Durable Goods and Monetary Policy in a Menu-Cost Economy

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Abstract

This paper studies the distinctive pricing dynamics of durable goods and analyzes their implications for the conduct of monetary policy in a menu-cost economy. Using price microdata, I document the following new facts: (i) the dispersion of price changes in durables is higher than in nondurables; (ii) the frequency of price adjustment is countercyclical, however durable prices get relatively rigid in recessions; (iii) the dispersion of price changes is countercyclical for durables, and procyclical for nondurables. I develop a menu-cost model embedding durable consumption and calibrate it to match new and consolidated empirical evidence. I use the model to challenge the prevailing view holding that durable goods dampen the real effectiveness of monetary policy. I find that even though durable goods prices are relatively flexible, the model generates substantial monetary non-neutrality. Moreover, this paper puts forward a new channel whereby durable consumption can amplify the real effects of monetary policy. This result is driven by heterogeneous demand pass-through of aggregate shocks across sectors. Higher durable consumption enhances the sensitivity of nondurable output to interest rate shocks thus amplifying monetary non-neutrality.

Keywords: Durable Goods, Menu Costs, Monetary Policy, Sticky Prices.

JEL Classification: E31, E32, E52.

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1 Introduction

How do pricing frictions of durable goods influence the effectiveness of monetary policy? In this paper I show that durable goods prices display several, so far largely unexplored distinctive features. I then build a model that rationalizes these new evidence, and argue that monetary policy retains sizeable real effects despite the fact that durable goods prices are relatively more flexible than nondurables.

The relevance of durable goods in business cycle analysis is well acknowledged. Durables make up for a substantial share of the consumption and input expenditure of both households and firms, and a large literature has showed that durable expenditure displays countercyclical excess volatility and substantial lumpiness (among others see Berger & Vavra, 2015).[1] Even though our understanding of the aggregate consequences of durable demand frictions has substantially improved in recent years, we still know surprisingly little about how durables supply-side rigidities influence the wider macroeconomy. The central purpose of this paper is to fill this gap with respect to the best known source of supply-side nominal rigidity, prices. In typical New Keynesian models, sticky prices are in fact key to break the real-nominal dichotomy and generate monetary non-neutrality (see, among others, Calvo, 1983; Gali, 2008). A solid assessment of the business cycle implications of durable goods should therefore account for pricing frictions, the more so if prices of durable goods display distinctive properties. To date, we nonetheless lack both systematic evidence on the distinctive features of durables prices, as well as theoretical models consistent with such empirical regularities.

The contribution of this paper is twofold. First, using microdata underlying the UK consumer price index (CPI) I document new empirical facts that characterize the pricing dynamics of durables and nondurables, both in the cross-section and over time. Second, I develop a New Keynesian model with state-dependent pricing frictions embedding durable and nondurable goods that is consistent with these empirical facts. I then study the effectiveness of monetary policy in this environment.

The empirical analysis suggests that the following four features distinguish prices across durability: (i) prices of durables adjust more frequently than prices of nondurables; (ii) the dispersion of price changes in durables is higher than that in nondurables; (iii) the

[1] A large empirical literature has shown that durable consumption is particularly sensitive to changes in the interest rate (Mishkin, 1995; Barsky, House & Kimball, 2007; Sterk & Tenreyro, 2018). Berger & Vavra (2015) further document that the effectiveness of monetary policy on durable consumption is highly state-dependent. More recently, McKay & Wieland (2020) note that because expansionary monetary policy dampens future demand for durables, central banks need to keep persistently low interest rates to compensate for the resulting shortage of aggregate demand.

frequency of price changes is strongly countercyclical in both sectors, however the relative price flexibility of nondurables relative to durables is procyclical, (iv) the dispersion of price changes of durables is countercyclical, whereas that of nondurables is procyclical. This is the first paper to document facts (ii)-(iv). Fact (i) was instead first noted by Klenow & Malin (2010), who showed that durable goods prices adjust more frequently than nondurable ones.[2] Furthermore note that a straightforward consequence of points (iii) and (iv) is that the correlation between the frequency of adjustment and the dispersion of price changes for durable goods is positive, while it is negative for nondurables. This finding thus complements evidence by Vavra (2014) who, because he does not distinguish across durability, documents such positive correlation for all goods. To my knowledge, however, this is the first paper to systematically document the distinguishing features of prices based on the goods' durability.

These empirical facts motivate my theoretical contribution. As Vavra (2014) notes, standard menu-cost models almost by construction imply that the correlation between the frequency of price adjustment and the dispersion of price changes should be negative. To see why, consider the following scenario. In a menu-cost model, fixed costs define an inaction region within which firms do not find it profitable to adjust prices. An aggregate shock pushing firms out of this inaction region increases the frequency of adjustment. However, since the shock affects all firms in the same way, it also pushes them out of this inaction region in the same direction, thereby decreasing the dispersion of price changes. To tackle this modeling issue, I assume that durable consumption is subject to convex adjustment costs.[3] These induce countercyclical volatility of durable demand which allows to match the different signs of the correlation between frequency and dispersion of price changes in durable and nondurable goods. I calibrate my model to be consistent with existing empirical evidence as well as with facts (i)-(iv).

I summarize the insights the model provides as follows. First, despite the relative flexibility of durable goods prices, the model delivers sizeable monetary non-neutrality in both sectors. This contrasts the theoretical prediction of Barsky, House & Kimball (2007) who showed that in a New Keynesian model with time-dependent pricing frictions the aggregate degree of price rigidity is almost entirely driven by that in the durable sector. Second, the model resolves the "comovement puzzle" raised by Bouakez, Cardia & Ruge-Murcia (2011) whereby durables and nondurables tended to display counterfactually opposite responses to a monetary policy shock. Third, I find that higher steady-state

[2]The focus of Klenow & Malin (2010) is not to compare prices statistics across goods durability. The sector-level statistics they compute approximately suggest this finding nonetheless.

[3]I depart from Berger & Vavra (2015) and assume convex adjustment costs in durable consumption because kinked costs would enlarge the state space beyond computational tractability.

durable to nondurable consumption ratios are associated with amplified real effects of monetary policy. Contrary to most existing models, I thus show that durable consumption can strengthen monetary non-neutrality. This is because household demand for durable goods displays higher sensitivity to changes in the interest rate relative to nondurable consumption. In the model, through the input-output production structure this translates into higher demand for nondurable intermediate inputs. Ultimately, higher steady-state durable consumption therefore drives increased sensitivity of nondurable output to monetary policy shocks, thereby enhancing monetary non-neutrality.

Literature. The study of price setting dynamics using (S,s)-type models has been pioneered by Caplin & Spulber (1987). All first generation state-dependent pricing models show that when prices are sticky because of fixed adjustment costs, money features little to no effect on real economic activity (*e.g.* Caballero & Engel, 1991; Caplin & Leahy, 1997; Dotsey, King & Wolman, 1999). Golosov & Lucas (2007) embed this insight into a quantitative general equilibrium model to match new empirical stylized facts, and confirm that state-dependent pricing frictions imply little monetary non-neutrality.

Nakamura & Steinsson (2008) argue that the Golosov & Lucas (2007) model is unable to match a wide array of new pricing facts, mostly related to the shape of the distribution of price changes. Building on novel empirical evidence, a new generation of models finds that state-dependent frictions can be reconciled with large degrees of monetary non-neutrality. Among others, Nakamura & Steinsson (2010) show that input-output linkages in a multisector model lead to strategic complementarities that imply monetary non-neutrality. Midrigan (2011) finds the same effect in a framework with leptokurtic shocks to idiosyncratic productivity. Vavra (2014) finds that the frequency and dispersion of price changes are countercyclical, and introduces countercyclical uncertainty shocks to match this new fact and confirms monetary non-neutrality in a framework that otherwise resembles Golosov & Lucas (2007). Kehoe & Midrigan (2015) show that a baseline time-dependent pricing model with frictions *à la* Calvo (1983) that allows for temporary price adjustment yields quantitatively similar results to a state-dependent model.

A unifying approach of this line of research is that it combines quantitative, micro-founded models with growing empirical evidence on firm price setting. Starting from Bils & Klenow (2004), monetary economists started studying pricing dynamics using microdata underlying consumer and producer price indices. Bils & Klenow (2004) posed a substantial challenge to workhorse New Keynesian models whose transmission mechanism of monetary policy heavily relies on sticky prices, for they find that prices are adjusted very frequently. Nakamura & Steinsson (2008) challenge this view by noting that the frequency of adjustment substantially decreases once temporary price adjustments are filtered out.

Both Nakamura & Steinsson (2008) and Klenow & Kryvtsov (2008) provide evidence in favor of state-dependent frictions in price setting.

The papers mentioned thus far document regularities between price change statistics averaged across time. More recent research has emphasized that the time series variation of these series is potentially very informative. Vavra (2014) documents that the dispersion and frequency of price changes are both strongly countercyclical, thus posing a challenge to the predictions of a standard menu-cost model which implies the two to be negatively correlated. Berger & Vavra (2018) confirm this finding and show that higher-order moments do not display robust co-movement with inflation. Luo & Villar (2020) find that dispersion falls in high inflation times but, in contrast with the predictions of a state-dependent model, skewness does not. Alvarez *et al.* (2018) show that the price dynamics in Argentina are consistent with menu-cost models both in low and high inflation times.

To date, there is no menu cost model attempting to explicitly consider durable goods. There are, however, few studies within the New Keynesian monetary economics literature suggesting that durable goods may entail interesting insights and pose modeling challenges. Barsky, House & Kimball (2007) extend an otherwise baseline New Keynesian model to include durable consumption subject to depreciation. They show that the degree of aggregate price flexibility is almost entirely driven by that in durables only, because they display a constant shadow value of consumption. In a complementary work, Barsky *et al.* (2016) embed a Taylor-type monetary policy rule in that framework, and show that the effectiveness of such an interest rate rule depends crucially on the extent of price stickiness in the durable sector. Bouakez, Cardia & Ruge-Murcia (2011) embed an input-output structure in a New Keynesian model with durable goods, and show that the resulting economy's response to monetary policy shocks resembles that in the textbook one-sector model, even when durables have flexible prices. My model is related to all these, but builds on the menu cost literature and endogenizes the degree of stickiness in both sectors, whereas both Barsky, House & Kimball (2007) and Bouakez, Cardia & Ruge-Murcia (2011) adopt a standard Calvo pricing friction.

Berger & Vavra (2015) also study the business cycle implications of durable goods, albeit from the demand perspective. They develop and estimate a heterogeneous agents incomplete markets model where households adopt (S,s)-policies in response to fixed adjustment costs in durable consumption. They find that durable consumption reacts less to economic shocks during recessions because households adjust their durable holdings less frequently. This paper is also related to McKay & Wieland (2020), who explore how durable consumption influences the effectiveness of monetary policy. They argue that intertemporal substitution following a, say, expansionary monetary policy shock substantially and permanently decreases future durable demand, hence forcing the central bank to keep a low interest rate in the upcoming periods to make up for this demand shortage.

The rest of the paper is organized as follows. Section 2 reports the empirical results, focusing on the distinctive patters distinguishing durable from nondurable goods. These findings motivate the theoretical model which I describe in section 3. Section 4 takes the model to the data, presents the calibration and simulation results of the model, as well as its policy implications. I conclude and suggest possible future developments in section 5.

2 Empirical Results

I use product-level data underlying the CPI for the United Kingdom. The data are maintained by the Office for National Statistics (ONS) and contain monthly price quotes collected from local retailers covering a wide range of consumer and service goods over the period 1996 to 2018. This dataset has recently been made publicly available for the period 2008 to 2018 and used among others by Kryvtsov & Vincent (2020) and Baley & Blanco (2019).[4]

The CPI comprises goods and services that are included in the household final monetary consumption expenditure component of the UK National Accounts. To construct the dataset the ONS surveys the price of more than 1,100 individual goods and services per month, collected locally from more than 14,000 retail stores across the UK regions. Housing and related expenditures are not included in the survey. For each item, the ONS reports the region of the retailer, the 5-digit COICOP sector and the shop type (independent or chain). Examples of an entry of the dataset would be a 250g box of french fries sold in an independent shop in Yorkshire and the Humber in October 1999, or a pair of men's trousers sold in a chain shop in London in May 2013. It also reports flags indicating whether the item was on sale, or had been subject to substitution relative to the previous survey. For each pair of region-shop type the ONS provides sampling weigths that reflect the product's relative importance in the consumption expenditure of households. Unless otherwise stated all the statistic I calculate are weighted using these CPI consumption expenditure weights. My sample thus includes 238 months, from January 1996 to December 2018. Following Kryvtsov & Vincent (2020), who use the same partially overlapping 1996-2013 dataset, I delete observations that are deemed invalid by the ONS for the construction of the CPI. I split a price line whenever a substitution flag is reported. Last, I only keep items for which at least ten not necessarily consecutive price quotes are observed. Results are robust to variations on these practices.

[4] The public portion of the data is available here. A more detailed description of the data can be found in Kryvtsov & Vincent (2020) Online Appendix.

I identify durable and nondurable goods using the 4-digits COICOP classification (UN, 2018). COICOP 2018 classes distinguish between durable, semi-durable and non-durable goods. My main results contrast statistics computed for durable and nondurable goods only. Statistics on semi-durables, which cover a minor share of the consumption expenditure in my dataset, can be found in the Online Appendix. My sample ends up consisting of approximately 25 million observations, among which 14 million refer to nondurable goods, and 11 million to durable goods.

