A more recent version of this article has been accepted in:
RAND Journal of Economics, 2009

Do Retail Gasoline Prices Respond Asymmetrically to Cost Shocks? The Influence of Edgeworth Cycles

Michael Noel
University of California, San Diego

March 29, 2009

Abstract

Asymmetric price cycles similar to Edgeworth Cycles are appearing in increasingly many retail gasoline markets in the U.S. and worldwide. The asymmetry in the cycles can give rise to a finding of asymmetric price *responses* to cost shocks ("asymmetric passthrough"). This article estimates asymmetric passthrough for the market of Toronto, which exhibits cycles, and decomposes it into two components – that part explainable by the cycles and that part driven by other unknown sources. Significant asymmetric passthrough is found, with increases passed through more quickly than decreases. A significant cause of the finding is the presence of the cycles themselves.

JEL Classification L13, L41, L81

1 Introduction

The question of whether firms pass cost increases through to prices more quickly than they do decreases has long generated interest by economists, especially in the context of gasoline markets. A large literature has developed to examine this phenomenon – known as asymmetric passthrough – for gasoline markets in the U.S. and in many other countries. A widely cited article is Borenstein et al. (1997), who find evidence of asymmetric passthrough from crude prices into retail prices in the U.S. and suggest retailer market power and inventory asymmetries as some possible causes. Other authors suggest other possibilities (Lewis (2004), Radchenko (2005)) or find no asymmetry at all (Bachmeier & Griffin (2003)).[1]

A new literature has emerged that has the potential to explain some or much of the asymmetric passthrough found in certain gasoline markets by the earlier studies. The literature examines the rapid and asymmetric retail price cycles recently found in many retail gasoline markets around the world including in Canada (Noel (2007a,b), Eckert (2002,2003)), the U.S. (Castanias & Johnson (1993), Lewis (2007)), Australia (Wang (2005)) and in several European countries. Although newly discovered with the availability of high frequency price data, asymmetric cycles have existed in some markets for decades. As an example of the cycles, in Figure 1, I plot the retail prices for two gasoline stations (one major firm, one independent) and the wholesale ("rack") price over four months in 2001 in the market of Toronto, Canada, which experiences cycles. The twelve-hourly data shows the cycle clearly.

These authors argue the cycles are the theoretical Edgeworth Cycles of Maskin & Tirole (1988) and I defer to them for further evidence. In an Edgeworth Cycle, firms selling homogeneous goods repeatedly undercut one another by small amounts to steal market share. When margins get too low, one firm "relents" by raising its price significantly higher. Other firms follow quickly by relenting themselves and then from the new high price, another round

[1] Other studies include Bacon (1991), Manning (1991) (U.K.), Reilly & Witt (1998) (N.Z.), Godby et al. (2000) (Canada), Kirshgassner & Kubler (1992) (Germany), Duffy-Deno (1996), Karrenbrock (1991) and Balke et al. (1999) (U.S.). Peltzman (2000) finds asymmetric passthrough more generally across a broad range of U.S. manufacturing industries.

of undercutting begins. The asymmetric price process – large increases and small decreases – repeats over and over. This is true even in the *absence* of any cost shocks at all.

But there is an interaction between the asymmetry inherent in an Edgeworth Cycle and cost shocks that can result in asymmetric passthrough. For example, a positive rack shock can trigger a new relenting phase and, if it does, a large price increase. In contrast, a negative shock will not cause a large price decrease, as it only allows more room for undercutting and undercuts tend to be small.[2] The result is that cost increases can be passed through to retail prices more quickly than decreases, relative to the pre-shock prices. Eckert (2002) observes this in his study of retail price cycles in Windsor, Canada and argues that the cycles are a source for at least some portion of the asymmetric passthrough he finds there.

It is an excellent insight, but such a finding still cannot tell us if Edgeworth Cycles are the *sole* cause for the asymmetric passthrough found or if they are just one of many possible contributing factors. This is important to know and begs the question that is the focus of this article: When asymmetric passthrough is found in a market with Edgeworth Cycles, how much of it is attributable directly to the Edgeworth Cycles themselves, and how much of it remains to be explained with other sources? Can the cycles explain 100%? With the exception of Eckert (2002), prior studies have not considered Edgeworth Cycles as a potential cause and their influence is not well understood.[3] Clearly, it is important to separate the known effects of Edgeworth Cycles from potential other causes of asymmetric passthrough that would warrant further study. In this article, I do this. I show asymmetric passthrough exists for the city of Toronto, where strong retail cycles exist, and then decompose it into two components: that caused solely by cycles – the "Edgeworth-explained" component – and that which remains – the "residual" component. The source of the latter is unknown and may include interactions between those unknown causes and the Edgeworth Cycles themselves. For Toronto, I find that the "Edgeworth-explained" component is large and

[2] Noel(2008) shows this theoretically.

[3] Some studies were conducted in markets now known to have had Edgeworth Cycles. For example, the sample used by Godby et al. (2000) includes the market studied here.

plays a significant role in generating asymmetric passthrough.

2 Components of Overall Asymmetric Passthrough

"Overall" asymmetric passthrough (from all sources) is intuitively found by comparing *post-shock* prices to *pre-shock* prices – first after a rack increase, then after a decrease, and then differencing the two series. This is the comparison implicit in the usual techniques used in the literature (e.g. VAR models). The use of pre-shock prices as the reference point is standard and based on the idea that prices would not change but for the shock.

What is unique about markets with cycles, however, is that prices do keep changing and in an asymmetric way, even absent a shock. And we can predict how. It turns out that this predicted "no shock" price path holds the key to decomposing overall asymmetric passthrough into its Edgeworth-explained and residual components.

