant, time trend, and the logarithms of total population, real disposable income, real hourly compensation, and the relative price of raw peanuts.

Figure 2: The Impact of the U.S. Farm Act of 2002  
on the Market for Peanut Butter



margin is relatively small compared with the extensive margin.

### 3.2 Confirmation from a “Natural Experiment”

In the early 2000s the U.S. peanut butter market encountered a large, discrete, transparent, and exogenous supply shock: the enactment of the Farm Act of 2002.<sup>16</sup> This legislation eliminated the quotas on peanut farm production that had been in place since 1949, leading to a substantial decline in raw peanut prices that in turn placed downward pressure on the retail price of peanut butter. Indeed, as shown in figure 2, the national average price of peanut butter (in dollars per pound) had been fairly steady at about \$1.95 around the beginning of the decade but dropped to about \$1.70 by 2005—a decline of about 13 percent. Over this same period, the volume of peanut butter consumption (measured at an annual rate) grew from about 800 million pounds in 2001 to about 950 million pounds in 2005—a rise of about 19 percent. Thus, this “natural experiment” implies that the own-price elasticity of peanut butter demand is about -1.4, a value that is well within the confidence bands of the 2SLS estimate reported above.

<sup>16</sup>See Dohlman et al. (2004) and Dohlman and Livezey (2005) for a detailed discussion of the peanut-related provisions of the Farm Act of 2002 and its effects on peanut growers’ output and prices.

### 3.3 Substitution between Narrow Product Categories

We now move onto the analysis of the substitution between narrow product categories. In order to do this, we analyze the demand of peanut butter using the disaggregated household scanner data. In particular, the current analysis corresponds to the middle level within the three stage demand system used in Hausman, Leonard and Zona (1994).

In the estimation of demand equations described below, we consider two segments for peanut butter: creamy peanut butter and chunky peanut butter. The estimation results for product segments can be summarized as follows:

$$\begin{aligned}
 \log q_{crnt} &= 1.0 \log y_{Bnt} + 0.9 \log \pi_{crnt} - 0.9 \log \pi_{chnt} - 0.2 - 0.03 d_{crnt} + \epsilon_{crnt} \\
 &\quad (0.02) \qquad (0.2) \qquad (0.2) \qquad (0.2) \quad (0.02) \\
 \log q_{chnt} &= 1.0 \log y_{Bnt} - 1.5 \log \pi_{crnt} + 1.4 \log \pi_{chnt} - 0.3 - 0.01 d_{chnt} + \epsilon_{chnt} \\
 &\quad (0.02) \qquad (0.2) \qquad (0.2) \qquad (0.2) \quad (0.02)
 \end{aligned} \tag{3}$$

where  $q_{mnt}$  is log quantity of the  $m$ th segment in city  $n$  at period  $t$ , the expenditure variable  $y_{Bnt}$  is the total peanut butter expenditure, and the  $\pi_{mkt}$  is the price index for segment  $m$ ,  $d_{mnt}$  is the city dummy. In addition,  $m = cr$  denotes the creamy peanut butter and  $m = ch$  corresponds to the chunky peanut butter. We also construct the price index for each segment,  $\pi_{mkt}$ , by calculating a weighted average of average transaction prices of brands in each segment.

## 4 A New Analytical Framework

In this section, we specify a new analytical framework in which consumers have imperfect information about the characteristics of each producer within a narrow product category.

We begin with the product space of our model. Our product space is two-dimensional. Along the first dimension, there are a lot of different product categories. Each household purchases many different specific types of goods and services (bath soap, breakfast cereal, toothpaste, haircuts, auto repairs). Moreover, there are a lot of producers within each product category. For each specific type of good, each household purchases that item from a single one of many nearly-identical producers.

In order to generate a non-degenerate price distribution for each product category, we assume that each producer with a narrow product category is affected by idiosyncratic technology shocks. These idiosyncratic shocks are identically and independently distributed across different product categories and over time. The production technology of each producer is linear in labor. Labor services are traded in a perfectly competitive labor market and wages are fully flexible.

Turning to the household's information, the household knows the properties of the distribution of firm-specific characteristics and the distribution of prices for each specific product category. The consumer does not have ex ante knowledge of the characteristics of each individual producer nor of the price charged by each producer. Therefore, in the presence of firm-level heterogeneity, each consumer has an incentive to search and thereby obtain information about individual producers.