As is standard in the literature following Nakamura & Steinsson (2008), I largely restrict the attention to regular price changes.[5] A price change is regular if it is neither due to a sale nor to a product substitution. I identify substitutions using the flag provided by the ONS. Unfortunately, the sales flag is not available for the period 2013-2017, hence I construct several sales filters developed in the literature to identify sales episodes.

In general, a k-order V-shaped sales filter identifies as a sale any negative price change that is followed by a positive price change within k months. The symmetric V-shaped filter requires the new price be equal to the one before the sale (Bils & Klenow, 2004). The asymmetric filter drops this requirement (Nakamura & Steinsson, 2008). Both types of filter place either k missing values in the resulting regular price series whenever a sale is identified, or assume that the underlying regular price is unchanged. For each filter, I thus repeat the analysis keeping the missing values, and assuming that the regular price does not change through these k periods. Therefore, I construct regular price series using both filters, setting k equal to 1 and 3 months, and keeping or filling the missing values, and find that results here are robust to all these practices. For concreteness, the statistics I report here refer to the 3-months asymmetric filter, assuming that regular prices do not change during the sales period.

2.1 Size and Frequency of Price Changes

The first empirical question I ask is whether the two most overlooked pricing statistics, the median frequency and size of price adjustment, differ depending on the durability of goods. Table I reports the mean and median frequency of price changes, as well as the frequency of price increases and decreases. The first three rows report estimates for all price changes, all items, and durable and nondurable items separately. The second three rows provide the same estimates, but for regular price changes only. The first three rows

[5] Recent evidence by Kryvtsov & Vincent (2020) and Sheremirov (2019) suggest that sales display interesting properties and thus should not be filtered out. However, I find that sales in durable and nondurable sectors are very similar, both in terms of frequency and size. Since the scope of this work is to uncover the main facts distinguishing durable and nondurable prices, I choose to discard them. Qualitatively little would change otherwise.

thus include product substitutions and sales, while the second three drop both.

TABLE I: FREQUENCY OF PRICE CHANGES

		Mean			Median		
		All	Durable	Nondurable	All	Durable	Nondurable
Price Changes	All	21.64	26.29	18.27	16.36	21.43	14.44
	Increases	11.09	12.37	10.15	8.93	10.00	8.40
	Decreases	9.36	12.11	7.36	6.49	9.38	5.41
Regular Price Changes	All	8.38	9.47	7.59	7.14	8.11	6.77
	Increases	5.12	4.98	5.23	4.35	4.29	4.35
	Decreases	3.79	5.11	2.83	2.65	3.49	2.19
Sales		4.77	5.75	4.05	2.75	3.70	2.27

Notes. Durables and nondurables identified within the COICOP taxonomy. Weights are computed by the UK Official Statistics office. Regular price changes comprise all price changes except sales and substitutions.

The monthly mean frequency of price adjustment is roughly 26% for durables and 18% for nondurables, while the median frequency of adjustment is 21% in durables and 14% in nondurables. Both estimates are lower than those estimated by Nakamura & Steinsson (2008) and Klenow & Malin (2010) for the US. This is consistent with widespread sense that prices in Europe would be less flexible than in the US (Dhyne *et al.*, 2006). Accounting for sales and substitutions further reduces both the mean and median frequency of changes in both sectors. Despite substitutions being more frequent in durable sectors, the mean and median frequency of regular price adjustment are nontheless higher in durables than in nondurables.

That durable goods display higher frequency of price adjustment is not a novel finding (Klenow & Malin, 2010). It is, however, important to highlight that the implied price duration is a key moment that one targets to estimate menu-cost models. Furthermore, the evidence I provide aggregates statistics on the basis of the durability of the item, hence one could argue that the relative price flexibility of durables results from compositional effects. This is, however, unlikely, for Klenow & Malin (2010) estimate the duration of price spells at a more disaggregated level, and confirm this finding. Last, table I suggests that price adjustments in durables are split evenly between increases and decreases, whereas price increases are more common than price decreases in nondurable sectors. As a result, I show below that the mean and median price change in nondurables is higher than in durables, and that the distribution of the latter is more dispersed.

In table II I report the estimated mean and median size of price adjustment. As before, I distinguish between price increases and decreases, and provide distinct estimates for all price changes and regular price changes only.

TABLE II: SIZE OF PRICE CHANGES

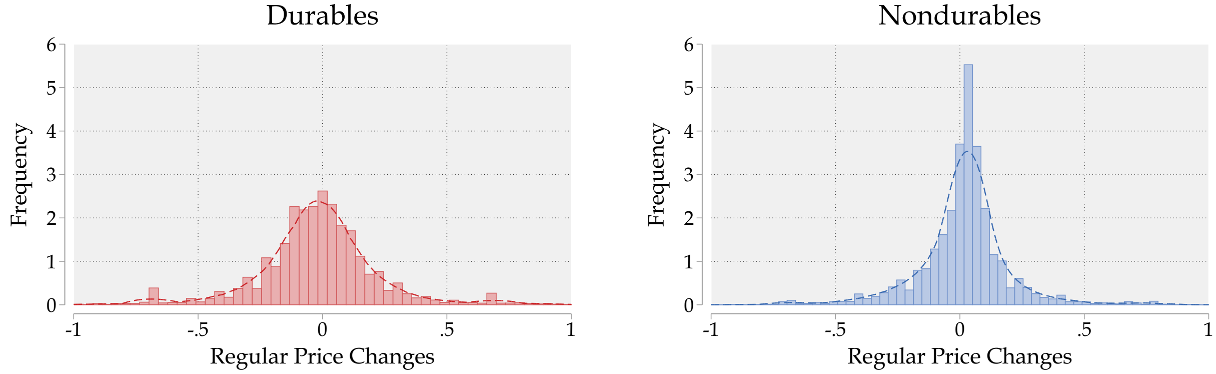
		Mean			Median		
		All	Durable	Nondurable	All	Durable	Nondurable
Price Changes	All	-0.51	-1.37	0.35	0.03	-0.49	0.58
	Increases	18.76	20.11	17.53	15.63	16.64	14.85
	Decreases	-20.57	-20.43	-20.74	-17.77	-17.23	-18.42
Regular Price Changes	All	-0.53	-1.94	0.81	0.49	-1.19	1.72
	Increases	15.34	18.58	12.75	11.03	13.88	9.53
	Decreases	-17.10	-18.31	-15.52	-12.86	-13.68	-11.81
Sales		-23.32	-21.79	-24.90	-20.90	-18.95	-22.65

Notes. Durables and nondurables identified within the COICOP taxonomy. Weights are computed by the UK Official Statistics office. Regular price changes comprise all price changes except sales and substitutions.

Table II confirms that the mean and median price adjustments are higher for nondurables, across statistics and series. Evidence also suggest that price adjustments are large in both directions. The mean price increase is 20% and 17% in durables and nondurables respectively, and in both sectors the mean price decrease is about 20% of the outstanding posted price. Price changes are thus lumpy, not only because they are infrequent, but also because they account for a sizeable share of the posted price whenever they occur. However, the mean and median price decrease in nondurable goods exceed the corresponding price increase by about 2% points, as in the US (Nakamura & Steinsson, 2008). This however does not translate into lower average price adjustments overall because price increases are more frequent than price decreases. Hence, it implies that the distribution of price changes of nondurables is leptokurtic, while that of durables displays no excess kurtosis.

Since product substitutions are more common in durable sectors, evidence on regular price changes for such goods is particularly informative. The absolute mean, and median, regular price increase (decrease) is larger by 5% (3%) for durable goods than for nondurable goods. Putting together this fact with previous evidence conveys the idea that the distribution of regular price changes of durables is more dispersed and symmetric than that of nondurables. I provide graphical evidence on this in figure I.

FIGURE I: DISTRIBUTIONS OF REGULAR PRICE CHANGES



Notes. Price changes are computed as log-differences. Figures report the distribution of regular price changes, by durability. The dashed line reports a kernel density estimate. Kernel is Epanechnikov, bandwidth is 0.1.

The panels in figure I plot the distribution of price changes by durability over the observation timespan. I characterize the evolution of the distribution in the next section. From a timeless perspective, the distribution of price changes in durables is clearly more dispersed than that of nondurables. Other quantitative facts are more difficult to infer. The average size of adjustment in durables is lower than in nondurables. Moreover, the left panel shows that the distribution of regular price changes in durables is essentially symmetric, while the one for nondurables displays negative skewness. I provide more formal evidence on these facts over the business cycle in the next section.

It is not novel that durable goods display a higher frequency of price adjustment, even accounting for sales and product substitutions. To the best of my knowledge, to date there is however no study documenting the relative excess dispersion of the distribution of regular price changes in durable goods. Below I argue that this dispersion exhibits differing behavior over the business cycle between the two sectors as well.

2.2 Price Changes and the Business Cycle

I now ask whether the degree of durability influences the comovement between the frequency of price adjustment, the moments of the price change distribution and the business cycle. There is increasing evidence, mainly from US data, that the dispersion of the distribution of regular price changes and their frequency are negatively correlated (Vavra, 2014; Berger & Vavra, 2018). Here I show that accounting for durability enriches the picture. To construct the statistics on the distribution of price changes over time I follow Vavra (2014). The frequency of adjustment is computed by first taking a within-quote line k-month moving average of an indicator function of regular price changes, and then averaging the resulting series over time. The series for the moments of the price distribution are computed similarly, except that the price adjustment instead of its indicator pops in. Results would not change had I reversed the order of the two operations.

I take the unemployment rate as a proxy for the business cycle. This choice is due to the fact that I have information on the region where the price line was collected. Hence I can clean for region-level confounding effects. To do so, I need a proxy for the business cycle at regional level at monthly frequency. The only available statistics at this frequency and level of aggregation in the UK is the unemployment rate.

In table III I report the median, standard deviation, skewness and kurtosis of the regular price change distribution, regressed against the unemployment rate and a recession dummy. All regressions include time and region fixed effects. In Appendix A.2 I report the results of the estimates for a wide range of models for all the statistics as a robustness check.

TABLE III: THE PRICE CHANGES DISTRIBUTION AND THE BUSINESS CYCLE

	Median		Std. Dev.		Skewness		Kurtosis	
	D	ND	D	ND	D	ND	D	ND
$\Delta \log u_t$	0.025***	0.008***	0.194***	-0.110***	-0.102**	-0.108***	0.019	0.294***
	(0.006)	(0.002)	(0.042)	(0.022)	(0.039)	(0.028)	(0.047)	(0.033)
ξ_t	0.033***	0.007***	0.057**	-0.169***	-0.046*	-0.033	0.153***	0.258***
	(0.002)	(0.001)	(0.018)	(0.011)	(0.022)	(0.024)	(0.040)	(0.018)
Const.	-0.013***	0.022***	-1.505***	-1.696***	0.693***	0.477***	1.414***	1.851***
	(0.000)	(0.000)	(0.002)	(0.001)	(0.001)	(0.001)	(0.003)	(0.001)
Obs.	3,276	3,276	3,276	3,276	3,276	3,276	3,276	3,276
R^2	0.250	0.101	0.553	0.493	0.131	0.169	0.296	0.208

Notes. D: durables; ND: nondurables. Dependent variables are moments of the regular price change distribution. Robust standard errors in parentheses are clustered by region. Variable u is unemployment (%), ξ is a recession dummy. All regressions include region fixed effects and a time trend. *** $p < .01$, **$p < .05$, * $p < .1$.

Evidence from a dataset stretching back to the 1980s by Nakamura *et al.* (2018) suggest that there is little comovement between the median absolute price change, a proxy for the price *level* dispersion, and the business cycle. I confirm this finding in the first column of table III. There is a significant correlation between the median price change and the unemployment rate, but it is very low. It is, however, of the expected sign suggesting that price dispersion rises in bad times.[6]

[6]Assuming that inflation is countercyclical, this result would contradict evidence by Sheremirov (2019) who

The second column reports the correlation between the dispersion of the price changes distribution and the business cycle. This statistic is particularly relevant because menu cost models by construction imply that dispersion should be negatively correlated with the frequency of price adjustment (Vavra, 2014).[7] Here I find that the correlation between the dispersion of price changes and the business cycle is positive for durable goods, and negative for nondurables. The coefficients are highly significant, and the signs are robust to a number of different specifications. Moreover, the dispersion of durable goods slightly increases during the Great Recession, whereas that of nondurables decreases. I conclude that the dispersion of regular price changes is robustly countercyclical in durable goods, and procyclical in nondurables. This finding complements US evidence by Vavra (2014) who documents countercyclical dispersion of price changes, but does not distinguish between durable and nondurable goods.

The remaining moments are of little interest, as discussed by Berger & Vavra (2018) for the US. The skewness of the distribution of price changes is procyclical, but the magnitude of the overall correlation is small. Moreover, durable and nondurable goods display a very similar third moment comovement with the business cycle. An almost similar argument applies to the kurtosis of the distribution. The fourth moment is countercyclical, thus suggesting that large price adjustment are less likely to occur in good times. This is in line with previous evidence. The kurtosis of nondurable goods price changes nonetheless features a stronger negative comovement with the business cycle than that of durables. This relates to results discussed in the previous section.

Table III conveys a number of interesting insights on how the distribution of price changes evolves over the business cycle. Moreover, it sheds light on the different behavior of durable and nondurable goods. The most interesting finding is that the dispersion of price changes comoves positively with the business cycle for nondurable goods, and negatively for durables. As I discuss more in detail below, this has profound implications if one is willing to model these dynamics using a menu cost model.