The reason is that each individual part of a theoretical Edgeworth Cycle taken separately responds *symmetrically* to cost shocks – the probability of switching between the two phases of the cycle responds symmetrically as do the magnitudes of each expected retail price change conditional on the phase. So if Edgeworth Cycles were the sole cause of overall asymmetric passthrough (the residual component were zero), post-shock prices would be shifted either up (after a rack increase) or down (after a decrease) by identical amounts in any given period, *relative to what they would have been along the cycle absent the shock*. This is why the "no shock" price path is critical. If instead these "cycle-relative" price changes are not the same, then there is evidence firms are deviating from the normal cyclical pattern to pass shocks through asymmetrically for some other reason.[4]

I therefore estimate the residual component by comparing post-shock prices not to pre-shock prices but rather to what prices would have been going forward had there been no shock at all. This new reference point is an asymmetrically moving target but easily estimable. I compare the two paths after a rack increase, then after a decrease, and then take the

[4]Eckert (2002) implicitly constrains non-Edgeworth-caused passthrough to be zero.

difference-in-differences as the residual component. Effectively this technique "differences out" the cycle itself. To get the Edgeworth-explained component, I just subtract the residual component from the overall.

Figure 2 gives a stylized graphical exposition of the distinction between overall asymmetric passthrough and its residual component. Panel A shows the effect of a rack price increase on retail prices and Panel B shows it for a decrease. Imagine that in each case the next relent would have occurred at time t, but the shock to rack price triggers it earlier (Panel A) or later (Panel B). Overall asymmetric passthrough – which uses pre-shock prices as its reference – is measured by comparing the large vertical distance XY in Panel A to the small vertical distance Y'Z' in Panel B. These price changes, easily observed at the pump, can differ greatly. The residual component on the other hand – which uses "no-shock" prices as its reference – is measured by comparing the vertical distance XZ in Panel A to the corresponding distance X'Z' in Panel B. Parts of these price changes are not observable in a simple pre-post comparison, especially so for rack decreases. This is how cycles can contribute to overall asymmetric passthrough – the large price increases observable at the pump after positive cost shocks appear in the distance XY, but the large price increases that *would have occured* but do *not* because they are *preempted* by negative cost shocks (and thus unobservable at the pump) are excluded from Y'Z'. If in the end it turns out that the distance XZ equals the distance X'Z', the residual component is zero and we can conclude Edgeworth Cycles are the sole cause of overall asymmetric passthrough.

3 Data

I analyze the effect of Edgeworth Cycles on asymmetric passthrough for the city of Toronto, where retail prices cycle, using a dataset of twice-daily retail prices on 22 service stations along an assortment of major city routes over 131 consecutive days between February 12^{th} and June 22^{nd} 2001. The stations are operated by a representative mix of major integrated national and regional firms and smaller independent firms – thirteen by majors, nine by independents. Twelve firms are represented in all including all national and regional firms.[5]

Retail prices, $RETAIL_{st}$, are for regular unleaded, 87 octane, self-serve gasoline, in Canadian cents per liter (cpl), and before taxes. The wholesale price I use is the daily spot rack price for the largest wholesaler at the Toronto rack point, $RACK_{st}$, as collected and reported by OPIS. This measure is not ideal, because only independents buy at rack and because there can be small discounts from it, but with contract prices unavailable, it is the best available measure. Rack and contract prices should be well correlated and, importantly, discounts off rack are not tied to the retail cycles. Because of readily available U.S. sources of wholesale gasoline, the rack price can be reasonably modeled as exogenous to retail price setting (Hendricks (1996)). The mean before-tax retail price over the sample is 43.1 cpl (s.d. = 4.4) and the mean rack price is 39.8 (s.d. = 4.0).

4 Empirical Model and Results

To estimate overall asymmetric passthrough and its Edgeworth-explained and residual components, I nest a model of asymmetric passthrough into a model of Edgeworth Cycles. The estimation technique is a latent regime Markov switching regression model that incorporates direction-specific sequences of lagged rack price changes. The goal is to use the estimates of the model to simulate cumulative response functions (CRFs) of retail prices to positive and negative rack price shocks – first using pre-shock prices as the reference point to get "overall asymmetric passthrough" and then using "no-shock" prices (i.e. what prices would have been) as the reference path to get the residual component.

For each station at a point in time, two pricing regimes are clearly suggested by the theory and the data – the relenting phase (regime "R") and the undercutting phase (regime "U") with discrete switching between the two.[6] Because undercutting phases tend to persist

[5] Capacity constraints are not binding for stations at any reasonable set of retail prices.

[6] All stations in the sample are very clearly pricing along an asymmetric price cycle throughout the sample

for many periods whereas relenting phases tend to last a single period, the current regime carries information about the likelihood of the next regime. The Markov framework captures this.

I assume a station s operating under regime i at time t sets its retail price as:

$$\Delta RETAIL_{st} = \begin{cases} X^i_{st}\beta^i + \varepsilon^i_{st} & \text{with prob. } 1-\gamma^i_{st} \\ 0 & \text{with prob. } \gamma^i_{st} \end{cases} \tag{1}$$

where $\Delta RETAIL_{st}$ is the first difference of $RETAIL_{st}$; X^i_{st} is a row vector containing the variables for station s at time t; and β is a column vector of parameters. Each ε^i_{st} is a normal error term with mean zero and variance σ^2_i. I model the nonstochastic component $X^i_{st}\beta$ as:

$$\begin{aligned} X^i_{st}\beta \;=\;& \beta^i_0 + \beta^i_1 RACK_{st} + \beta^i_2 RETAIL_{s,t-1} + \beta^i_3 IND_s \\ &+ \sum_{r=1}^{N/2-1} \beta^{i-}_r \Delta RACK^-_{s,t-2r} + \sum_{r=1}^{N/2-1} \beta^{i+}_r \Delta RACK^+_{s,t-2r} \end{aligned} \tag{2}$$

which I describe more fully below. Define $\alpha^i_{st} = E(\Delta RETAIL_{st} \mid X^i_{st}, \Delta RETAIL_{st} \neq 0)$ as the regime-conditional expected price change, excluding zeros.