Furthermore, a lot of infinitely-lived identical households exist in the economy. Each household is comprised of many members, where each household member searches across producers of a single item. There is a fixed cost per search which varies randomly across members of the household. In particular, household members cannot communicate with each other during the search process. Although this assumption may be rather restrictive, households' search decisions turn out to resemble the search process of one single product, though they purchase a continuum of goods at the same time. After search is concluded, the household makes its spending decisions given the vector of prices.

Finally, a fraction of firms may need to set their prices greater than the maximum reservation price because they are hit by very inefficient productivity shocks. Firms that undergo this situation are assumed to shut down their production activities temporarily until their prices go back within the range of reservation prices of consumers.



## 4.1 Household Optimization and Search Behavior

Each period is divided into two sub-periods: the first-half is search stage and the second half is spending stage.

We first describe the spending stage at which households optimize their total expenditures and hours worked. The preference of each household at period 0 is given by

$$\sum_{t=0}^{\infty} E_0[U(C_t, \bar{H} - H_t)], \quad (4)$$

where  $C_t$  is the consumption at period  $t$ ,  $\bar{H}$  is the amount of time endowment available for each household,  $H_t$  is the amount of hours worked at period  $t$ . The instantaneous utility function  $U(C_t, \bar{H} - H_t)$  is continuously twice differentiable and concave in consumption and leisure. Households aggregate differentiated goods to produce composite goods using the Dixit-Stiglitz aggregator:

$$C_t = \left( \int_{j=0}^1 C_{it}(j)^{\frac{\theta-1}{\theta}} dj \right)^{\frac{\theta}{\theta-1}}, \quad (5)$$

where  $C_t$  is the real amount of the composite goods and  $C_{it}(j)$  is the amount of type  $j$  goods that each household purchases from a seller  $i$ .

In the spending stage, each household already has finished its searches during the first-half of each period. Having the perfect information on prices of sellers that the household wants to purchase, each household minimizes the total cost of obtaining  $C_t$  to determine the intensive margin of demand:  $C_{it}(j) = (P_{it}(j)/P_t)^{-\theta} C_t$ , where  $P_t$  denotes the Lagrange multiplier of this cost minimization problem:  $P_t = \int_{j=0}^1 (P_{it}(j))^{1-\theta} dj$ . The nominal expenditure of the household ( $= L_t$ ) is then given by  $L_t = P_t C_t$ . Moreover, we note that this Lagrange multiplier is identical across households because search costs are identically and independently distributed across different products and households in each period.

Furthermore, there is a complete financial market in which all agents trade contingent claims. In addition, wages are fully flexible in a perfectly competitive market. Given these assumptions, the period budget constraint of each household can be written as

$$\int_0^1 (P_{it}(j)C_{jt}(i) + z_t(j)X_t(j))dj + E_t[Q_{t,t+1}B_{t+1}] \leq W_t^N H_t + B_t + \Phi_t, \quad (6)$$

where  $P_{it}(j)$  is the dollar price at period  $t$  of good  $j$  at seller  $i$ ,  $X_t(i)$  is the number of search that an individual household has made in order to determine a seller,  $z_t(j)$  is the nominal cost of each visit to a seller,  $Q_{t,t+1}$  is the stochastic discount factor used for computing the

dollar value at period  $t$  of one dollar at period  $t + 1$ ,  $B_t$  is the nominal payoff of the bond portfolio held between periods  $t - 1$  and  $t$ ,  $W_t^N$  is the nominal wage rate, and  $\Phi_t$  is the dividend distributed to households. The utility maximization of the household leads to the following optimization conditions:  $U_2(C_t, \bar{H} - H_t) = (W_t^N / P_t)U_1(C_t, \bar{H} - H_t)$  and  $Q_{t,t+1} = \beta U_1(C_{t+1}, \bar{H} - H_{t+1})P_t / (U_1(C_t, \bar{H} - H_t)P_{t+1})$  where  $U_1(C_t, \bar{H} - H_t)$  is the marginal utility of consumption and  $U_2(C_t, \bar{H} - H_t)$  is the marginal utility of leisure. The labor supply decision leads to the first optimization condition and the inter-temporal substitution of consumption between periods  $t$  and  $t + 1$  corresponds to the second equation.