The other crucial statistic is the frequency of price adjustment over the business cycle. Evidence on this does not substantially depart from that reported by Vavra (2014) and Berger & Vavra (2018). I find that the frequency of regular price adjustment is robustly countercyclical for both durable and nondurable goods. Moreover, durable prices display

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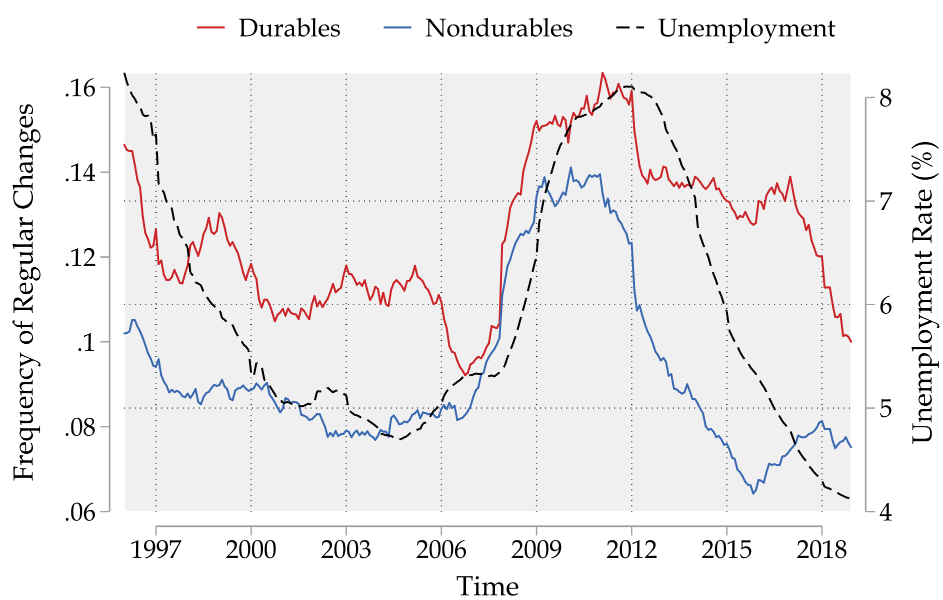
finds a positive comovement between inflation and the dispersion of regular prices. However, he measures dispersion as the standard deviation of log price *levels*, while Nakamura *et al.* (2018) proxy for it with the absolute median size of price *change*, as I do.

[7] The argument follows from the seminal contribution by Barro (1972). Fixed costs in Ss models lead to an inaction region within which it is not worth changing prices. The frequency of adjustment increases whenever a shock pushes firms out of this inaction region. An *aggregate* shock, however, pushes all firms in the same direction, thereby lowering the dispersion of price changes.

a higher frequency of adjustment over the whole observation sample. Figure II displays the frequency of adjustment for the two categories, and the unemployment rate.

FIGURE II: FREQUENCY OF PRICE ADJUSTMENT AND THE BUSINESS CYCLE



Notes. Figure reports 12-month centered moving average median weighted frequencies of regular price changes, and unemployment rate.

The frequency of price adjustment clearly positively comoves with the unemployment rate, hence it is countercyclical, in both durables and nondurables. It is, in particular, comparatively larger than average in both sectors during the two high unemployment periods in the sample, namely the late 1990s and the Great Recession. Figure II also shows that the frequency of price adjustment in durables is consistently higher than that in nondurables throughout the sample period, hence confirming preliminary evidence reported in table I. Figure II further suggests that the response of the frequency of adjustment to changes in unemployment might differ across degrees of durability. I provide more formal evidence on this in table IV.

Table IV reports the correlation between the relative price flexibility, defined as the ratio between the frequency of price adjustment in durables over that in nondurables, and the business cycle.

Regression evidence indicates that an increase in the unemployment rate leads to a decrease in the log-ratio between the frequency of adjustment of durables and nondurables.[8] Hence, prices of durable goods become relatively more rigid than prices of

[8]Table XII in Appendix A.2 provides direct evidence on the correlation between the frequency of adjustment and the unemployment rate.

TABLE IV: RELATIVE FREQUENCY OF ADJUSTMENT AND THE BUSINESS CYCLE

Model	(1)	(2)	(3)	(4)
$\Delta \log u_t$	-0.472***	-0.316***	-0.315***	-0.280***
	(0.081)	(0.067)	(0.068)	(0.064)
ξ_t		-0.178***	-0.179***	-0.201***
		(0.025)	(0.023)	(0.022)
Constant	0.278***	0.289***	0.233***	0.230***
	(0.023)	(0.023)	(0.001)	(0.002)
Obs.	3,073	3,073	3,073	3,073
R^2	0.006	0.030	0.110	0.283
Region FE	✗	✗	✓	✓
Time Trend	✗	✗	✗	✓

Notes. Dependent variable is the log-ratio of the frequency of regular price changes of durables relative to nondurables. Robust standard errors in parentheses are clustered by region. Variable u is unemployment (%), ξ is a recession dummy. *** $p < .01$, **$p < .05$, * $p < .1$.

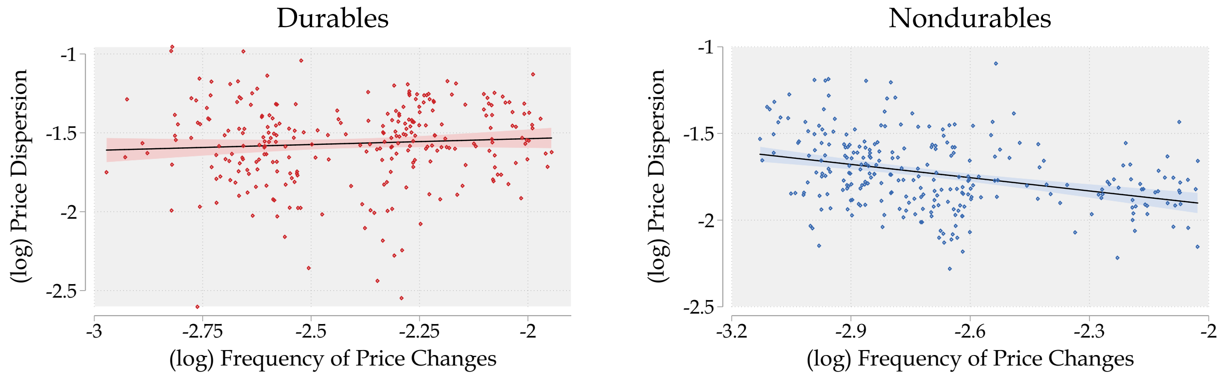
nondurables following an increase in the unemployment rate. In other words, the frequency of adjustment of nondurable goods reacts more in response to sudden movements in the unemployment rate relative to that of durables. This differential response to shocks has modeling implications which I discuss more in detail in the next section.

The dynamic patterns of the frequency of adjustment and the moments of the distribution of price changes overall convey two broad messages. First, the co-movement between the dispersion of the distribution and the business cycle varies radically between durables and nondurables. The dispersion of the former exhibits positive correlation with the unemployment rate, whereas the latter is robustly countercyclical. Second, durables display higher frequency of adjustment than nondurables. This notwithstanding, their relative price rigidity is countercyclical. In the next section I discuss the implications of these results for a mainstream menu cost model.

2.3 Frequency and Dispersion of Price Changes

By construction, in menu cost models the frequency of adjustment of the control variable and its cross-sectional dispersion are negatively correlated. Fixed cost of adjustment define an inaction region within which it does not pay to change the control. If an aggregate shock pushes agents out of these inaction region, the frequency of adjustment raises. However, all agents react to the same shock in the same direction, thereby decreasing the dispersion of changes in the control (Barro, 1972). In figure III I show the correlation between the frequency of price changes and the dispersion of their distribution.

FIGURE III: FREQUENCY OF DISPERSION OF PRICE CHANGES



Notes. Lines plot the OLS fit. Confidence bands report 90% confidence level. Plots are by durability.

The figure plots aggregate dispersion and frequencies, and thus abstracts from regional heterogeneity. In table V I provide a more formal assessment of the robustness of the relationship pictured in figure III, and show that the qualitative behavior is unchanged. Figure III is a by-product of the fact that dispersion is countercyclical in durables and procyclical in nondurables, whereas the frequency is countercyclical in both categories. As a consequence, the correlation between the two for nondurable goods is negative, as one would expect through the lens of a menu cost model. It is, however, positive in durables, thus posing a major modeling challenge.

In the next section I show that a model with convex adjustment costs in durable consumption features countercyclical volatility of demand, a well-known empirical regularity (*e.g.* Berger & Vavra, 2015). Countercyclical volatility of demand entails a twofold effect in a menu cost environment. On the one hand, greater volatility in bad times pushes more firm out of the inaction region. On the other, it also increases the option value of waiting. Vavra (2014) shows that the first effect dominates the second also out of the steady-state. Thus, a model featuring countercyclical volatility of demand for durables allows to reconcile the opposed correlations between dispersion and frequency in durables and nondurables.

The mechanism I identify is akin to countercyclical uncertainty shocks *à la* Vavra (2014). He shows that countercyclical uncertainty at the firm level induces the same dynamics I outlined for countercyclical durable demand volatility, and is consistent with robust empirical evidence (*i.a.* Bloom, 2009). There is no reason to think, however, that uncertainty shocks disproportionately affect firms operating in durable sectors. Since I find that the negative correlation between the frequency of adjustment and the dispersion of price changes holds in durable sectors only, I develop a theory of countercyclical volatility

TABLE V: DISPERSION AND FREQUENCY OF REGULAR PRICE CHANGES

	Durables		Nondurables	
Model	(1)	(2)	(1)	(2)
$\log f_t$	0.197***	0.201***	-0.233***	-0.189***
	(0.036)	(0.034)	(0.019)	(0.029)
ξ_t		-0.070***		-0.041**
		(0.021)		(0.018)
Constant	-1.072***	-0.907***	-2.344***	-2.235***
	(0.078)	(0.088)	(0.050)	(0.072)
Obs.	3,043	3,043	3,043	3,043
R^2	0.080	0.314	0.244	0.308
Region FE	✗	✓	✗	✓
Time Trend	✗	✓	✗	✓

Notes. Dependent variable is the log-standard deviation of the regular price distribution. Variabe f is the frequency of price adjustment. Variable ξ is a recession dummy. Robust standard errors in parentheses are clustered by region. *** $p < .01$, **$p < .05$, * $p < .1$.

that is specific to firms operating in those sectors only.

3 A Menu-Cost Model with Durable Goods

The model I develop is a generalization of the environment described by Golosov & Lucas (2007), in which households enjoy utility from consumption of a durable as well as a perishable good. Firms produce differentiated varieties of one of the two goods. Firms producing either one are collectively referred to as a "sector". Both sectors are populated by a continuum of measure one of firms. In this section I discuss the problem of the representative household, that of durable and nondurable firms, and then define an equilibrium for this economy. Finally, I discuss how to compute the equilibrium numerically.

3.1 Households

The economy is populated by a representative household seeking to maximize his discounted intertemporal utility. The preferences of the household are defined over labor and the two consumption goods, which are composites of a continuum of imperfectly substitutable varieties purchased from the firms. The household sells labor to firms, owns shares in all firms in all sectors, and trades a full set of state-contingent Arrow securities. The problem of the household can then be cast as follows:

$$\max_{\left\{\substack{C_{t+\tau}, D_{t+\tau}, \\ N_{t+\tau}, B_{t+\tau+1}}\right\}_{\tau=0}^{\infty}} E_t \left[\sum_{\tau=0}^{\infty} \beta^{\tau} \left(\frac{\left(C_{t+\tau}^{\nu} D_{t+\tau}^{1-\nu}\right)^{1-\gamma} - 1}{1-\gamma} - \omega \frac{N_{t+\tau}^{1+\psi}}{1+\psi} \right) \right] \tag{1}$$

subject to the period budget constraint,

$$\begin{aligned} P_t^C C_t + P_t^D D_t + E_t\left[Q_{t,t+1} B_{t+1}\right] + P_t^D \Phi\left(D_{t-1}\right) \leq B_t + W_t N_t + P_t^D (1-\delta) D_{t-1} + \\ + \int_0^1 \Pi_t^C(z)\, dz + \int_0^1 \Pi_t^D(z)\, dz \end{aligned} \tag{2}$$

The operator $E_t[\cdot]$ denotes the expectation conditional on the information available at time t, C_t and D_t denote nondurable and durable consumption goods, respectively, and N_t is labor supplied. The household discounts future utility by a factor $\beta \in [0, 1)$, places a relative weight on nondurable consumption of $\nu \in [0, 1]$, and has risk aversion denoted by $\gamma > 0$; the level and convexity of the disutility induced by labor supplied are captured by $\omega > 0$ and $\psi > 0$, respectively.

Because I assume that households trade a full set of state-contingent Arrow securities, B_{t+1} is a random variable that delivers payoff at time $t + 1$ from financial assets purchased in period t at price $Q_{t,t+1}$. The terms P_t^C and P_t^D denote the prices of the nondurable and durable goods, respectively; W_t is the nominal wage rate in the economy, and $\Phi(\cdot)$ is an adjustment cost term to be defined below. Durable goods depreciate at rate $\delta \in (0, 1)$. Terms Π_t^D and Π_t^C respectively denote nominal profits of firms in the durable and nondurable sectors. Constraint (2) is accompanied by non-negativity constraints on consumption and labor, namely $C_t, D_t, N_t \geq 0$, and a No-Ponzi game condition ruling out explosive paths of financial wealth.

Following Berger & Vavra (2015), I assume that durable goods are subject to adjustment costs defined as

$$\Phi\left(D_{t-1}\right) = \varphi(1-\delta) D_{t-1} \tag{3}$$

where $\varphi > 0$ captures their magnitude.[9] Households thus face an adjustment cost that is proportional to the outstanding stock of durable goods they held at the end of the previous period, net of depreciation. Since durable goods do not fully depreciate, the choice of D_t in equilibrium is forward looking. Moreover, the shape of (3) implies that D_t displays excess volatility relative to C_t.