Note that I have allowed a mass point of zero within each regime, with a zero change occurring with probability γ^i_{st}. Letting J^i_{st} be the indicator function equal to one when, conditional on being in regime i, the price at station s does not change, I model γ^i_{st} as:

$$\Pr(J^i_{st} = 1 \mid I_{st} = i, V^i_{st}) = \gamma^i_{st} = \frac{\exp(V^i_{st}\zeta^i)}{1+\exp(V^i_{st}\zeta^i)} \tag{3}$$

$$V^R_{st}\zeta^R = \zeta^R_0 \tag{4}$$

$$\begin{aligned} V^U_{st}\zeta^U =& \zeta^U_0 + \zeta^U_1 RACK_{st} + \zeta^U_2 RETAIL_{s,t-1} + \zeta^U_3 IND_s \\ &+ \sum_{r=1}^{N/2-1} \zeta^{U-} \Delta RACK^-_{s,t-2r} + \sum_{r=1}^{N/2-1} \zeta^{U+} \Delta RACK^+_{s,t-2r} \end{aligned} \tag{5}$$

described more fully below. Given the high frequency of the data, one would naturally

period, similar to those in Figure 1, and justifying a two-regime-only model.

expect some zero price changes in the data even if firms were undercutting every "true" period. Also, Eckert (2003) and Noel (2008) show in many situations that firms match an opponent's price rather of undercut. The zero mass point allows for these situations.

Finally, there are four Markov switching probabilities governing regime transitions. Letting I_{st} equal "R" ("U") when station s at time t is in the relenting (undercutting) phase, I model the Markov probability a station switches from regime i in period $t-1$ to regime "R" in period t as:

$$\lambda_{st}^{iR} = \Pr(I_{st} = \text{“}R\text{”} \mid I_{s,t-1} = i, W_{st}^{i}) = \frac{\exp(W_{st}^{i}\theta^{i})}{1+\exp(W_{st}^{i}\theta^{i})}, \quad i = R, U \tag{6}$$

$$W_{st}^{R}\theta^{R} = \theta_0^{R} \tag{7}$$

$$\begin{aligned} W_{st}^{U}\theta^{U} &= \theta_0^{U} + \theta_1^{U} RACK_{st} + \theta_2^{U} RETAIL_{s,t-1} + \theta_3^{U} IND_s \\ &+ \sum_{r=1}^{N/2-1} \theta_r^{U-} \Delta RACK_{s,t-2r}^{-} + \sum_{r=1}^{N/2-1} \theta_r^{U+} \Delta RACK_{s,t-2r}^{+} \end{aligned} \tag{8}$$

with $\lambda_{st}^{iU} = 1 - \lambda_{st}^{iR}$.

In each of the X_{st}^{R}, X_{st}^{U}, W_{st}^{U}, and V_{st}^{U} explanatory row vectors, I include not only the current rack price $RACK_{st}$ and previous retail price $RETAIL_{s,t-1}$,which are relevant for Edgeworth Cycles, but also a series of direction-specific lagged rack price differences, $\Delta RACK_{s,t-r}^{+} = \max(0, \Delta RACK_{s,t-r})$ and $\Delta RACK_{s,t-r}^{-} = \min(0, \Delta RACK_{s,t-r})$. I also include a control for whether the station is operated by an independent firm (IND_s) in the X_{st}^{i}, V_{st}^{U} and W_{st}^{U}. I use a lag length N of forty periods. Because the retail price data are twelve-hourly and consecutive (twelve-hourly) rack prices are highly collinear, I fit each set of coefficients $\Delta RACK^{-}$ and $\Delta RACK^{+}$ to a quadratic polynomial. For the same reason, I include every second two-period lagged difference of rack prices instead of every single lagged difference.[7] I estimate the model parameters $(\beta^{i}, \sigma^{i}, \theta^{i}, \zeta^{i})$ by maximum likelihood and calculate robust Newey-West standard errors. The switching probabilities $(\lambda^{ij}, \gamma^{i})$ are just transformations of the model parameters, with standard errors calculated by the multivariate delta method.

[7] Results are robust with other reasonable lag lengths, or when fit to a cubic.

Before turning to the main analysis, it is instructive to perform two preliminary specifications based on simplifications of the above model. Specification (1), reported in Table 1, establishes empirically that cycles exist and are asymmetric. It can be thought of as a "summary statistics" specification (post-categorization) and is estimated by setting each W^i, V^i, and X^i to a column of ones. The null hypothesis is that each corresponding pair of parameters are equal across regimes ($\alpha^R = \alpha^U, \gamma^R = \gamma^U, \lambda^{RR} = \lambda^{UU}$), i.e. that regimes are symmetric. The estimates soundly reject the null. The mean price change in a relenting phase ($\alpha^R = 5.57$) is significantly higher (in absolute value) than that in an undercutting phase ($\alpha^U = 0.75$). Also, zero price changes in an undercutting phase are common ($\gamma^U = 0.429$) but effectively non-existent in the relenting phase ($\gamma^R = 0.000$), and undercutting phases are persistent ($\lambda^{UU} = 1 - \lambda^{UR} = 0.922$) whereas two consecutive relenting phases at a station are extremely rare ($\lambda^{RR} = 0.008$). Consistent with Figure 1, cycles are highly asymmetric – prices rise faster than they fall.[8] Note that there is virtually no meaningful variation in the λ^{RR} and γ^R estimates, and so they are modeled as constants in the main specification.

Preliminary specification (2) establishes that a station is more likely to relent the closer it is to the bottom of the cycle (i.e. when markups are low), consistent with the theory of Edgeworth Cycles.[9] In this specification, I include $RETAIL_{t-1}$, $RACK_t$, and a constant in each of the X^i_{st}, W^U_{st}, and V^U_{st}. The null hypothesis that $\partial\lambda^{UR}/\partial RETAIL = 0$ and $\partial\lambda^{UR}/\partial RACK = 0$ is easily rejected in favor of the alternative $\partial\lambda^{UR}/\partial RETAIL < 0$ and $\partial\lambda^{UR}/\partial RACK > 0$. Lower $RETAIL_{t-1}$ or higher $RACK_t$, which squeezes margins, increases the probability of relenting. To a lesser extent it affects other actions – increasing relenting phase price jumps and decreasing undercuts. This justifies the need to include these variables in the model.