Having described the spending decision, we now explain how households determine reservation prices for their sequential searches. At the beginning of each period, a shopping member of the representative household is endowed with a realized value of a random variable  $z$ . Each visit to a seller incurs a nominal amount of cost that is proportional to the total expenditure of the household:  $zL_t$ .<sup>17</sup> The random variable  $z$  is identically and independently distributed across households and product categories: a uniform distribution on a bounded interval between  $\underline{z}$  and  $\bar{z}$ .

We now turn to the determination of reservation prices. From now on, we will pick a representative product category, so that we do not use any subscript for different product categories when we describe the search decision of each household. Each shopping member stops searching for any price observation  $P_{it} \leq R_t(z)$ , while for any  $P_{it} \geq R_t(z)$ , they continue to search. In order to describe the determination of a reservation price in the context of dynamic programming, we let  $V(P_{it})$  represent the value function of search cost when the nominal price of his or her first visit is  $P_{it}$ . Then, the optimization of a shopping member whose objective is to find a seller with the lowest price can be written as

$$V(P_{it}) = \min\{L_t(P_{it}), zP_{it}C_t + \int_0^{P_{\max,t}} V(K)dF(K)\}. \quad (7)$$

The reservation price then satisfies the following condition:

$$zP_t^{1-\theta} = \int_0^{R_t(z)} \{P_{it}^{-\theta} F(P_{it})\} dP_{it}. \quad (8)$$

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<sup>17</sup>A particular level of search cost is randomly assigned to each household for each narrow product in each period and a continuum of different products exist in the economy, we can rely on the law of large numbers in order to have an identical level of expected total search cost across households. It is also not difficult to see that households have incentives to find a seller that gives the lowest price for each narrow product category. The partial derivative of the consumption expenditure function with respect to the relative price of an individual price is positive:  $\partial L_t / \partial P_{it}(j) = (P_{it}(j) / P_t)^{-\theta} C_t$ . Hence, to the extent that  $\theta$  is not very big and search does not require an arbitrary large amount of costs, we can find that households have incentive to search for sellers with the lowest price for each type of goods. As a result, the standard Dixit-Stiglitz model without search can be viewed as implicitly assuming that search costs are arbitrarily large so that no consumer wants to search.

The left-hand side of (8) corresponds to the cost of an additional search, while the right-hand side is its expected benefit. Meanwhile, it is noteworthy that, given the reservation price strategy, the fraction of the aggregate search cost in the aggregate consumption is  $(\int_{\underline{z}}^{\bar{z}} \frac{z}{F(R_t(z))} dz)/(\bar{z} - \underline{z})$ .

## 4.2 Matching between Customers and Sellers and the Resulting Demand Curve

Having described the search behavior of the representative household, we now turn to the demand curve facing each seller within a narrow product category. Moreover, we continue to describe the demand curve facing an individual seller without any subscript to specify each product category.

We first describe the matching between customers and sellers. Consumers whose reservation price is  $R_t(z)$  are randomly distributed to a set of sellers whose prices are less than  $R_t(z)$ . Thus, the measure of consumers with reservation price  $R_t(z)$  who are assigned to a group of sellers whose nominal price is  $P_{it}$  is given by  $f(P_{it})/(F(R_t(z))(\bar{z} - \underline{z}))$ . Therefore, the total expected number of consumers who purchase their products at a shop with its nominal price  $P_{it}$  is given by

$$\frac{1}{\bar{z} - \underline{z}} \int_{P_{it}}^{\bar{R}_t} \frac{f(P_{it})}{F(R_t(z))} dz$$

where  $\bar{R}_t$  is the maximum reservation price at period  $t$ . In order to rewrite the total expected number of consumers in terms of prices, we note that the impact of an incremental increase in search cost on reservation price is  $dz = P_{it}^{\theta-1} \{F(R_t(z))R_t(z)^{-\theta}\} dR_t(z)$ . Substituting this equation into the integral specified above, we can find that the expected number of consumers for each individual seller whose nominal price is  $P_{it}$  can be written as

$$N_t(P_{it}) = (\bar{z} - \underline{z})^{-1} \left( \frac{\bar{R}_t^{1-\theta}}{1-\theta} - \frac{P_{it}^{1-\theta}}{1-\theta} \right) P_{it}^{\theta-1}.$$