[9] The functional form of (3) implies that adjustment costs are isomorphic to higher depreciation, parametrized by the new rate $\tilde{\delta} \equiv \delta + \varphi - \delta\varphi$, where by assumption $\tilde{\delta} > \delta$ because $\delta \in (0, 1)$ and $\varphi > 0$.

Households consume a continuum of differentiated durable and nondurable products. Let z denote the generic variety as well as the unique firm producing it. The composite nondurable consumption good C_t is defined as a Dixit-Stiglitz index over these differentiated nondurable goods:

$$C_t = \left[\int_0^1 c_t(z)^{\frac{\theta-1}{\theta}} \, dz \right]^{\frac{\theta}{\theta-1}} \tag{4}$$

where $c_t(z)$ denotes the household's consumption of variety z of the nondurable good at time t, and $\theta > 0$ denotes the elasticity of substitution across varieties. Similarly, the composite durable consumption good D_t is defined as a Dixit-Stiglitz index over differentiated durable goods:

$$D_t = \left[\int_0^1 d_t(z)^{\frac{\theta-1}{\theta}} \, dz \right]^{\frac{\theta}{\theta-1}} \tag{5}$$

where $d_t(z)$ is the household's consumption of variety z of the durable good at time t.

The household in each period decides how much to consume of the different varieties of the two goods. For a fixed consumption level at time t of both the durable and the nondurable good, the household minimizes the expenditure that is needed to achieve that level. This implies that the demand for the generic variety z in each sector is given by the following:[10]

$$c_t(z) = \left(\frac{p_t^C(z)}{P_t^C} \right)^{-\theta} C_t \tag{6}$$

$$d_t(z) = \left(\frac{p_t^D(z)}{P_t^D} \right)^{-\theta} D_t \tag{7}$$

where $p_t^C(z)$ and $p_t^D(z)$ denote the prices of a generic variety z of the nondurable and durable good, respectively. Implicitly, P_t^C and P_t^D are defined as the Dixit-Stliglitz price indexes in the two sectors.

In the remainder of the paper I assume log-utility setting $\gamma = 1$ following, among others, Nakamura & Steinsson (2010) and Midrigan (2011). Moreover, in the spirit of Hansen (1985) and Rogerson (1988) I set $\psi = 0$ and assume indivisible labor decisions implemented through lotteries. Thus the first-order conditions associated to the household's maximization problem (1) imply the following optimality relations:

[10] I provide detailed analytical derivations in Appendix B.1.

$$C_t = \frac{\nu}{\omega}\frac{W_t}{P_t^C} \tag{8}$$

$$D_t = \frac{1-\nu}{\omega}\left(\frac{P_t^D}{W_t} - \beta(1-\delta)(1-\varphi)E_t\left[\frac{P_{t+1}^D}{W_{t+1}}\right]\right)^{-1} \tag{9}$$

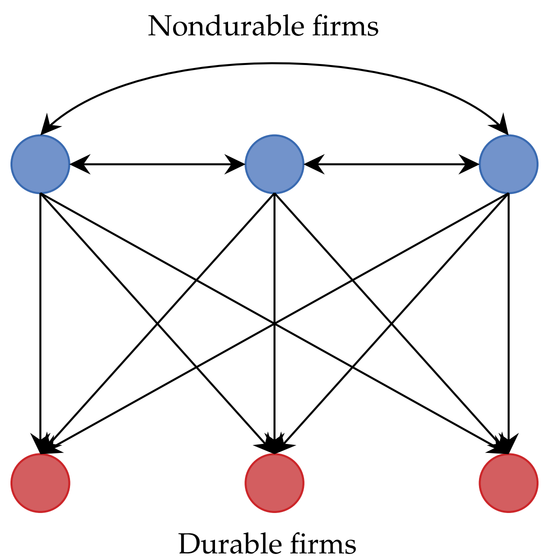
$$E_t\left[Q_{t,t+1}\right] = \beta E_t\left[\frac{W_t}{W_{t+1}}\right] \tag{10}$$

and a transversality condition. Equations (8) and (9) pin down the two components of consumption given prices and the wage, and can be understood as optimal labor supply schedules. Equation (10) determines the pricing kernel in this economy.

3.2 Firms

There are two sectors, call them D and C denoting the durable and the nondurable one. Each sector is populated by a continuum of measure one of firms. Each firm produces a variety z of the good whose sector it belongs. Varieties are assumed to be imperfectly substitutable, hence firms are monopolistically competitive. The differentiated varieties of the nondurable good serve as an intermediate production input in both sectors.

FIGURE IV: THE INPUT-OUTPUT NETWORK OF THE ECONOMY



Notes. Blue nodes are nondurable firms, red nodes are durable firms. Reciprocal links mean that the nodes use each other's output as a production input; directed links mean that the upstream firm does not use the downstream's output as production input.

Following Nakamura & Steinsson (2010), who in turn build on Basu (1995), I assume that nondurable goods serve both as consumption goods as well as inputs into the production of firms. This “roundabout” structure, shown in figure IV, allows me to capture in a parsimonious way the complex structure of modern production networks (*i.a.* Acemoglu *et al.*, 2012). Moreover Basu (1995) shows that the price rigidity induced by menu costs coupled with this roundabout production structure implies that pricing decisions are strategic complements across firms, as Nakamura & Steinsson (2010) emphasize. This is in turn the bulk of the mechanism prompting monetary non-neutrality in their model. Furthermore, I introduce an asymmetry in the roundabout production structure because the nondurable good is a production factor for durable goods firms, but the converse is not true. Besides greatly simplifying the model, this assumption relies on empirical evidence by Bouakez, Cardia & Ruge-Murcia (2011). Using BLS data, they document that 45% of the total material-input expenditure in durable sectors is spent on goods produced in non-durable sectors, while less than 10% of the total material-input expenditure in nondurable sectors is spent on goods produced in durable sectors. I capture this fact in a stylized manner by assuming that durable goods firms use nondurable goods as production inputs, but nondurable goods firms do not use durable goods as intermediate input.

Moreover, the material-input expenditure share of nondurable materials in nondurable sectors is as high as 90%, thus suggesting that within-sector complementarities are important and worth including in this sector. On the contrary, this share is much lower in durable sectors and I thus abstract from within-sector complementarities across durable firms.

3.2.1 Durable goods firms

Let z denote both a firm in the durable sector D, as well as the variety it produces. The production function of firm z is then given by

$$y_t^D(z) = A_t^D(z) N_t^D(z)^\alpha M_t^D(z)^{1-\alpha} \tag{11}$$

where $y_t^D(z)$ is the quantity of the variety z of the durable consumption good D firm z is producing at time t, $A_t^D(z)$ denotes its idiosyncratic productivity, $N_t^D(z)$ is the quantity of labor it employs, and $M_t^D(z)$ denotes an index over varieties of the nondurable good which firm z uses as intermediate inputs in production. The term $\alpha \in [0,1]$ captures the share of intermediate inputs that are used in production. The index of intermediate inputs is defined as a Dixit-Stiglitz composite over varieties of nondurable goods:

$$M_t^D(z) = \left[\int_0^1 m_t^D(z,z')^{\frac{\theta-1}{\theta}} \, dz' \right]^{\frac{\theta}{\theta-1}} \tag{12}$$

where θ captures the elasticity of substitution across varieties of the inputs, and z' denotes a firm producing variety z' of the *nondurable* good. Equation (12) thus implies that firm z in the durable sector uses a bundle of intermediate nondurable inputs as production factors.

Firm z decides in each period t how much to purchase of each intermediate nondurable product it uses as production input. Cost minimization then implies that the demand for variety z' is given by

$$m_t^D(z,z') = \left(\frac{p_t^C(z')}{P_t^C}\right)^{-\theta} M_t^D(z) \tag{13}$$

The problem of a durable good firm z is to maximize the value of its expected discounted profits, which are given by

$$E_t\left[\sum_{\tau=0}^{\infty} Q_{t,t+\tau+1}\Pi_{t+\tau}^D(z)\right] \tag{14}$$

where $Q_{t,t+1}$ is the unique stochastic discount factor given by (10), and $\Pi_t^D(z)$ denotes the nominal profits firm z attains. The latter are given by total revenues net of expenditure on labor and intermediate inputs. Firms also face a fixed "menu" cost that they must pay whenever they wish to undergo a price changes. Then, profits are given by

$$\Pi_t^D(z) = p_t^D(z)y_t^D(z) - W_tN_t^D(z) - P_t^C M_t^D(z) - \varphi^D W_t \mathcal{I}\left(p_t^D(z), p_{t-1}^D(z)\right) \tag{15}$$

where $\mathcal{I}(\cdot)$ is an indicator function that is equal to one only if $p_t^D(z) \neq p_{t-1}^D(z)$, and φ^D determines the level of the menu cost, which is denominated in labor units.

A firm at time t thus picks a sequence of prices, labor demand and intermediate inputs $\{p_{t+\tau}^D(z), N_{t+\tau}^D(z), M_{t+\tau}^D(z)\}_{\tau=0}^{\infty}$ to maximize (14), where the profit function is defined by (15), subject to its production function (11), demand for its product (7)-(9), idiosyncratic productivity and the behavior of aggregate states.

3.2.2 Nondurable goods firms

As before, let z denote both a firm in the nondurable sector C, as well as the variety it produces. The production function for this firm is linear in labor:

$$y_t^C(z) = A_t^C(z)N_t^C(z)^{\alpha}M_t^C(z)^{1-\alpha} \tag{16}$$

where $y_t^C(z)$ is the quantity of variety z of the nondurable consumption good C firm z produces at time t employing $N_t^C(z)$ units of labor, $A_t^C(z)$ denotes its idiosyncratic productivity and $M_t^C(z)$ is the amount of intermediate nondurable goods that firm z uses as intermediate production inputs. Notice that the production function (16) differs from (11) because the varieties of the nondurable good serve as intermediate input in both the nondurable and the durable sector. As before, the term α captures the share of intermediate inputs that are used in production. The index of intermediate inputs is a composite over varieties:

$$M_t^C(z) = \left[\int_0^1 m_t^C(z,z')^{\frac{\theta-1}{\theta}}\, dz'\right]^{\frac{\theta}{\theta-1}} \tag{17}$$

Firm z in each period t decides how much to purchase of each variety of the nondurable product it uses for production purposes. Analogously to (13), cost minimization then implies the following downward-sloped demand schedule for each variety z':

$$m_t^C(z,z') = \left(\frac{p_t^C(z')}{P_t^C}\right)^{-\theta} M_t^C(z) \tag{18}$$

Define total nondurable output as $Y_t^C \equiv C_t + \int_0^1 M_t^C(z)\, dz + \int_0^1 M_t^D(z)\, dz$. Using the household's demand for variety z' (8) and the firms' demand for the same variety (13)-(18) one can show that

$$y_t^C(z') = \left(\frac{p_t^C(z')}{P_t^C}\right)^{-\theta} Y_t^C \tag{19}$$

where $y_t^C(z') \equiv c_t(z') + \int_0^1 m_t^C(z,z')\, dz + \int_0^1 m_t^D(z,z')\, dz$ is the total demand that firm z' in the nondurable sector faces.

The problem of nondurable firm z is thus to maximize the value of its expected discounted profits:

$$E_t\left[\sum_{\tau=0}^{\infty} Q_{t,t+\tau+1}\Pi_t^C(z)\right] \tag{20}$$

where $\Pi_t^C(z)$ are defined as

$$\Pi_t^C(z) = p_t^C(z)y_t^C(z) - W_t N_t^C(z) - P_t^C M_t^C(z) - \varphi^C W_t \mathcal{I}\left(p_t^C(z), p_{t-1}^C(z)\right) \tag{21}$$

Nominal profits are analogous to (15), except that intermediate production inputs belong to the same sector of the optimizing firm. As before, I assume that firms need to pay a fixed menu cost whenever they wish to undergo a price change.

A firm at time t thus picks a sequence of prices, employment and intermediate inputs $\{p_{t+\tau}^C(z), N_{t+\tau}^C(z), M_{t+\tau}^C(z)\}_{\tau=0}^{\infty}$ to maximize (20), where the profit function is defined by (21), subject to its production function (16), the demand for its variety (19), its idiosyncratic productivity and the aggregate states.

3.3 Equilibrium

I assume that the log of firm z's productivity follows a stationary autoregressive process of order one, given by

$$\log A_t^i(z) = \rho^i \log A_{t-1}^i(z) + \sigma^i \eta_t(z) \tag{22}$$

for $i = C, D$, $\eta_t(z) \overset{iid}{\sim} \mathcal{N}(0,1)$, $\rho^i \in [0,1)$ and $\sigma^i > 0$ for all i.

In the spirit of Nakamura & Steinsson (2010) I assume that the variance of firms' idiosyncratic shocks σ^i is sector-specific, and further let the persistence of shocks to vary across sectors. Following Golosov & Lucas (2007) I assume that the monetary authority every period targets the nominal wage. In particular, I assume that the nominal wage in logs follows a random walk with drift:

$$\log W_t = \mu^W + \log W_{t-1} + \sigma^W \varepsilon_t \tag{23}$$

where $\mu^W > 0$, $\sigma^W > 0$ and $\varepsilon_t \overset{iid}{\sim} \mathcal{N}(0,1)$.

As in Golosov & Lucas (2007), targeting the nominal wage rate in equilibrium is analogous to assume that the monetary authority sets the nominal spending rate. This can be noted most clearly from the household's optimality conditions (8)-(9). Moreover, equation (10) implies that the nominal interest rate in this economy is completely pinned down by the path of the nominal wage rate. Therefore, I ultimately think of (23) as describing the behavior of a monetary authority that has full control over the nominal interest rate, as is standard in most monetary models (*e.g.* Gali, 2008).