I now turn to the full asymmetric model and estimate overall asymmetric passthrough and its Edgeworth-explained and residual components. The raw series of lagged, direction-specific rack price difference estimates in the X^i, W^U, and V^U are central to the estimation

[8] See Noel (2007b) for derivations of amplitude, period, and asymmetry based on underlying parameters.

[9] See Maskin & Tirole (1988), Eckert (2003) and Noel (2008) for theoretical analyses.

but not intuitively interpretable, so I follow the standard practice in the literature of deriving and then basing my hypothesis tests on the more meaningful cumulative response functions of retail prices to rack price shocks.

To calculate the cumulative response functions of retail prices to rack price shocks under *overall passthrough*, I simulate 500 retail price paths in each of two scenarios: 1.) $RACK\ INCREASE$, where I impose a positive, permanent shock to $RACK_t$ beginning in some period q, and 2.) $RACK\ DECREASE$, where I impose a permanent negative shock in q. For each simulation, I draw a new core parameter vector $(\beta, \sigma, \theta, \zeta)$ from its distribution. The "Overall Passthrough CRF" after a positive (or negative) rack shock is the mean difference between the retail price in the $RACK\ INCREASE$ (or $RACK\ DECREASE$) scenario and the *pre-shock* retail price, calculated at every t, and normalized by the size of the shock to yield percentage responses. Pre-shock rack and retail prices are set to their means and the size of the shock is set to the mean rack shock magnitude. These Overall Passthrough CRFs (which formalize the responses XY and Y'Z' from Figure 2) yield the simple, observable pre-post comparison that is standard in the literature. As they do not take into account the fact that retail prices will keep changing in the absence of a shock because of the cycle, they mix asymmetric passthrough due to Edgeworth Cycles together with that from other causes. The vertical distance between the two Overall Passthrough CRFs is the measure of overall asymmetric passthrough at each time t.

Although such CRFs are usually generated in the literature with a VAR model, I maintain the nested model here because straight VARs are not ideal for studying markets with cycles. They tend not to fit the data well given the bimodal, non-normal distribution of price changes.

Next I separate overall asymmetric passthrough into Edgeworth-explained and residual components by calculating "Cycle-Relative CRFs". I simulate 500 retail price paths for three scenarios 1.) $RACK\ INCREASE$, 2.) $RACK\ DECREASE$, both as above, and 3.) $NO\ SHOCK$. For the latter I assume there is no rack price shock and then calculate for each t the expected retail price, which evolves naturally along the Edgeworth Cycle. In each case, pre-shock rack and retail prices are set to its mean. I then calculate the mean difference in the retail price paths between the $RACK\ INCREASE$ and $NO\ SHOCK$ scenarios and the mean difference between the $RACK\ DECREASE$ and $NO\ SHOCK$ scenarios to generate the two Cycle-Relative CRFs, which are normalized by the shock to give percentage responses.[10] These Cycle-Relative CRFs (which formalize the responses XZ and X'Z' in Figure 2), yield a comparison of post-shock retail prices to what retail prices *would have been* in those same later periods in the absence of a shock. Each CRF effectively differences out the cycles, and the difference in the CRFs themselves yields a measure of residual asymmetry.[11] Edgeworth-explained asymmetric passthrough is then given by the difference between the residual component and the overall.

I use the Overall Passthrough CRFs and the Cycle-Relative CRFs to test a number of hypotheses. First, I test for overall asymmetric passthrough, from the combination of all sources, which can go in either direction. The null hypothesis of zero overall asymmetric passthrough is equivalent to the null that the Overall Passthrough CRF for a rack increase is equal to that for a decrease at each time t. I report the estimated Overall Passthrough CRFs in Figure 3. They differ significantly in many periods, soundly rejecting the null and establishing overall asymmetric passthrough.[12]

Before saying more, there are several unusual characteristics of CRFs inherent to Edgeworth Cycle markets that merit explanation. First, in Figure 3 (and later in Figure 4) passthrough rates can overshoot 100% complete passthrough, and then tend to oscillate around 100%, until convergence. (These features are equally present in fully symmetric models.) The overshooting occurs because even small rack price changes can trigger a change in phase and a large change in expected price. For example, a small rack increase, if it triggers

[10]The standard errors around the reported mean CRFs account for heteroskedasticity and serial correlation because the variance-covariance matrix of the parameter vector, on which the CRFs are based, has been adjusted by the Newey-West formula.

[11]In the symmetric constrained version of the model, with $\Delta RACK^{+}_{s,t-r} = \Delta RACK^{+}_{s,t-r}$, the Cycle-Relative CRFs are identical at every t.

[12]Statistical tests are taken at the 5% level. Figures show unidimensional 95% confidence intervals.

a new relent phase, creates a roughly 5.5 cent observable price jump in expectation.[13] The oscillation occurs because prices are constantly changing along the cycle under all scenarios, so passthrough rates fluctuate in a cyclic way. Probablistically, this creates oscillating CRFs that eventually converge as the variance on the distribution of possible states grow.[14]

Given these features of the CRFs, the most critical window for observing total asymmetric passthrough is the period up to the first peak in Figure 3. It is during this period firms are first able to move prices upward following a positive shock or delay lowering them following a negative shock. The early asymmetry is clear – positive shocks are passed through more quickly than negative shocks, statistically significantly so up to period 10. The difference is also economically large, reaching a maximum of 62% of the original shock by period 6. At the maximum differential, retail prices respond at almost *twice* the speed to positive shocks than negative ones – 136% of a rack increase has been passed through whereas only 74% of a decrease has. The 62% difference in rates adds a full 0.53 cpl on top of the 3.32 cpl mean markup (16%) for every pair of mean sized shocks. It is larger than the asymmetry often found in many studies of asymmetric passthrough. Borenstein et al. (1997), in their seminal article on asymmetric passthrough, find a maximum difference at the retail-rack level in the U.S. of 40%, two-thirds as much.