Having described the extensive margin of the demand curve, we point out that the demand of an individual firm comes from not only the demand of an individual consumer but also the number of consumers who decides to purchase. We call the former *the demand at the intensive margin* and the latter *the demand at the extensive margin*. We thus combine both the extensive and intensive margins in order to have the following demand curve of each seller:

$$D_t(\tilde{P}_{it}) = \tilde{P}_{it}^{-\theta} \left( \frac{\tilde{R}_t^{1-\theta}}{1-\theta} - \frac{\tilde{P}_{it}^{1-\theta}}{1-\theta} \right) Y_t / (\bar{z} - \underline{z}), \quad (9)$$

where  $D_t(\tilde{P}_{it})$  is the demand function at period  $t$  when a seller sets its relative price at  $\tilde{P}_{it}$  and  $\tilde{R}_t$  is the relative price of the maximum reservation price.

An immediate implication of the demand curve (9) is that the elasticity of demand for each good, denoted by  $\epsilon(\tilde{P}_{it})$ , depends on its relative price. The main reason for this is associated with the presence of the maximum relative price. In particular, the expected number of consumers turns out to be nil when relative price of each firm exceeds the maximum reservation price. Thus, the logarithm of the expected number of consumers is not linear in the logarithm of the relative price. Specifically, the elasticity of demand can be written as follows:

$$\epsilon(\tilde{P}_{it}) = \theta + \frac{\tilde{P}_{it}^{1-\theta}}{\tilde{R}_t^{1-\theta}/(1-\theta) - \tilde{P}_{it}^{1-\theta}/(1-\theta)}. \quad (10)$$

The demand elasticity reflects both of the elasticity of demand at the intensive margin and the elasticity of demand at the extensive margin. For example, the first-term in the right-hand side of this equation is the elasticity of demand at the intensive margin, while the second-term corresponds to the elasticity of demand at the extensive margin. We also see that the elasticity of demand approaches infinity as  $\bar{z}$  gets close to zero so that  $\tilde{R}_t = \tilde{P}_{it}$ . It means that all firms are subject to perfect competition in the absence of consumer search frictions. As a result, we can find that the important source of the monopoly power of firms is the presence of search costs together with imperfect information of consumers about the location of prices.

The aggregate price level can be measured by the GDP deflator, which is the ratio of the aggregate nominal output to the real output. Since nominal outputs of individual firms should sum up to the nominal aggregate output, the GDP deflator can be written as

$$\frac{\bar{P}_t}{P_t} = \frac{P_t^{2(\theta-1)}}{\bar{z} - \underline{z}} \int_{P_{\min,t}}^{P_{\max,t}} P_{it}^{1-\theta} \left( \frac{\bar{R}_t^{1-\theta}}{1-\theta} - \frac{P_{it}^{1-\theta}}{1-\theta} \right) dF(P_{it})$$

where  $\bar{P}_t$  is the price index of output. In addition, the aggregate social resource constraint becomes  $Y_t = (P_t/\bar{P}_t) C_t(1 + X_t)$ . Here, we note that the value of output differs from that of consumption when a fraction of firms shut down their production activities temporarily because of inefficient productivity shocks. But this difference disappears when all firms are willing to participate in production activities because the maximum reservation price is higher than the maximum actual price. In this case, the value of output should be identical to that of consumption:  $\bar{P}_t = P_t$ . As a result, we have the following equilibrium condition:

$$P_t^{2(1-\theta)} = \frac{1}{\bar{z} - \underline{z}} \int_{P_{\min,t}}^{P_{\max,t}} P_{it}^{1-\theta} \left( \frac{\bar{R}_t^{1-\theta}}{1-\theta} - \frac{P_{it}^{1-\theta}}{1-\theta} \right) dF(P_{it}). \quad (11)$$

The aggregate social resource constraint also becomes  $Y_t = C_t(1 + X_t)$ .