An equilibrium in this economy is a collection of endogenous processes governing prices and quantities which, given the path of exogenous variables $\{W_t, A_t^D(z), A_t^C(z)\}$ induced by (22)-(23), are consistent with the household's and firms' maximization problems (1)-(14)-(20), and market clearing.

3.4 Computing the Equilibrium

The state space of firms' problems is infinite-dimensional because the general price level in both sectors, and in turn other aggregate quantities such as C_t and D_t, depend on the entire joint distributions of all firms' price and productivity levels. Following Krusell & Smith (1998) I restrict the state space by assuming that firms perceive the evolution of the aggregate price levels in terms of a finite number of moments of their distributions. More specifically, I assume that firms perceive the evolution of P_t^C and P_t^D in terms of W_t, P_{t-1}^C and P_{t-1}^D:

$$\frac{P_t^i}{P_{t-1}^i} = \Gamma^i \left(\frac{W_t}{P_{t-1}^C}, \frac{P_{t-1}^D}{P_{t-1}^C} \right) = \varsigma_0^i + \varsigma_1^i \log \left(1 + \frac{W_t}{P_{t-1}^C} \right) + \varsigma_2^i \log \left(1 + \frac{W_t}{P_{t-1}^D} \right) \tag{24}$$

for $i = C, D$.

It is now possible to recast the maximization problem of firms in recursive form. In Appendix B.2 I show that up to a first-order log-linear approximation around the flexible-prices steady-state, the set of states $\Omega_t^i(z)$ for firm z operating in sector i in period t is given by $\Omega_t^i(z) = \left\{ W_t/P_{t-1}^D, W_t/P_{t-1}^C, A_t^i(z), p_{t-1}^i(z)/P_{t-1}^i \right\}$. The problem of a generic firm z in sector i is then characterized by the following Bellman equation:

$$V^i \left(\Omega_t^i(z) \right) = \max_{p_t^i(z)} \left\{ \hat{\Pi}_t^i(z) + E_t \left[\hat{Q}_{t,t+1} V^i \left(\Omega_{t+1}^i(z) \right) \right] \right\} \tag{25}$$

where $i = C, D$, subject to (24) and $\hat{x}$ denotes the real counterpart of the generic variable x. Here $V^i(\cdot)$ is firm z's value, and the full expression of profits $\hat{\Pi}_t^i(z)$ can be found in Appendix B.2.

The solution algorithm closely resembles that by Vavra (2014). Let k denote the k-th iteration of the algorithm. Given a guess for the approximating laws of motion $\Gamma_k^C(\cdot)$ and $\Gamma_k^D(\cdot)$, solving (25) by projection methods yields a policy function mapping the states onto firms' optimal prices. I then simulate the durable and nondurable goods firms' decision rules and use the simulated data to update the initial guess for the approximating laws of motion to get a new guess $\Gamma_{k+1}^C(\cdot)$ and $\Gamma_{k+1}^D(\cdot)$. The algorithm stops when the distance between the actual (simulated) and the predicted (through the approximating laws of motions) aggregated price series is small. As a sanity check, I make sure that adding moments beyond the first neither quantitatively changes nor qualitatively improves the fit of the approximated laws of motion. I discuss in more detail the computational approach in Appendix B.3.

Nakamura & Steinsson (2010) point out that a drawback of this numerical procedure is the difficulty to prove uniqueness of the equilibrium. However, they also note that large values of the volatility of the idiosyncratic productivity process largely reduce the scope for multiple equilibria (Caballero & Engel, 1993). Moreover, the stability of this equilibrium relative to possible other coordinated self-fulfilling ones can be checked by including higher-order beliefs in the perceived laws of motion.

4 Model Results

I present now my main results. I first discuss how I discipline the model using the data. I will calibrate some of the parameters taking estimates from existing studies, and set the values of others to roughly match some relevant moments I outlined in the empirical analysis. Then, I simulate the so-calibrated model and compare the resulting statistics with the moments computed from the data. Finally, I assess the effectiveness of monetary policy by looking at the extent of money neutrality generated by the model.

4.1 Calibration

I calibrate some of the parameters of the model using estimates from the literature. I report in table VI the benchmark calibration. The discount factor β is set at $0.96^{1/12}$, a standard value for a monthly calibration. The expenditure share on nondurable consumption ν is set at 0.8. I thus adopt a value at the lower bound of the estimates by Berger & Vavra (2015) for the US, in order to stay consistent with the long-run share of durable consumption in the UK aggregate consumption series. I set the coefficient of relative risk aversion γ to 1 because I assume log-utility. This assumption is common in the literature, is not crucial for the results and substantially simplifies the computational procedure. Following Hansen (1985), Rogerson (1988) and much of the literature on menu-cost models in price-setting, I assume indivisible labor decisions implemented through lotteries, and as such set the convexity of the disutility induced by labor supply ψ to 1.

The parameters of the adjustment cost of durable holdings ϕ and δ are estimated by Berger & Vavra (2015). The former captures the level of the adjustment cost while the latter determines the depreciation rate of the durable stock. Both are calibrated at 5% monthly, however their values are not qualitatively key for the results.

The calibrated value of the elasticity of substitution θ is crucial, because it affects the level of menu costs. In particular, higher θ implies higher menu costs. Moreover, higher θ also implies lower $(1-\alpha)$ because of the strategic complementarity effect. I thus pick a conservative estimate for the elasticity of substitution, following Nakamura & Steinsson (2008) who in turn refer to the empirical work by Berry, Levinsohn & Pakes (1995). Midrigan (2011) and Sheremirov (2019) use a value of θ around 3, while Golosov & Lucas (2007) and Vavra (2014) report $\theta = 7$, hence my calibration is in between these.

Because of the Cobb-Douglas production function in both sectors, $(1-\alpha)$ captures the share of expenditure of intermediate inputs in production. I calibrate $(1-\alpha)$ to 0.6 as suggested by Nakamura & Steinsson (2010) for the US.[11] Since I work with UK data, I explore in detail how the results are affected by changing α in the Online Appendix.

The exogenous process of the nominal wage is fully characterized by the mean growth

[11] Nakamura & Steinsson (2010) calibrate $\alpha = 0.3$ in their one-sector model. Because Bouakez, Cardia & Ruge-Murcia (2011) report that the expenditure share of nondurable intermediate goods is lower in durable sectors, I adjust the value of α accordingly.

TABLE VI: BASELINE CALIBRATION

Parameter	Description	Value	Source
β	Intertemporal discount factor	$0.96^{1/12}$	Implied by monthly calibration
ν	Relative weight on nondurable consumption	0.8	Berger & Vavra (2015)
γ	Relative risk aversion	1	Log-utility in consumption
ψ	Convexity of labor disutility	1	Hansen (1985) and Rogerson (1988)
φ	Slope of adjustment cost of durable consumption	0.05	Berger & Vavra (2015)
δ	Depreciation rate of durable goods	0.05	
θ	Elasticity of substitution across varieties	4	Berry, Levinsohn & Pakes (1995)
$1-\alpha$	Expenditure share of nondurables intermediate goods by firms	0.6	Nakamura & Steinsson (2010)
μ^W	Mean growth rate of nominal wage	0.0028	Nakamura & Steinsson (2010)
σ^W	Standard deviation of log nominal wage	0.0037	Nakamura & Steinsson (2010)
σ^D	Standard deviation of log-productivity of durable goods firms	0.035	Calibrated to match moments estimated from the data
σ^C	Standard deviation of log-productivity of nondurable goods firms	0.038	
ρ^D	Persistence of log-productivity of durable firms	0.70	
ρ^C	Persistence of log-productivity of nondurable firms	0.66	
φ^D	Menu-cost of durable goods firms	0.15	
φ^C	Menu-cost of nondurable goods firms	0.16	

Notes. The table reports the calibration of the model. Further detailed discussion is found in the body of the text.

rate and its variance. I already discussed that assuming an exogenous path for the nominal wage is equivalent to posing that same process for nominal expenditure, hence for comparability purposes with previous works I assume $\mu^W = 0.0028$ and $\sigma^W = 0.0037$. Results are essentially unchanged by assuming $\mu^W = 0$, which implies stationarity of all variables in the stochastic stead- state.

I calibrate the rest of the parameters to roughly match the statistics computed using the UK CPI data.[12] I set the persistence of the idiosyncratic productivity process equal to 0.7, as estimated by Nakamura & Steinsson (2008), for durable goods. In nondurable goods, I set the persistence to 0.66 to match the relatively frequent small price changes that are observed in the data. It is well-known that in menu-cost models the size of the fixed costs maps onto the frequency of price changes, whereas the standard deviation of the idiosyncratic shocks can be calibrated to match the average size of price changes (Luo & Villar, 2020). It follows that the size of menu costs for durable firms is slightly lower than

[12] An obvious step forward is to estimate those parameters, using simulated method of moments or indirect inference.

that for nondurables, because prices of durable goods are found to adjust more frequently. Moreover, the dispersion of the innovations to idiosyncratic productivity is smaller for durable firms because the price change distribution features excess dispersion relative to that of nondurables. However, the calibrated levels of menu costs imply that fixed costs undertaken to change the regular price never exceed 1% of nominal revenues.

In the Online Appendix I explore how results change in the space of the parameters, particularly α, θ and the last four in table VI. The calibrated values of menu costs and idiosyncratic volatilities reported in table VI are broadly in line with empirical estimated provided in the literature.[13]

4.2 Heterogeneous Durability

Table VII reports the best fit of the model with the moments computed from the data. I report a set of time-averaged statistics, and a set of time series correlations. I pick the calibration so that the model best matches the dispersion and frequency of price changes for the two categories of consumption goods. These yield four moments identifying four parameters, namely the fixed costs of adjustment and the volatilities of the productivity processes.

The model does a good job at replicating the time-averaged statistics. In particular, it replicates the excess volatility of price changes of durable goods -fact (i) in the introduction- as well as their relative price flexibility, relative to nondurables, *i.e.* fact (ii). However, the model understates the magnitude of price dispersion, and slightly overstates the price flexibility of durable goods prices. The model also successfully matches the relative share of price increases for both categories of goods, although this statistic is not explicitly targeted in the calibration. I also report the median price changes, as well as the median price increase and decrease, for both categories, and confirm the model overall acceptable fit with the data.

While it is standard to confront menu-cost models with time-averaged statistics, only recently have studies begun to evaluate their performance in terms of the time-series correlations they imply (Vavra, 2014; Berger & Vavra, 2018; Luo & Villar, 2020). Moreover notice that I cannot target time-series correlations in my calibration because table VII reports the correlation with real output, whereas my empirical analysis exploits variation in region-level unemployment, absent equally granular output statistics at monthly frequency. This notwithstanding, since in the model real output and unemployment are positively correlated, the lower half of table VII provides some qualitative evidence that the model

[13] Vavra (2014) for instance estimates a menu cost equal to 0.09 and an idiosyncratic volatility term equal to 0.08.

TABLE VII: MODEL FIT

		Model		Data	
		Durables	Nondurables	Durables	Nondurables
Frequency (%)					
	All	10.06	6.83	8.11	6.77
	Up	6.39	5.13	4.29	4.35
	Down	3.67	1.75	3.49	2.19
Median Change (%)					
	All	3.03	2.35	-1.19	1.72
	Up	16.81	6.89	13.88	9.53
	Down	-21.07	-11.18	-13.68	-11.81
Std. Dev.*		0.189	0.102	0.238	0.182
Corr. w/ΔOutput†					
	Frequency	-0.091	-0.127	-0.025	-0.305
	Median	0.013	0.034	-0.025	-0.008
	Std. Dev.	-0.148	0.222	-0.194	0.110

Notes. The table reports selected statistics computed from real and simulated data. Model-based statistics are obtained by simulating the model $N = 50$ times over $T = 3500$ periods. *: standard deviation of price changes proper, *i.e.* excluding zeros. †: time-series correlations from the data report -1 times the correlation with changes in unemployment rate.

replicates the main insights of the statistical analysis provided in section 2. In particular, the frequency of adjustment is negatively correlated with output. The strength of the correlation is stronger in nondurables, hence the model matches fact (iii) whereby the relative price flexibility of durables is procyclical. The median size of price changes displays little correlation with the cycle, whereas the second moment is procyclical in nondurables, and countercyclical in durables. This is consistent with the empirical evidence -fact (iv)- and in line with the mechanism outlined in the previous section. Adjustment costs in durable consumption imply that the demand for durables displays countercyclical volatility, thereby increasing the frequency *and* the dispersion of price changes. This exercise suggests that menu-cost models manage to replicate a wide array of facts, both in the cross-section and over time. Due to computational constraints, I am unable to estimate the key four parameters that characterize the behavior of the model. However, even a relatively raw exercise of calibration yields suggestive results.[14]

[14] I do not report the correlation of higher moments with the cycle because the model suffers from the critique of Luo & Villar (2020) and cannot match those computed from the data. The authors propose to include

4.3 Effectiveness of Monetary Policy

Having established that the model I laid down in section 3 is consistent with the empirical stylized facts I outlined in the empirical analysis, I now evaluate the effectiveness of monetary policy in this environment. This is relevant at least for two reasons. First, early state-dependent pricing models delivered little monetary non-neutrality, thereby coming at odds with empirical evidence (Caplin & Spulber, 1987; Golosov & Lucas, 2007). Second, the literature studying New Keynesian models with durable consumption documents a strong irrelevance result whereby the extent of aggregate price flexibility should be almost entirely driven by that in the durable sector (Barsky, House & Kimball, 2007). Since the calibration in table VI and the statistics provided in table VII imply that prices in the durable sector are relatively flexible, one could expect that the model delivered monetary neutrality.