Beyond the first peak in Figure 3, one must be more cautious. The figure still shows overall passthrough for rack increases and decreases at each time t, of course, but now path dependence plays a role. The first instance of asymmetric passthrough puts cycles under the different scenarios out of phase and the CRFs oscillate, shifting cycle peaks forward or backward in time by different amounts. Measures of asymmetric passthrough naturally

[13]Because Overall Passthrough CRFs include only the observed pre-post price responses, overshooting is most pronounced after a positive rack shock. Cycle-Relative CRFs include both observed and unobserved price responses and overshooting is strong after both types of shocks.

[14]These features arise also since the CRFs are drawn from a single starting position in the cycle, in this case with rack and retail prices at their means. If instead one averaged the CRFs across a distribution of starting points, the peaks and troughs would occur at slightly different t's for each starting point, and the features would largely be averaged away. I maintain the mean starting point approach to highlight the effect of a given shock, but all the results on overall asymmetric passthrough and its decomposition to follow are robust to the particular method used.

oscillate as well. Notice that overall asymmetric passthrough turns significantly negative for awhile in the middle of the figure. (These cautions also apply to the Cycle-Relative CRFs below.) Later in this article I will propose a more comprehensive measure for overall asymmetric passthrough (and its components) that incorporates responses at all times t.

I now test for a positive contribution of each component to the overall. First, I test the null that the residual component is zero against the two-sided alternative that asymmetric passthrough from other sources exists. In terms of CRFs, the null hypothesis is that the Cycle-Relative CRF after a positive rack shock is equal to that after a negative shock at each time t.

I report the estimated Cycle-Relative CRFs in Figure 4. They differ significantly and soundly reject the null in favor of the alternative.[15] Positive rack price shocks are passed through more quickly than decreases in the periods up to the first peak, after removing the cyclical pattern in the data. The residual component is significant to period 11 and reaches a maximum of 26% in period 6.[16] Figure 5 shows overall asymmetric passthrough and its residual component, with confidence intervals excluded for readability.

There are two potential transmission mechanisms for this result – differences in how rack price shocks affect regime switching, or differences in how rack price shocks affect expected within-regime price changes. The second turns out to be negligible, and the first drives the result. Practically speaking, firms increase the probability of a relenting phase after a rack price increase more than they decrease it after a decrease. Said less formally, firms in the Toronto market hurry relenting phases after a cost increase more than they delay relenting phases after a decrease.

Although I have shown the residual component is significantly different from zero, it remains to show whether the Edgeworth-explained component is significantly non-zero. This

[15] This null is equivalent to the joint test that $\Delta RACK_{st}^{-} = \Delta RACK_{st}^{+}$ for all s and t. The F test soundly rejects with a value of 17.1 and p-value below < 0.0001. Other nulls (which involve comparisons to the pre-shock price) do not have an equivalent coefficient test and must be based on CRFs.

[16] Since the different CRFs are positively correlated across simulations, the overlap of the univariate confidence intervals drawn understates the statistical significance of the *difference* of the CRFs.

leads to the second null hypothesis – that none of the overall asymmetric passthrough is due to Edgeworth Cycles, i.e. it is from residual sources. The one-sided alternative is that Edgeworth Cycles contributes to asymmetric passthrough with increases passed through more quickly than decreases in the early periods. To test this, I difference overall asymmetric passthrough (the difference in the Overall Passthrough CRFs) and residual asymmetric passthrough (the difference in the Cycle-Relative CRFs) to derive the Edgeworth-explained component of overall asymmetric passthrough. The Edgeworth-explained asymmetric passthrough function is represented as the difference in the curves in Figure 5. The null is that the Edgeworth-explained asymmetric passthrough function is zero for all t. But contrary to the null, I find this component is positive and statistically significant from periods 2 to 10 before the first peak, reaching a maximum of 37% in period 5. I conclude that both Edgeworth-explained and residual asymmetric passthrough exist and each contribute significantly to the overall.

To understand the result better, it is instructive to relate the CRFs in Figures 3 and 4 back to the stylized example in Figure 2. The Overall Passthrough CRFs – which compare pre- and post-shock prices – include only the changes in the retail price observable at the pump. Although the large relenting phase price increases that follow positive rack shocks are included in the Overall Passthrough CRF for increases, the large unobserved price increases that do not occur because they are pre-empted by negative rack shocks are not included in the Overall Passthrough CRF for decreases. In contrast, Cycle-Relative CRFs include both effects – observable and unobservable – and as seen in Figure 2, unobservable effects are more important for rack decreases. So whereas the Overall and Cycle-Relative CRFs in Figures 3 and 4 are relatively similar for increases, the Overall Passthrough CRF for a negative shock falls short of its Cycle-Relative counterpart. The difference is from the effect of Edgeworth Cycles.

I noted that the oscillating property of the various CRFs suggests that analysis at a particular point in time is unlikely to yield the best summary measure of asymmetric passthrough.

What should matter instead is the cumulative *sum* of asymmetric passthrough – overall and within each component – up to each time t, until the shock has fully dissipated. To implement this, I introduce "*cumulative* asymmetric passthrough functions" (CAPFs) – one for the overall and one for each component. These effectively compare the difference in total consumer *expenditures* following a positive and negative cost shock, assuming one unit is purchased each period, up to each time t.[17] Mathematically, I take the integral of each of the three asymmetric passthrough functions to derive the three respective CAPFs.