Furthermore, a price distortion can arise when there is a price dispersion, namely relative price distortion. Specifically, the relative price distortion is defined as the part of output that is foregone because of price dispersion. In particular, the relative price distortion turns out to be

$$\Delta_t = \frac{P_t^{2\theta-1}}{\bar{z} - \underline{z}} \int_{P_{\min,t}}^{P_{\max,t}} P_{it}^{-\theta} \left( \frac{\bar{R}_t^{1-\theta}}{1-\theta} - \frac{P_{it}^{1-\theta}}{1-\theta} \right) dF(P_{it}). \quad (12)$$

Therefore, the aggregate production function can be written as  $Y_t = H_t/\Delta_t$  where  $H_t$  is the aggregate amount of hours worked.

## 5 Implications for Demand Analysis

Having described the model, we discuss implications of customer search models for the shape of demand curves facing individual sellers. We first show that the demand curve of the search model can mimic a quasi-kinked demand curve locally around an average price. Second, we allow for the possibility that a group of consumers do not search at all because of high search costs. In this case, demand elasticities can be lower at high prices than at low prices.

### 5.1 Quasi-Kinked Demand Curve

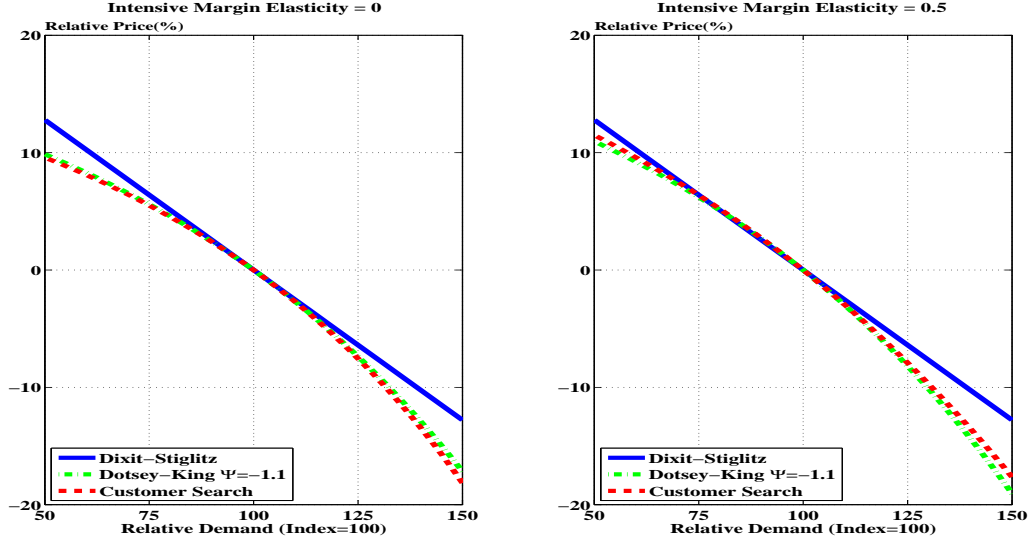
In order to generate an equilibrium price dispersion for each product, we introduce idiosyncratic productivity shocks into the model. Specifically, firm  $i$  produces its output using a production function of the form:  $Y_{it} = H_{it}/A_{it}$ , where  $A_{it}$  is the firm-specific shock at period  $t$ ,  $H_{it}$  is the amount of labor hired by firm  $i$ , and  $Y_{it}$  is the output level at period  $t$  of firm  $i$ . In addition, we assume that  $A_{it}$  is an i.i.d. random variable over time and across individual firms and its distribution is a uniform distribution whose support is  $[\underline{A}, \bar{A}]$ .

Given the demand curve and the production function specified above, we write the profit maximization condition in terms of nominal price as follows:

$$AW_t^N (\theta \bar{R}_t^{1-\theta} - (2\theta - 1) P_{it}^{1-\theta}) = (1 - \theta) P_{it} (2 P_{it}^{1-\theta} - \bar{R}_t^{1-\theta}). \quad (13)$$

where the realized value at period  $t$  of the idiosyncratic shock is  $A_{it} = A$ . Thus, we can use this representation of profit maximization condition to characterize the distribution of nominal prices denoted by  $F(P_{it})$ . For example, suppose that firm-specific shocks

Figure 3: Comparing the Curvature of Demand under Customer Search vs. Kimball-Style Preferences