To assess this claim I provide in figure V the impulse response functions (IRFs) of durable and nondurable consumption and inflation rates to a one standard deviation positive permanent shock to the nominal wage. All panels report the log-deviation from the stochastic steady-state in percentage terms. Since the nominal wage is integrated, I report the deviation from the steady-state growth rate instead.[15]

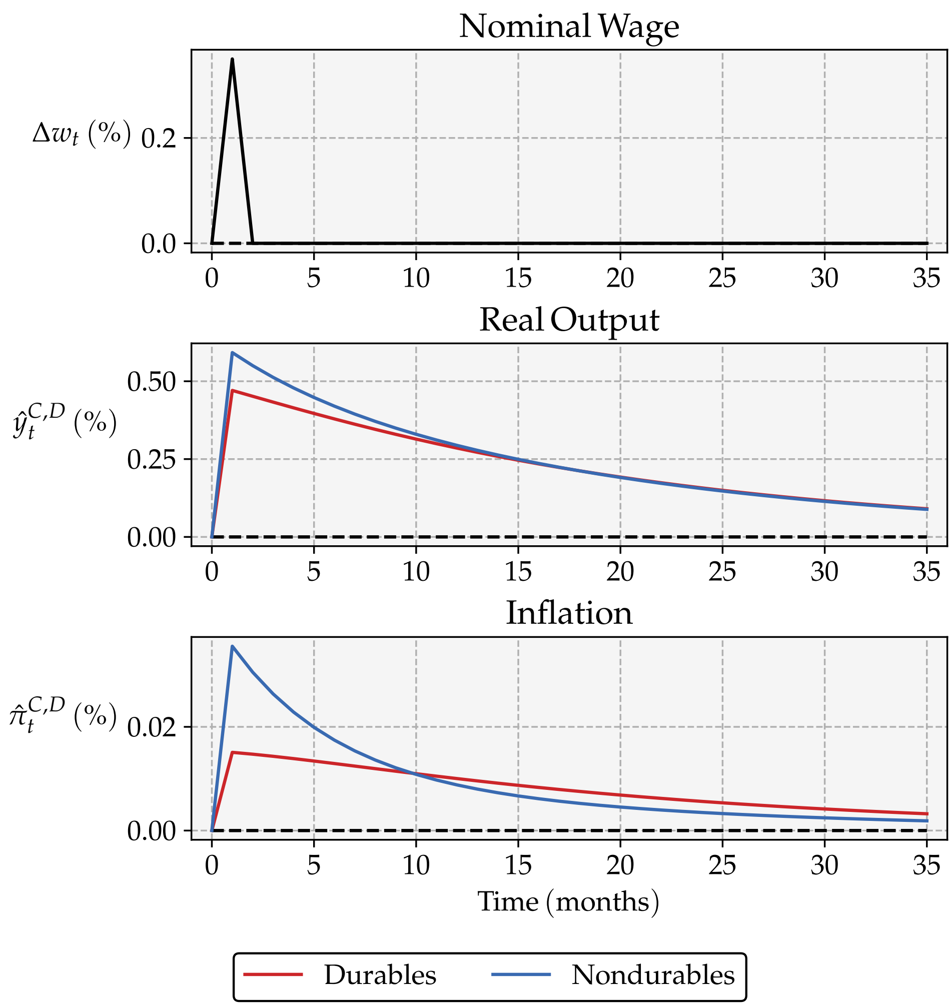
The model delivers substantial monetary non-neutrality, as is transparent from the two bottom panels of figure V. Output in both sectors increases by half a percentage point following the shock to the nominal wage. Since the shock is permanent, it also has long lasting effects although I truncate the IRFs to the equivalent of a 3 years horizon. The rationale for this is clear from the bottom panel of figure V which displays the response of inflation in the two sectors in response to this unanticipated shock. Firms, particularly in the durable sector, optimally delay the price change decision depending on their position in the inaction region defined by the presence of fixed costs. Since the shock does not move all firms out of their inaction region, it entails real effects akin to that of a standard nominal rigidity induced by Calvo (1983) time-dependent pricing.

The responses of durable consumption and nondurable output to a decrease in the nominal rate, which is an equivalent interpretation to an increase in the nominal wage, are positively correlated and in fact almost identical. This sharply contrasts the model

random menu costs; however since the skewness and kurtosis do not display differential correlation with the cycle across durability, this would complicate the model and yield no further insights on the fundamental mechanism I outline.

[15] I solved the model under the assumption that the monetary authority targets a random walk for the nominal wage process. This decreases the computational burden at the expense of realism of the exogenous process. The literature nonetheless showed that this class of models can deliver hump-shaped impulse responses under autocorrelated shocks (*e.g.* Nakamura & Steinsson, 2010).

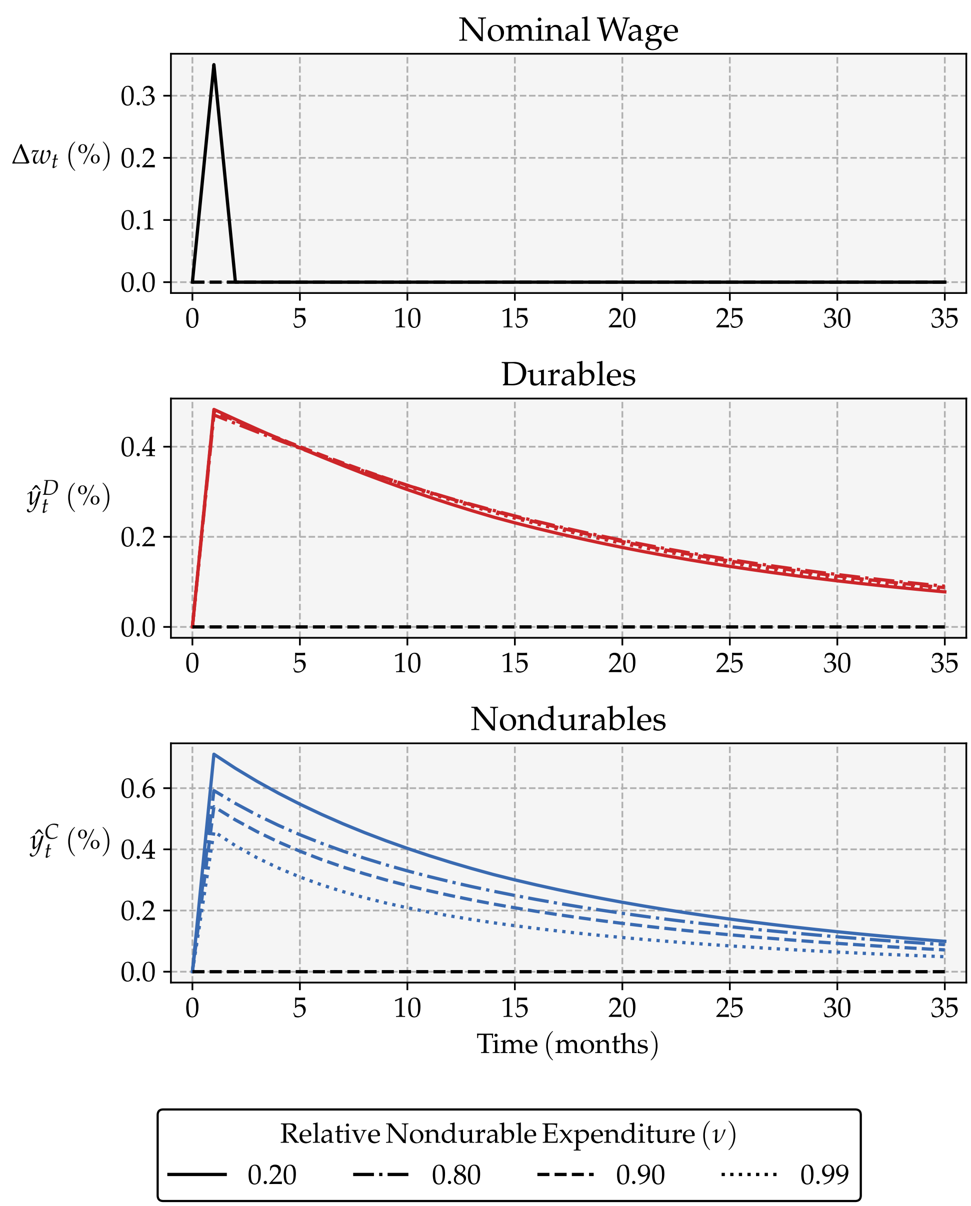
FIGURE V: IMPULSE RESPONSE FUNCTIONS



Notes. The figure plots the impulse response functions of real output and inflation to a one standard deviation positive shock to the nominal wage. The first panel plots the percentage deviation of the *growth rate* of the nominal wage from is stochastic steady-state level. The remaining panels plot the percentage deviation of output and inflation *levels* from their stochastic steady-state values.

by Barsky, House & Kimball (2007), where durable and nondurable consumption display counterfactual opposite responses to nominal shocks. Bouakez, Cardia & Ruge-Murcia (2011) label this a "comovement puzzle" and identify it as a major empirical challenge that durable goods pose to New Keynesian models. In this framework, the puzzle is resolved because strategic complementarities entail a strong comovement effect across sectors, as noted by Nakamura & Steinsson (2010). In some sense, this mechanism is akin to the input-output effect that Bouakez, Cardia & Ruge-Murcia (2011) put forward to solve the comovement puzzle. Here I thus show that the puzzle does not stem from the nature of nominal rigidity that is assumed, but rather depends on the market structure.

FIGURE VI: IRFS - VARYING ν



Notes. The figure plots the impulse response functions of real durable and nondurable output to a one standard deviation positive shock to the nominal wage. The figure reports the percentage deviation of durable and nondurable output from their stochastic steady-state values.

In figure VI I report the results a simple yet suggestive exercise. I solve the model four times for different values of ν, *i.e.* the relative weight of nondurable consumption, and keep the rest of the calibration unchanged. Higher values of ν imply lower household demand for durables, and the contrary holds for lower values of ν. This allows to explore how durables interact with the economy and affect the aggregate degree of monetary non-neutrality. The bottom panel shows the impulse response of nondurable consumption to a positive wage shock, which in the model is isomorphic to a negative interest rate one. The response of nondurable output is decreasing in ν: the higher the marginal utility of durable goods, the more nondurable output responds to a monetary policy shock. By contrast, in the mid panel I show that durable output is only marginally sensitive to changes in ν. The underlying economic intuition is clear. In the model, demand for durables only depends on households. Therefore, higher values of ν imply a lower steady-state *level* of durable consumption. Parameter ν does not, however, affect the intertemporal tradeoff inherent to the choice of durable consumption, hence the responsiveness of D_t to changes in the interest rate is unaffected. Because nondurable output instead serves as an input for firms, total demand for nondurables has two components, stemming respectively from the household and the firms. Low values of ν are associated with higher demand for durable goods by households. This pushes up the demand for nondurable goods by firms producing durables. Hence, the fraction of nondurable demand that is driven by durable-producing firms increases. Since household demand for durables is more responsive than that of nondurables to changes in the interest rate, this in turn prompts higher responsiveness of nondurable output.

This result is significant because it provides evidence against Barsky, House & Kimball (2007). They argued that since the aggregate degree of monetary neutrality in a New Keynesian economy with durable consumption is only driven by durables, if firms producing those goods have more flexible prices, then the overall economy features equally flexible prices. Moreover, figure VI builds on Nakamura & Steinsson (2010) who were the first to prove that state-dependent pricing models can deliver monetary non-neutrality *à la* Calvo (1983). Here I show that the degree of monetary non-neutrality in such models is further enhanced by durable goods, despite the fact that they exhibit relatively more flexible prices. The contribution of durable goods to overall monetary non-neutrality is substantial, as figure VI reports. It is finally interesting, albeit at first not intuitive, to note that the enhanced monetary non-neutrality prompted by durable goods is fully channelled into increased reactivity of nondurable output to changes in the interest rate.

5 Conclusion

This paper provides a set of new empirical results on the properties of prices of durable goods, and develops a theoretical framework to rationalize their implications for monetary policy.

Using comprehensive microdata underlying the UK CPI, I showed that three key properties distinguish durable from nondurable goods prices. First, the dispersion of price changes is higher in durables than in nondurables. The distribution of price changes of durables over the observation timespan is substantially more dispersed, but features neither skewness nor excess kurtosis relative to that of nondurables. Moreover, both the median price increase and decrease are in absolute value larger for durables than for nondurables.

Following recent contributions, I computed time-series statistics to study the distinctive pricing dynamics of durable goods. The second fact documents that the frequency of price changes is countercyclical across durability, albeit more strongly so for nondurables. Moreover, the relative frequency of price changes in nondurable goods increases as unemployment rises, hence the price rigidity of durable goods is procyclical, although this latter effect is entirely driven by the Great Recession. Third, the dispersion of durables price changes comoves positively with the business cycle, while it is countercyclical in nondurable goods. Facts (ii) and (iii) jointly imply that the correlation between frequency and dispersion of price changes differs across durability. In particular, it is positive in durable goods and negative in nondurables. This poses a substantial challenge to standard menu-cost models which, by construction, imply that the two should be negatively correlated.