Figure 6 shows the CAPFs for overall asymmetric passthrough and the residual component. The Overall CAPF shows that the additional expenditures consumers incur after a one cent rack increase exceeds the savings they enjoy after a one cent rack decrease, up to any time t. This gives the definitive measure of direction – positive shocks are passed through more quickly than negative ones. Cumulative overall asymmetric passthrough reaches a maximum of 423% of the original shock in the 12^{th} period, statistically significantly different from zero, and economically large (108% of the mean markup of 3.32 cpl after a mean shock.) It converges to a value of about 116% (still significant at the 10% level) by period 43. In terms of its components, the Residual CAPF reaches a maximum of 205% in period 16, significantly different from zero, converging to a value of 53% by the 31^{st} period. The difference between them – the Edgeworth-explained CAPF – reaches a maximum of 245% in period 11 and converges to 62% by period 43. The Edgeworth-explained CAPF is drawn separately in Figure 7.[18]

Using the Cumulative Asymmetric Passthrough Functions, it is now possible to answer the question "Does Edgeworth Cycles account for all the asymmetric passthrough?" A quick look at Figures 6 and 7 shows that the Edgeworth-explained component is a substantial portion of overall asymmetric passthrough for Toronto, but does not explain all of it. The fraction of the overall accounted for by the Edgeworth-explained component varies slightly

[17] In calling these "expenditures", I put aside issues of intertemporal substitution.

[18] Two-sided 95% confidence interval bounds are shown for parsimony. The lower bound corresponds to a 97.5% lower confidence bound under the one-sided alternative that Edgeworth Cycles contribute to overall asymmetric passthrough in the positive direction.

with t but always stays in the range 45% to 60% and averages 56.1% (s.e. 18%) across the entire time horizon.[19] I conclude that Edgeworth Cycles contributes significantly but not completely to the overall asymmetric passthrough found in the study market of Toronto.

5 Conclusion

In this article, I have estimated the influence of Edgeworth Cycles on overall asymmetric passthrough for the city of Toronto. I have shown that the cycles are a significant contributing factor to the finding that rack price increases are passed through more quickly than decreases. They are not the only factor, however – I have found that firms tend to hurry relenting phases after a rack price increase more than they delay them after a decrease for reasons outside the model of Edgeworth Cycles.

I have argued that Edgeworth Cycles are a potential cause for overall asymmetric passthrough, but I have also cautioned against assuming by their presence they must be the only cause. Where cycles do not exist, obviously, they can explain nothing. And where they do exist, they may contribute a little or a lot to a finding of asymmetric passthrough – each market needs to be evaluated on its own merit. But their presence or the potential for their presence cannot be ignored. Once considered only a theoretical construct, asymmetric price cycles that appear to be Edgeworth Cycles have now been detected in markets across the U.S., Canada, Australia, and in several European countries. And although there is still much unknown about the cycles, one thing seems certain. In retail markets where they exist, Edgeworth Cycles play an important role in the competitive landscape.

[19] This is not to say that Edgeworth Cycles alone account for exactly 56.1% and other independent causes separately account for exactly 43.9%. There may be interactions between Edgeworth Cycles and other causes of asymmetry, in ways unknown to us, included in the residual component.

6 References

Atkinson, B. (2006) "Retail Gasoline Price Cycles: Evidence from Guelph, Ontario Using Bi-Hourly Station-Specific Retail Price Data", Competition Bureau Canada Working Paper.

Bachmeier, L and Griffin, J.M. (2003) "New Evidence on Asymmetric Gasoline Price Responses", *Review of Economics and Statistics* 85, pp.772-776.

Bacon, R. (1991). "Rockets and Feathers: the Asymmetric Speed of Adjustment of UK Retail Gasoline Prices to Cost Changes" *Energy Economics* 13, pp.211-218.

Balke, N., Brown S. and Yucel, M. (1998). "Crude Oil and Gasoline Prices: An Asymmetric Relationship?" *Federal Reserve Bank of Dallas Economic Review* 1st Qtr 1998, pp.2-11.

Borenstein, S., Cameron, A. C., and Gilbert, R. (1997) "Do Gasoline Markets Respond Asymmetrically to Crude Oil Price Changes?" *Quarterly Journal of Economics* 112, pp.305-339.

Castanias, R. and Johnson, H. (1993) "Gas Wars: Retail Gasoline Price Fluctuations", *Review of Economics and Statistics* 75, pp.171-174.

Duffy-Deno, K. (1996) "Retail Price Asymmetries in Local Gasoline Markets" *Energy Economics* 18, pp.81-92.

Eckert, A. (2002) "Retail Price Cycles and Response Asymmetry", *Canadian Journal of Economics* 35, pp.52-77.

Eckert, A. (2003) "Retail Price Cycles and Presence of Small Firms", *International Journal of Industrial Organization* 21, pp.151-170.

Godby, R., Lintner, A., Stengos, T. and Wandschneider, B. (2000) "Testing for Asymmetric Pricing in the Canadian Retail Gasoline Market", *Energy Economics* 22, pp.349-368.

Hamilton, J.D. (1996) "Specification Testing in Markov-Switching Time-Series Models", Journal of Econometrics 70, pp.127-157.

Hendricks, K. (1996) "Analysis and Opinion on Retail Gas Inquiry." Report prepared for Industry Canada.

Karrenbrock, J. (1991) "The Behavior of Retail Gasoline Prices: Symmetric or Not?" *Federal Reserve Bank of St. Louis Review* 73, pp.19-29.

Kirchgassner, G. and Kubler, K. (1992). "Symmetric or Asymmetric Price Adjustments in the Oil Market: An Empirical Analysis of the Relations between International and Domestic Prices in the Federal Republic of Germany, 1972-1989" *Energy Economics* 14, pp.171-185.

Lewis, M. (2004). "Asymmetric Price Adjustment and Consumer Search: An Examination of the Retail Gasoline Market". CSEM Working Paper 120.

Lewis, M. (2007) "Temporary Wholesale Gasoline Price Spikes have Long Lasting Retail Effects: The Aftermath of Hurricane Rita", Ohio State University Working Paper.

Manning, D. (1991). "Petrol Prices, Oil Price Rises and Oil Price Falls: Some Evidence for the UK since 1972", *Applied Economics* 23, pp.1535-1941.

MJ Ervin & Associates. (1997) "Canadian Retail Petroleum Markets Study." Report prepared for Industry Canada.