Note: this figure compares quasi-kinked demand curves that are derived from the Dotsey-King aggregator and the search model analyzed in this paper. In order to compare three different demand curves, we adopt a normalization to make the logarithm of demand in the search model become 100 when the logarithm of real price is zero. The intensive margin price elasticity of household expenditure is denoted by  $\theta$  in the text.

are uniformly distributed over a compact interval, as we did above. Then, the resulting distribution of prices can be written as follows:

$$F(P_{it}) = \frac{P_{it} - P_{\min,t}}{P_{\max,t} - P_{\min,t}}, \quad (14)$$

where  $P_{\max,t}$  is the price that satisfies the profit maximization condition when  $A = A_{\max}$  and  $P_{\min,t}$  is the price that satisfies the profit maximization condition when  $A = A_{\min}$ .

Turning to numerical examples of the model, Figure 3 shows that the search model's demand curves match closely those derived from the Dotsey-King's aggregator with its curvature parameter  $\psi = -1.1$ . But since our comparison focuses on the neighborhood of an average price, this figure does not indicate that the customer search model can mimic the quasi-kinked demand curve globally. In addition, we note that these two models build on different mechanisms to obtain quasi-kinked demand curves. For example, the Dotsey-King aggregator requires that a satiation level should exist for each type of differentiated goods in order to generate quasi-kinked demand curves, which holds true only when the parameter  $\psi$  takes a negative value. On the other hand, the customer search model relies

on the sensitivity of customers with respect to changes in prices in the generation of quasi-kinked demand curves.<sup>18</sup>

## 5.2 Life-Cycle Prices

In the model analyzed above, we have assumed that search costs are randomly distributed over different products for each household in each period. We do this in order to make households identical each period, though individual households end up with different prices for a particular product. But search costs of an individual consumer, especially time opportunity costs of search, may change over his or her life-cycle. In particular, Aguiar and Hurst (2007) document substantial heterogeneity in prices paid for identical goods for the same area and time, with older households shopping the most and paying the lowest prices. For example, doubling shopping frequency lowers a good's price by 7 to 10 percent. In this vein, it would be interesting to incorporate cross-sectional heterogeneous aspects of search costs into the current modeling framework.

Now, we briefly highlight consequences of the possibility that when customers have different opportunity costs of time, a customer with a lower opportunity cost can reduce the market price for a given basket of goods by shopping more intensively. First, this extension of our model can help explain substantial heterogeneity in prices paid for identical goods for the same area and time with older households shopping the most and paying the lowest prices, documented by Aguiar and Hurst (2007). Second, the presence of households with extremely high search costs can make sellers face inelastic demands at high prices, though their demand curves are still kinked at lower prices.

For example, we consider a representative household that consists of young and old family members. The total number of family members is normalized to be one in each period and the fraction of the young is  $a$ . Furthermore, the young do not search sellers because of their high wage, while the old search for shoppers with low prices. As a result, the demand curve of each seller is given by

$$\left\{ \frac{(1-a)P_{it}^{\theta-1}}{(\bar{z}-\underline{z})W_t^o} \left( \frac{\bar{R}_t^{1-\theta}}{1-\theta} - \frac{P_{it}^{1-\theta}}{1-\theta} \right) + a \right\} \left( \frac{P_{it}}{P_t} \right)^{-\theta} Y_t$$

where the maximum reservation price of the old is  $\bar{R}_t$  and  $W_t^o$  is the real time cost of the old. In this case, the elasticity of demand increases with price when the price is below the

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<sup>18</sup>In order to generate this figure, we assume that the range of cost shocks covers only a very small interval around one:  $\underline{A} = 0.95$  and  $\bar{A} = 1.05$ . In addition, we choose a somewhat wide range of search costs:  $z_{\max} = 0.20$  and  $z_{\min} = 0.001$  for the support of search cost parameter. We do this so as to guarantee that the maximum reservation price is higher than the maximum actual price in our numerical examples.

maximum reservation price of the old, while it becomes less elastic and remains constant as long as the price is above the maximum reservation price of the old.

## 6 Implications for Monetary Policy

As an application of our benchmark framework, we demonstrate that nominal price rigidity can be easily incorporated into the model of customer search. In the example below, firms set prices following the Calvo-type staggered price-setting rule. In particular, we emphasize that the nominal rigidity model with customer search is not equivalent to those with the Dixit-Stiglitz aggregator or the Kimball-type aggregator including the Dotsey-King aggregator. For search costs provide a separate source of the welfare cost of inflation, which is independent of the relative price distortion associated with the staggered price-setting.