These findings motivate the theoretical contribution. I develop a menu-cost model that accounts for heterogeneous durability over consumption goods. Because durable consumption is subject to adjustment costs, it features countercyclical volatility. This prompts a positive comovement between the frequency and the dispersion of price adjustments in durables only. I calibrate the model to match existing evidence as well as the newly documented facts. The model successfully replicates a wide array of stylized facts concerning both time-averaged statistics, as well as more nuanced correlations between the moments of the time-varying distribution of price changes and the business cycle. In particular, it matches the positive (resp. negative) correlation between the dispersion of price changes and their frequency in durable (resp. nondurable) goods. Last, I show that the model delivers a sizeable degree of monetary non-neutrality to nominal shocks. A permanent decrease in the nominal rate entails a positive and persistent effect on both durable and nondurable consumption because inflation fails to promptly catch-up with the shock.

This study confronts with a largely neglected topic in applied monetary economics, that of durable consumption. It shows that durable goods prices display distinctive features and yield interesting insights when embedded into the benchmark state-dependent pricing model. It also paves the way for a number of possible extensions. First, it would be interesting to study how incomplete markets would affect the results. A precautionary savings motive could in fact enrich the dynamics of consumption reallocation across goods. It would also be insightful to allow for a set of different durability, again to study the reallocation effects across sectors. Finally, durable goods here serve for sole consumption purposes. In reality, however, durables are typically put up as collateral, housing being the most prominent example. Adding collateralizable durable wealth and incomplete markets would shed further light on the effectiveness of monetary policy with endogenously sticky prices.

Milan, June, 2022
Davide M. Coluccia

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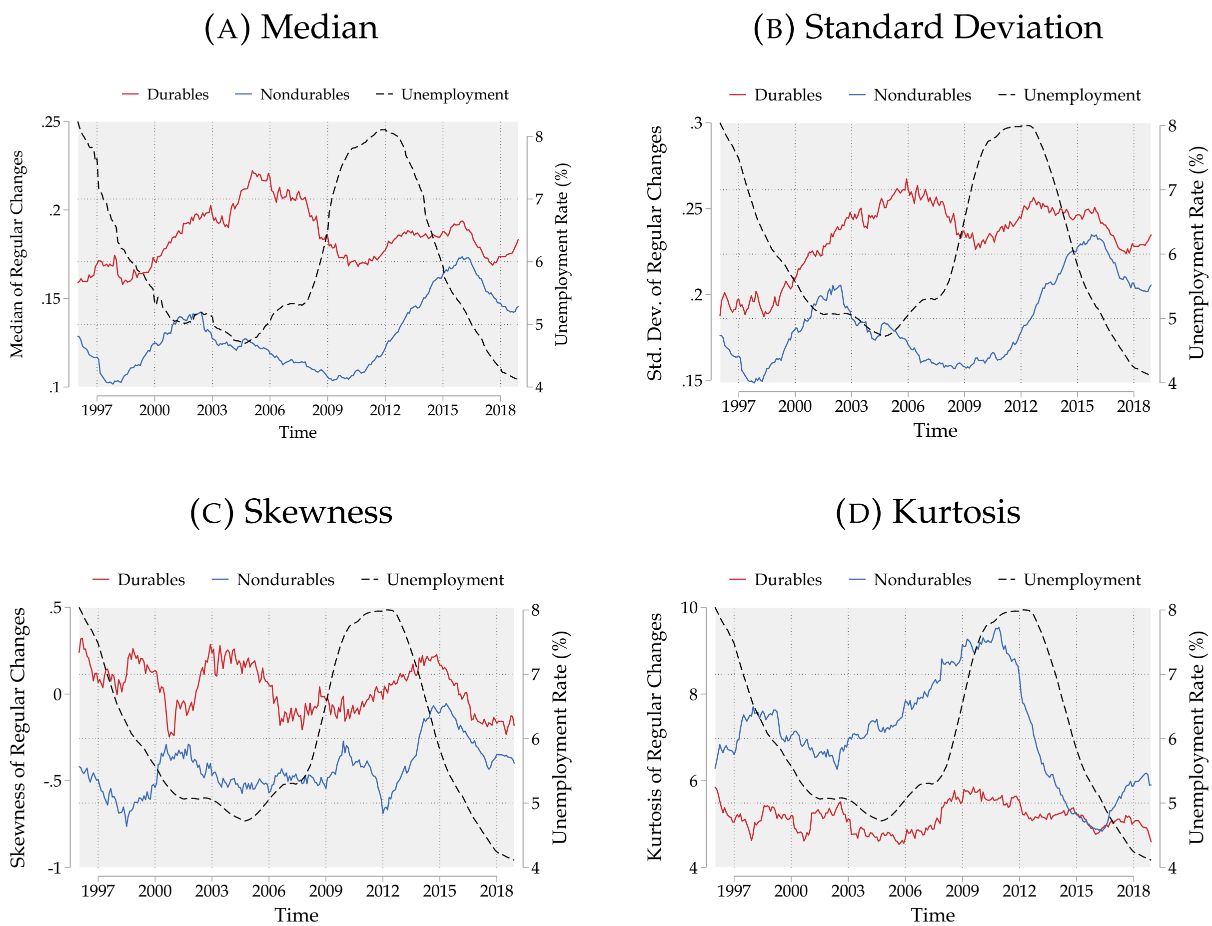
A Data Appendix

A.1 Additional Figures

FIGURE VII: DYNAMICS OF THE MOMENTS OF THE DISTRIBUTION OF PRICE CHANGES AND THE BUSINESS CYCLE



Notes. The figures plot the median, and second to fourth central moments of the distribution of price changes over time. Price changes are log-differences. Price series report weighted 12-month centered moving average data do adjust for seasonality. The dashed black line plots the population-weighted mean region unemployment rate in the same period.

A.2 Additional Tables

TABLE VIII: MEDIAN OF THE REGULAR CHANGES DISTRIBUTION AND THE BUSINESS CYCLE

	Durables				Nondurables			
Model	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
$\Delta \log u_t$	0.053***	0.026***	0.025***	0.025***	0.014***	0.008***	0.008***	0.008***
	(0.007)	(0.006)	(0.006)	(0.006)	(0.003)	(0.002)	(0.002)	(0.002)
ξ_t		0.033***	0.033***	0.033***		0.007***	0.007***	0.007***
		(0.003)	(0.003)	(0.002)		(0.001)	(0.001)	(0.001)
Constant	-0.018***	-0.020***	-0.013***	-0.013***	0.020***	0.020***	0.022***	0.022***
	(0.003)	(0.003)	(0.000)	(0.000)	(0.001)	(0.001)	(0.000)	(0.000)
Obs.	3,276	3,276	3,276	3,276	3,276	3,276	3,276	3,276
R^2	0.007	0.082	0.247	0.250	0.002	0.016	0.100	0.101
Region FE	✗	✗	✓	✓	✗	✗	✓	✓
Time Trend	✗	✗	✗	✓	✗	✗	✗	✓

Notes. Dependent variable is the median of the regular price change distribution. Robust standard errors in parentheses are clustered by region. Variable u is unemployment (%), ξ is a recession dummy. *** $p < .01$, **$p < .05$, * $p < .1$.

TABLE IX: STANDARD DEVIATION OF THE REGULAR CHANGES DISTRIBUTION AND THE BUSINESS CYCLE

	Durables				Nondurables			
Model	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
$\Delta \log u_t$	0.237***	0.162***	0.151***	0.194***	-0.260***	-0.138***	-0.137***	-0.110***
	(0.053)	(0.043)	(0.044)	(0.042)	(0.024)	(0.021)	(0.022)	(0.022)
ξ_t		0.091***	0.092***	0.057**		-0.147***	-0.148***	-0.169***
		(0.021)	(0.021)	(0.018)		(0.010)	(0.010)	(0.011)
Constant	-1.574***	-1.579***	-1.498***	-1.505***	-1.723***	-1.715***	-1.691***	-1.696***
	(0.030)	(0.031)	(0.001)	(0.002)	(0.005)	(0.005)	(0.001)	(0.001)
Obs.	3,276	3,276	3,276	3,276	3,276	3,276	3,276	3,276
R^2	0.002	0.009	0.181	0.553	0.007	0.064	0.076	0.493
Region FE	✗	✗	✓	✓	✗	✗	✓	✓
Time Trend	✗	✗	✗	✓	✗	✗	✗	✓

Notes. Dependent variable is the standard deviation of the regular price change distribution. Robust standard errors in parentheses are clustered by region. Variable u is unemployment (%), ξ is a recession dummy. *** $p < .01$, ** $p < .05$, * $p < .1$.

TABLE X: SKEWNESS OF THE REGULAR CHANGES DISTRIBUTION AND THE BUSINESS CYCLE

	Durables				Nondurables			
Model	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
$\Delta \log u_t$	-0.140**	-0.096**	-0.093**	-0.102**	-0.144***	-0.125***	-0.120***	-0.108***
	(0.054)	(0.041)	(0.040)	(0.039)	(0.031)	(0.028)	(0.027)	(0.028)
ξ_t		-0.053**	-0.053**	-0.046*		-0.024	-0.024	-0.033
		(0.022)	(0.022)	(0.022)		(0.024)	(0.024)	(0.024)
Constant	0.683***	0.686***	0.692***	0.693***	0.462***	0.463***	0.479***	0.477***
	(0.007)	(0.008)	(0.001)	(0.001)	(0.009)	(0.009)	(0.001)	(0.001)
Obs.	3,276	3,276	3,276	3,276	3,276	3,276	3,276	3,276
R^2	0.003	0.015	0.060	0.131	0.003	0.005	0.059	0.169
Region FE	✗	✗	✓	✓	✗	✗	✓	✓
Time Trend	✗	✗	✗	✓	✗	✗	✗	✓

Notes. Dependent variable is the skewness of the regular price change distribution. Robust standard errors in parentheses are clustered by region. Variable u is unemployment (%), ξ is a recession dummy. *** $p < .01$, ** $p < .05$, * $p < .1$.

TABLE XI: KURTOSIS OF THE REGULAR CHANGES DISTRIBUTION AND THE BUSINESS CYCLE

	Durables				Nondurables			
Model	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
$\Delta \log u_t$	0.130	-0.019	-0.016	0.019	0.517***	0.312***	0.306***	0.294***
	(0.073)	(0.043)	(0.041)	(0.047)	(0.042)	(0.031)	(0.034)	(0.033)
ξ_t		0.180***	0.180***	0.153***		0.248***	0.248***	0.258***
		(0.044)	(0.044)	(0.040)		(0.018)	(0.018)	(0.018)
Constant	1.433***	1.422***	1.420***	1.414***	1.875***	1.861***	1.849***	1.851***
	(0.018)	(0.020)	(0.002)	(0.003)	(0.015)	(0.015)	(0.001)	(0.001)
Obs.	3,276	3,276	3,276	3,276	3,276	3,276	3,276	3,276
R^2	0.001	0.026	0.081	0.296	0.014	0.098	0.162	0.208
Region FE	✗	✗	✓	✓	✗	✗	✓	✓
Time Trend	✗	✗	✗	✓	✗	✗	✗	✓

Notes. Dependent variable is the kurtosis of the regular price change distribution. Robust standard errors in parentheses are clustered by region. Variable u is unemployment (%), ξ is a recession dummy. *** $p < .01$, ** $p < .05$, * $p < .1$.

TABLE XII: FREQUENCY OF PRICE CHANGES AND THE BUSINESS CYCLE BY DURABILITY

	Durables				Nondurables			
Model	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
$\Delta \log u_t$	0.215**	-0.003	-0.010	0.025	0.687***	0.313***	0.305***	0.305***
	(0.093)	(0.085)	(0.085)	(0.090)	(0.072)	(0.070)	(0.067)	(0.067)
ξ_t		0.246***	0.248***	0.226***		0.424***	0.427***	0.427***
		(0.017)	(0.017)	(0.016)		(0.012)	(0.011)	(0.011)
Constant	-2.395***	-2.410***	-2.459***	-2.462***	-2.673***	-2.699***	-2.692***	-2.692***
	(0.017)	(0.018)	(0.001)	(0.001)	(0.015)	(0.016)	(0.001)	(0.001)
Obs.	3,073	3,073	3,073	3,073	3,073	3,073	3,073	3,073
R^2	0.001	0.051	0.102	0.290	0.011	0.128	0.162	0.162
Region FE	✗	✗	✓	✓	✗	✗	✓	✓
Time Trend	✗	✗	✗	✓	✗	✗	✗	✓

Notes. Dependent variable is the frequency of regular price changes. Robust standard errors in parentheses are clustered by region. Variable u is unemployment (%), ξ is a recession dummy. *** $p < .01$, ** $p < .05$, * $p < .1$.

TABLE XIII: DISPERSION OF REGULAR PRICES AND FREQUENCY OF REGULAR PRICE CHANGES

	Durables				Nondurables			
Model	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
log f_t	0.197***	0.194***	0.172***	0.201***	-0.233***	-0.216***	-0.221***	-0.189***
	(0.036)	(0.038)	(0.036)	(0.034)	(0.023)	(0.025)	(0.029)	(0.015)
ξ_t		0.017	0.028	-0.070***		-0.060***	-0.058**	-0.041**
		(0.018)	(0.018)	(0.021)		(0.019)	(0.021)	(0.018)
Constant	-1.072***	-1.080***	-1.075***	-0.907***	-2.344***	-2.296***	-2.287***	-2.235***
	(0.078)	(0.083)	(0.089)	(0.088)	(0.050)	(0.060)	(0.067)	(0.072)
Obs.	3,043	3,043	3,043	3,043	3,043	3,043	3,043	3,043
R^2	0.080	0.080	0.169	0.314	0.244	0.252	0.272	0.308
Region FE	✗	✗	✓	✓	✗	✗	✓	✓
Time Trend	✗	✗	✗	✓	✗	✗	✗	✓

Notes. Dependent variable is the log-standard deviation of the regular price distribution. Robust standard errors in parentheses are clustered by region. Variable u is unemployment (%), ξ is a recession dummy. *** $p < .01$, **$p < .05$, * $p < .1$.