Maskin E., and Tirole, J. (1988) "A Theory of Dynamic Oligopoly II: Price Competition, Kinked Demand Curves and Edgeworth Cycles," *Econometrica* 56, pp.571-599.

Noel, M. (2007a) "Edgeworth Price Cycles, Cost-based Pricing and Sticky Pricing in Retail Gasoline Retail Markets," *Review of Economics and Statistics* 89, pp.324-334.

Noel, M. (2007b) "Edgeworth Price Cycles: Evidence from the Toronto Retail Gasoline Market," *Journal of Industrial Economics* 55, pp.69-92.

Noel, M. (2008) "Edgeworth Price Cycles and Focal Prices: Computational Dynamic Markov Equilibria", *Journal of Economics and Management Strategy 17,* pp.345-377.

Peltzman, S. (2000) “Prices Rise Faster than They Fall”, *Journal of Political Economy* 108, pp.466-502.

Radchenko, S. (2005). “Anticipated and Unanticipated Effects of Crude Oil Prices and Gasoline Inventory Changes on Gasoline Prices.” University of North Carolina - Charlotte Working Paper.

Reilly, B. and Witt, R.. (1998) “Petrol Price Asymmetries Revisited” *Energy Economics* 20, pp.297-308.

Wang, Z. (2005). “Strategy, Timing and Oligopoly Pricing: Evidence from a Natural Experiment in Gasoline Markets”. Northeastern University Working Paper.