### 6.1 Analytic Framework

In this model, we abstract from idiosyncratic productivity shocks to simplify the characterization of equilibrium conditions. In addition, we focus on the case in which the average long-run inflation is positive. Moreover, the aggregate exogenous shocks are not large and thus the most recently updated prices are higher than predetermined prices. This assumption guarantees that all sellers are willing to produce in each product market, even though their prices are predetermined.

Turning to the model, a fraction of firms  $1 - \alpha$  change their prices in each period, whereas the other fraction do not. Under the Calvo-type staggered price-setting, we still can use the same demand curve derived in the previous section. Furthermore, when the inflation rate is positive and exogenous shocks are sufficiently small, firms are likely to increase their nominal prices over time so that  $P_{t-n-1}^* \leq P_{t-n}^*$  for  $n = 0, 1, \dots, \infty$  where  $P_{t-n}^*$  is the nominal price set at period  $t - n$ . Since the Calvo-type price-setting rule generates a set of restrictions for the cumulative distribution of nominal prices, the cumulative distribution at period  $t$  of nominal prices can be written as

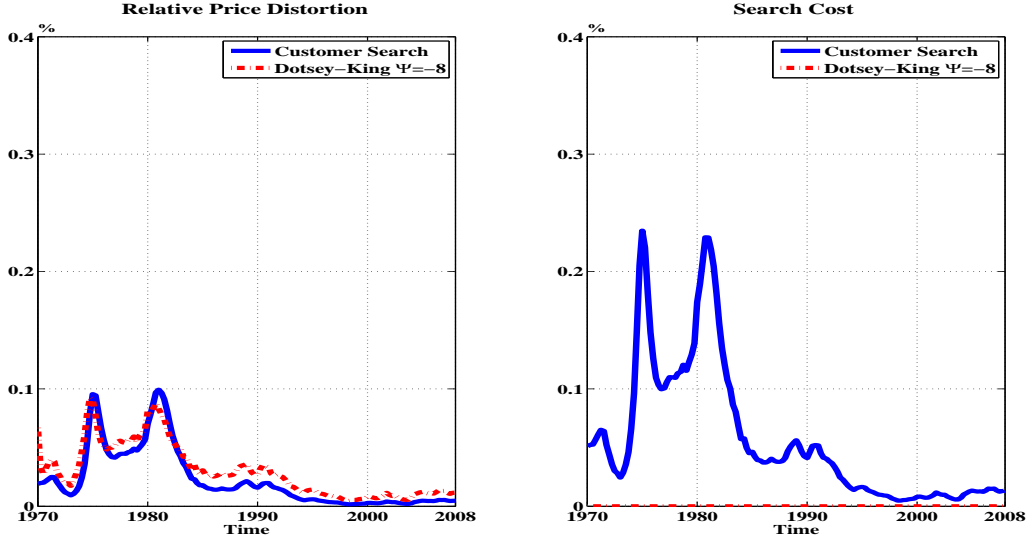
$$F(P) = \alpha^n \text{ if } P_{t-n}^* \leq P < P_{t-n+1}^*$$

for  $n = 1, 2, \dots, \infty$  and  $F(P_t^*) = 1$ .

Given these conditions, we show in the appendix that the fraction of aggregate search



Figure 4: Inflation Costs



Note: this figure shows the time series of relative price distortion and search cost that are constructed using the model. The solid line in the two columns depicts the Calvo model with customer search. The dashed line corresponds to the Calvo model with the Dotsey-King aggregator. The actual inflation rate is the four-quarter moving average of core PCE inflation rates. The relative price distortion and the aggregate search cost are measured as the percentage of the aggregate real output.