B Model Appendix

B.1 Analytical Derivations

Derivation of (6) and (7). Let $x_t(z)$ denote either $c_t(z)$ or $d_t(z)$, and X be C and D, respectively. For a given consumption level $\bar{X} > 0$, the expenditure minimization problem of the household reads out as follows:

$$\begin{aligned} \min_{\{x_t(z)\}_{z\in[0,1]}} & \int_0^1 p_t^X(z) x_t(z)\, dz \\ \text{s.t.} & \left[\int_0^1 x_t(z)^{\frac{\theta-1}{\theta}}\, dz\right]^{\frac{\theta}{\theta-1}} = \bar{X} \end{aligned} \tag{B.1}$$

The Lagrangian function associated to the problem is

$$\mathcal{L} = \int_0^1 p_t^X(z) x_t(z)\, dz + \lambda_t \left(\bar{X} - \left[\int_0^1 x_t(z)^{\frac{\theta-1}{\theta}}\, dz\right]^{\frac{\theta}{\theta-1}}\right) \tag{B.2}$$

Taking the first-order derivative of $\mathcal{L}$ with respect to two varieties z, z' yields

$$p_t(z) = \lambda_t X_t^{\frac{1}{\theta}} x_t(z)^{-\frac{1}{\theta}} \tag{B.3}$$

$$p_t(z') = \lambda_t X_t^{\frac{1}{\theta}} x_t(z')^{-\frac{1}{\theta}} \tag{B.4}$$

Using (B.3)-(B.4) to express $x_t(z)$ in terms of $p_t(z)$, $p_t(z')$ and $x_t(z')$ it is $x_t(z) = \left(\frac{p_t^X(z')}{p_t^X(z)}\right)^\theta x_t(z')$. Plugging the resulting expression into the definition of X_t yields (6) and (7), where P_t^X is the Dixit-Stiglitz price index:

$$P_t^X \equiv \left[\int_0^1 p_t^X(z)^{1-\theta}\, dz\right]^{\frac{1}{1-\theta}} \tag{B.5}$$

The derivation of the optimal demand for the differentiated varieties (13) is entirely analogous and is thus omitted.

Derivation of (8), (9) and (10). The problem of the household is entirely standard. Let μ_t be the multiplier attached to the budget constraint defined by (2) which at the optimum holds with equality by monotonicity of the utility function. The derivatives of the Lagrangian associated to problem (1) relative to C_t, D_t, N_t and B_{t+1} read out as follows:

$$\nu \frac{\left(C_t^{\nu} D_t^{1-\nu}\right)^{1-\gamma}}{C_t} = P_t^C \mu_t \tag{B.6}$$

$$(1-\nu) \frac{\left(C_t^{\nu} D_t^{1-\nu}\right)^{1-\gamma}}{D_t} = P_t^D - \beta(1-\delta)(1-\varphi) E_t \left[P_{t+1}^D \mu_{t+1}\right] \tag{B.7}$$

$$\omega N_t^{\psi} = W_t \mu_t \tag{B.8}$$

$$E_t \left[Q_{t,t+1}\right] = \beta E_t \left[\frac{\mu_{t+1}}{\mu_t}\right] \tag{B.9}$$

Assume $\gamma = 1$ and $\psi = 0$. Conditions (B.6)-(B.8) imply (8); (B.7) and (B.8) imply the demand for durables (9); (B.8) and (B.9) pin down the stochastic discount factor as in (10).

B.2 Profit Functions

Here I formally show how to write the firms' profit as a function of the state variables up to a first-order log-linear approximation around the flexible price steady-state along the lines of Nakamura & Steinsson (2010). Define $\tilde{X}_t \equiv \log(X_t/X)$ where X is the steady-state value of a generic variable X_t under flexible prices. For future reference, to a first-order approximation it is $\tilde{X}_t \approx (X_t - X)/X$.

Durable goods firm

In every period firm z chooses materials $M_t^D(z)$ and labor $N_t^D(z)$ to minimize the expenditure at a given production level $\bar{Y}$. The implied cost minimization problem yields the following optimality condition:

$$\frac{M_t^D(z)}{N_t^D(z)} = \frac{1-\alpha}{\alpha}\frac{W_t}{P_t^C} \tag{B.10}$$

Plugging (B.10) into the production function (11) yields

$$y_t^D(z) = A_t^D(z) N_t^D(z) \left(\frac{1-\alpha}{\alpha}\frac{W_t}{P_t^C}\right)^{1-\alpha} \tag{B.11}$$

Market clearing implies that $y_t^D(z) = d_t(z)$ for all z, hence using (7) it is

$$N_t^D(z) = \frac{1}{A_t^D(z)} \left(\frac{1-\alpha}{\alpha}\frac{W_t}{P_t^C}\right)^{\alpha-1} \left(\frac{p_t^D(z)}{P_t^D}\right)^{-\theta} \mathcal{D}(W_t, P_t^D) \tag{B.12}$$

where $\mathcal{D}_t(W_t, P_t^D)$ is defined by equation (10) to remind that the implied policy function is fully characterized by W_t and P_t^D.

Plugging (B.12) into (B.10), using that together with (B.11) and (B.12) into the profit function (15), and dividing by P_t^D one derives the real profit function $\hat{\Pi}_t^D(z)$:

$$\begin{aligned}\hat{\Pi}_t^D(z) = &\left(\frac{p_t^D(z)}{P_t^D}\right)^{1-\theta} \mathcal{D}(W_t, P_t^D) - \frac{W_t}{P_t^D A_t^D(z)} \left(\frac{1-\alpha}{\alpha}\frac{W_t}{P_t^C}\right)^{\alpha-1} \left(\frac{p_t^D(z)}{P_t^D}\right)^{-\theta} \mathcal{D}(W_t, P_t^D) + \\ &- \frac{P_t^C}{P_t^D A_t^D(z)} \left(\frac{1-\alpha}{\alpha}\frac{W_t}{P_t^C}\right)^{\alpha} \left(\frac{p_t^D(z)}{P_t^D}\right)^{-\theta} \mathcal{D}(W_t, P_t^D) - \varphi^D \frac{W_t}{P_t^D} \mathcal{I}\left(p_t^D(z), p_{t-1}^D(z)\right)\end{aligned} \tag{B.13}$$

From equation (B.13) it is clear that the state space for firm z in the durable sector is $\Omega_t^D(z) = \{p_{t-1}^D(z)/P_{t-1}^D, A_t^D(z), W_t/P_{t-1}^C, W_t/P_{t-1}^D\}$ where I use the approximating laws of motion (24) to write aggregate price levels in terms of past price indices and the nominal wage.

Nondurable goods firm

In every period firm z chooses materials $M_t^C(z)$ and labor $N_t^C(z)$ to minimize expenditure at a given production level $\bar{Y}$. The implied cost minimization problem yields

$$\frac{M_t^C(z)}{N_t^C(z)} = \frac{1-\alpha}{\alpha}\frac{W_t}{P_t^C} \tag{B.14}$$

From condition (B.10) and the labor supply schedule (8), it is

$$\tilde{M}_t^D(z) = \tilde{C}_t + \tilde{N}_t^D(z) \tag{B.15}$$

Loglinearizing the production function of durable goods firms (B.11) and substituting (8), it is

$$\tilde{y}_t^D(z) = \tilde{A}_t^D(z) + \tilde{N}_t^D(z) + (1-\alpha)\tilde{C}_t \tag{B.16}$$

Aggregating over z's, and loglinearizing the demand schedule for variety z (19), it is

$$\tilde{D}_t = \tilde{N}_t^D + (1-\alpha)\tilde{C}_t \tag{B.17}$$

Loglinearizing the production function of nondurable goods firms (15) and substituting in the loglinearized version of (B.14), upon accounting for the labor supply schedule (8) it is

$$\tilde{y}_t^C(z) = \tilde{A}_t^C(z) + \tilde{N}_t^C(z) + (1-\alpha)\tilde{C}_t \tag{B.18}$$

Aggregating over z's and loglinearizing the demand schedule (21) around the same steady-state yields:

$$\tilde{Y}_t^C = \tilde{N}_t^C + (1-\alpha)\tilde{C}_t \tag{B.19}$$

From the definition of total output in the nondurable sector, *i.e.* $Y_t^C \equiv C_t + \int_0^1 M_t^C(z)\,dz + \int_0^1 M_t^D(z)\,dz$, a first-order linear approximation around the flex-prices steady-state yields

$$\tilde{Y}_t^C = \frac{C}{Y}\tilde{C}_t + \frac{M^C}{Y}\int_0^1 \tilde{M}_t^C(z)\,dz + \frac{M^D}{Y}\int_0^1 \tilde{M}_t^D(z)\,dz \tag{B.20}$$

where variables without the time subscript t denote their steady-state values under flexible prices. Plugging the previous relations into (B.20) allows to express total output in the nondurable sector in terms of C_t and D_t:

$$\tilde{Y}_t^C = a_1\tilde{C}_t + a_2\tilde{D}_t \tag{B.21}$$

where $a_1 = [C + \alpha(M^C + M^D)]/(Y - M^C)$ and $a_2 = M^D/(Y - M^C)$.

Using equations (B.21) and the production function of nondurable goods firms, it is easy to see that the profit function for a generic firm z in real terms reads out as follows:

$$\begin{aligned}\hat{\Pi}_t^C(z) = \left(\frac{p_t^C(z)}{P_t^C}\right)^{1-\theta} Y^C e^{\tilde{Y}_t^C} - \frac{W_t}{P_t^C A_t^C(z)} \left(\frac{1-\alpha}{\alpha}\frac{W_t}{P_t^C}\right)^{\alpha-1} \left(\frac{p_t^C(z)}{P_t^C}\right)^{-\theta} Y^C e^{\tilde{Y}_t^C} + \\ - \frac{1}{A_t^C(z)} \left(\frac{1-\alpha}{\alpha}\frac{W_t}{P_t^C}\right)^{\alpha} \left(\frac{p_t^C(z)}{P_t^C}\right)^{-\theta} Y^C e^{\tilde{Y}_t^C} - \varphi^C \frac{W_t}{P_t^C} \mathcal{I}\left(p_t^C(z), p_{t-1}^C(z)\right)\end{aligned} \tag{B.22}$$

where $\tilde{Y}_t^C$ is defined in (B.21) and as such is a function of W_t, P_t^C and P_t^D. From equation (B.22), one concludes that the state-space for a nondurable firm z at time t is $\Omega_t^C(z) = \{p_{t-1}^C(z)/P_{t-1}^C, A_t^C(z), W_t/P_{t-1}^C, W_t/P_{t-1}^D\}$ where I use the approximating laws of motion (24) to write aggregate price levels in terms of past price indices and the nominal wage.

B.3 Computational Details

The solution algorithm follows Vavra (2014), who in turn exploits the seminal contribution by Krusell & Smith (1998) to solve models with aggregate and idiosyncratic uncertainty.

Below I provide a pseudocode of my implementation.

1. Define four grids for (i) the real wage in the nondurable sector; (ii) the real wage in the durable sector; (iii) the relative price $p^C(z)/P^C$ of nondurable firms; and (iv) the relative price of durable firms $p^D(z)/P^D$;[16]
2. Discretize the productivity processes $A^C(z)$ and $A^D(z)$. I use the Rouwenhorst method which, as Kopecky & Suen (2010) argue, is more accurate than traditional quadrature methods for persistent processes;
3. Define two matrices representing the profit functions for the two firms over the space defined by the grids above;
4. Set a tolerance level $\ell > 0$. Do:
   (a) Guess a set of parameters $\{\varsigma_j^i\}_{i=C,D;j=0,1,2}^{(k)}$ associated to the k-th guessed approximating laws of motion $\Gamma_k^C(\cdot)$, $\Gamma_k^D(\cdot)$;
   (b) Given this guess, solve the problem of the firm and obtain a set of policies $\mathcal{P}^C(z)$, $\mathcal{P}^D(z)$ where I omit to explicitly include the set of states. For performance, I implement a vectorized value function iteration algorithm;
   (c) Simulate N times the economy using the two policies over a panel of K firms for T periods, and an exogenous path for the nominal wage;
   (d) Call $\{P_{k,t}^C\}_{t=0}^T$ and $\{P_{k,t}^D\}_{t=0}^T$ the price level implied by the laws of motion $\Gamma_k^C(\cdot)$ and $\Gamma_k^D(\cdot)$ respectively, and let $\{\hat{P}_{k,t}^C\}_{t=0}^T$ and $\{\hat{P}_{k,t}^D\}_{t=0}^T$ be the true (simulated) price levels. Compute

$$d_k \equiv \sum_{t=0}^{T} \left[\left| P_{k,t}^C - \hat{P}_{k,t}^C \right| + \left| P_{k,t}^D - \hat{P}_{k,t}^D \right| \right]$$

   (e) If $d_k < \ell$, stop. Else, update the guess to $\Gamma_{k+1}^{C,D}(\cdot)$ and go back to point (a).

Some remarks are in order for the reader interested in replicating the results. As Nakamura & Steinsson (2010) cite in their code, the productivity process must be discretized over a sufficiently fine grid. I use 50 points for the real wages and relative prices grids, and 10 points for the productivity grid. This implies that the dimension of the state space of the problem is $50^3 \times 10$, hence the value function algorithm program must be efficient.

[16] Because I solve the model around the flex-price deterministic steady-state, I define the grids for the real wages around their values in such steady-state, and center that for relative prices around 1.