cost in the aggregate income takes a simple non-linear AR(1) representation of the form:

$$X_t - \frac{\bar{z}}{2} = \frac{1 - \alpha}{2\alpha\bar{z}} \left( \frac{\tilde{P}_{1t}^{1-\theta} - \Pi_t^{\theta-1} \tilde{P}_{1t-1}^{1-\theta}}{1 - \theta} \right)^2 + \alpha \Pi_t^{2(\theta-1)} (X_{t-1} - \frac{\bar{z}}{2})$$

where  $\Pi_t (= P_t/P_{t-1})$  is the ratio of the general price level at period  $t$  to its lagged value and a price index  $\tilde{P}_{1t}$  is defined as

$$\tilde{P}_{1t}^{1-\theta} = \alpha(\tilde{P}_t^*)^{1-\theta} + \alpha \Pi_t^{\theta-1} \tilde{P}_{1t-1}^{1-\theta}.$$

In addition, the relative price distortion at period  $t$  turns out to be

$$\Delta_t = \frac{1}{\bar{z}} \left( \frac{\tilde{R}_t^{1-\theta}}{1 - \theta} \Delta_{1t} - \frac{\Delta_{2t}}{1 - \theta} \right)$$

where  $\Delta_{1t}$  and  $\Delta_{2t}$  are defined as

$$\Delta_{1t} = (1 - \alpha)(\tilde{P}_t^*)^{-\theta} + \alpha \Pi_t^\theta \Delta_{1t-1}, \quad \Delta_{2t} = (1 - \alpha)(\tilde{P}_t^*)^{1-2\theta} + \alpha \Pi_t^{2\theta-1} \Delta_{2t-1}.$$

## 6.2 Welfare Costs of Inflation

Having described evolution equations of the aggregate search cost and the relative price distortion, we use them to compute the time-series of these two variables. In doing so, we assume that the model's inflation is the same as the actual inflation observed in the data. In order to set the initial values of the aggregate search cost and the relative price distortion, we also assume that the economy had attained a deterministic steady-state with a positive inflation until the period before our computation starts and the steady state inflation rate is the sample average of actual inflation rates. Given initial values of the aggregate search cost and the relative price distortion, we iterate AR(1) evolution equations successively and thus compute time series of these two variables.

Figure 4 depicts the time series of the aggregate search cost and the relative price price distortion. All series are measured as the percentage of the real output, while the search cost at the zero inflation is normalized to be zero. The aggregate search cost and the relative price price distortion tend to move in tandem with the aggregate inflation. For a higher inflation rate increases the dispersion of prices. More specifically, less firms have low prices as the inflation rate rises, and thus households do more searches.

In this figure, the relative price distortion of the Calvo model with the Dotsey-King aggregator is compared with that of the Calvo model with customer search. Under our calibration, the two time-series of the relative price distortion look similar.<sup>19</sup> Obviously, there is no search cost in the Calvo model with the Dotsey-King aggregator. Furthermore, the relative price distortion is less than the aggregate search cost in the customer search model. In relation to this, we note that the relative price distortion can be small in models with customer search due to the strategic complementarity of the price-setting, thereby reducing the size of price changes.

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<sup>19</sup>We set  $\beta = 0.9925$ ,  $\theta = 1.5$ ,  $\alpha = 0.5$ ,  $\bar{z} = 1/4.5$ , and  $\underline{z} = 0$ . We choose these parameter values to guarantee that the two models have the same demand elasticity at the deterministic steady-state with zero inflation. We also set the curvature parameter equal to  $\psi = -8$ . The relative price distortion in the Calvo model with the Dotsey-King aggregator becomes higher as this curvature parameter gets closer to zero.

## 7 Directions for Future Research

We have used household scanner data to document that most of households chooses select only one brand on average each month. Much of marketing or industrial organization literature has discussed household's selection of brands theoretically and empirically. For example, Anderson et al. (2001) examine a duopolistic market wherein brands repeatedly compete for heterogeneous consumers: the loyal consumers buy from only one of the brands; the semi-loyal consumers consider both brands but are willing to pay a premium for the brand purchased last period; the switchers value the two brands identically and buy the lowest priced brand. Villas-Boas (2004) also argues that consumers can gain further information regarding how well a product fits their preferences only by experiencing it after purchase, which could then generate loyalty for the products tried first. In sum, price promotion such as temporary sales would be closely associated with selection and loyalty of brands. In this regard, we expect that the customer search framework can be used to analyze micro foundations of temporary sales.

Finally, our search model framework can help develop deeper micro foundations for nominal price rigidity, allowing for household uncertainty about the current distribution of prices within each narrow product category and about the influence of aggregate shocks on the relative price of that item.

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