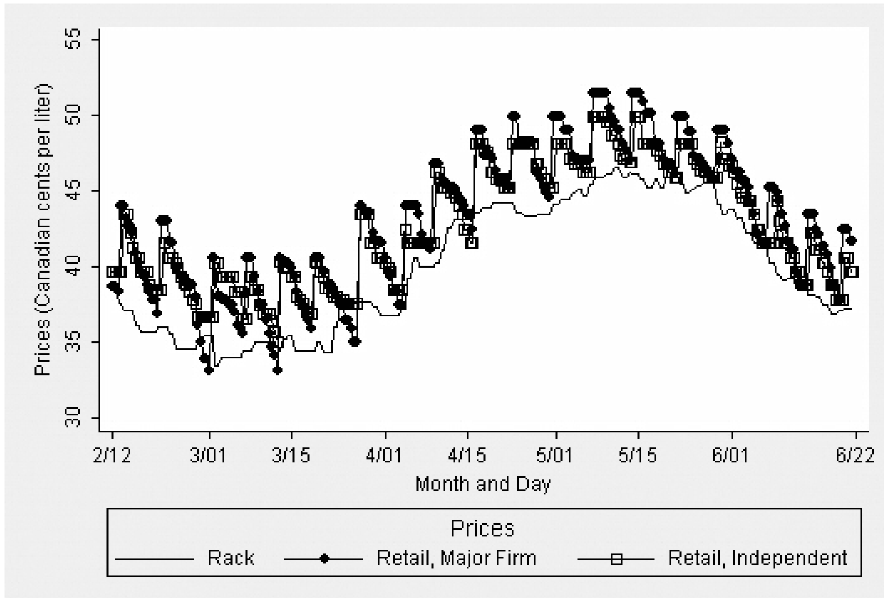

Figure 1: Retail Prices and Rack Price in Toronto, Jun. 2001 - Feb. 2001

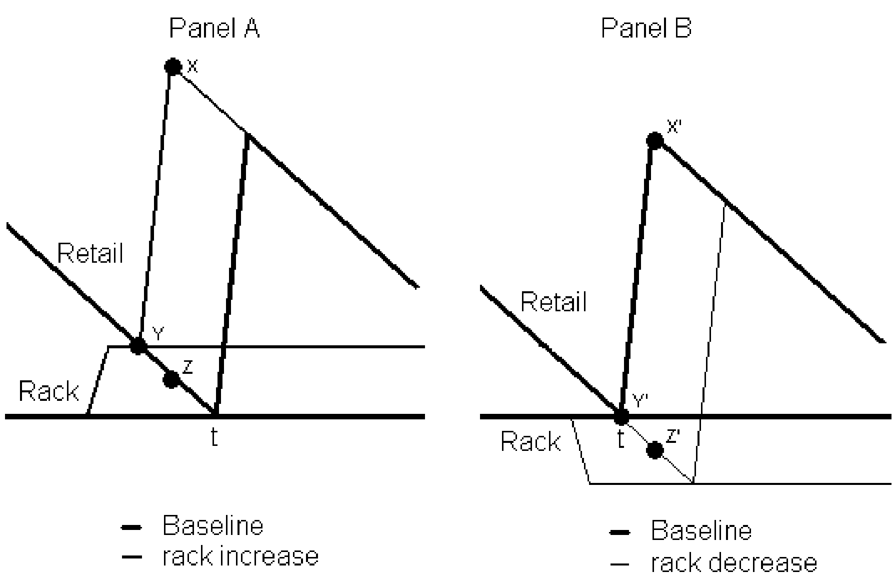

Figure 2: Decomposing Overall Asymmetric Passthrough

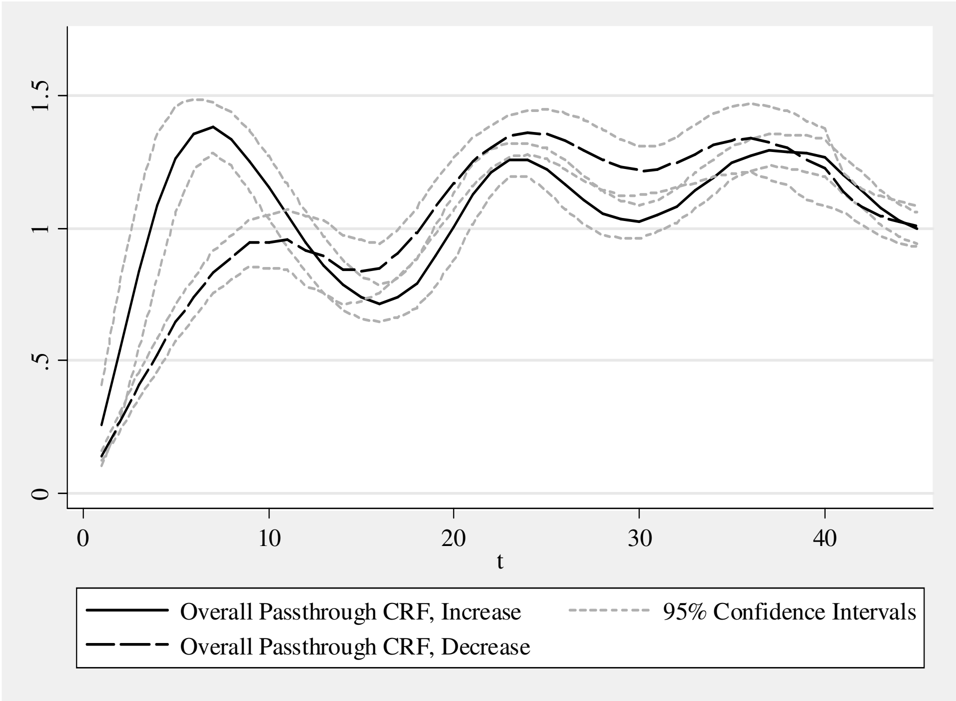

Figure 3: Overall Cumulative Response Functions

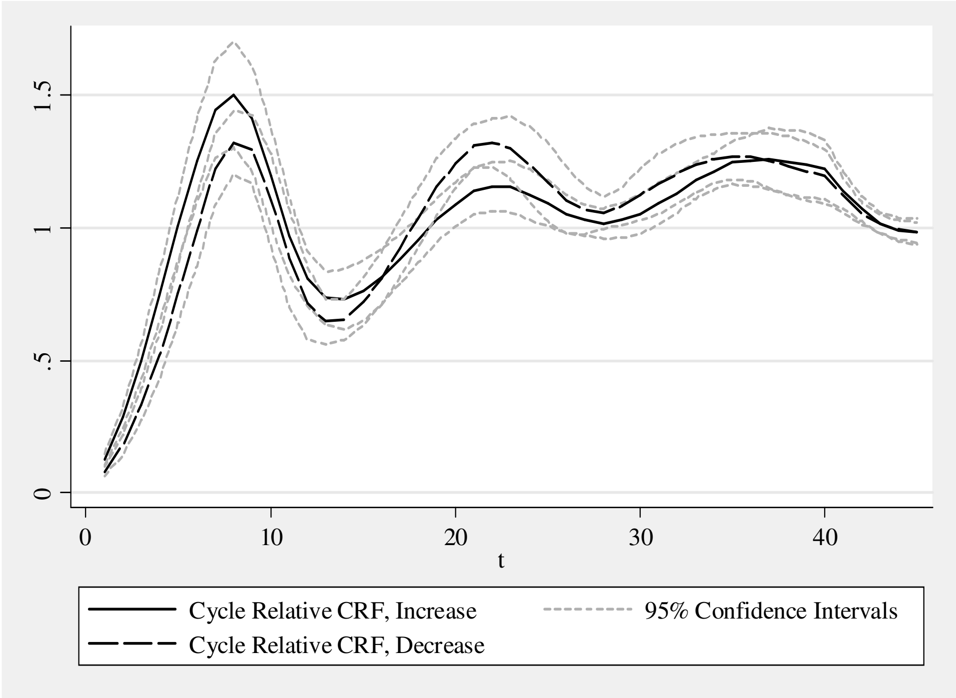

Figure 4: Cycle-Relative Cumulative Response Functions

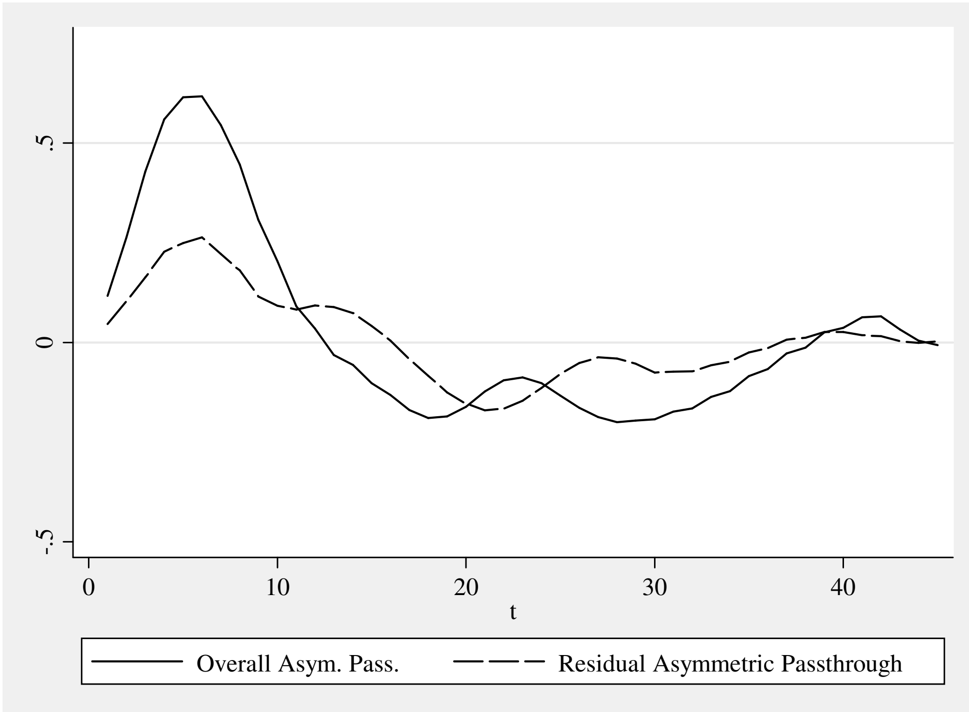

Figure 5: Overall and Residual Asymmetric Passthrough

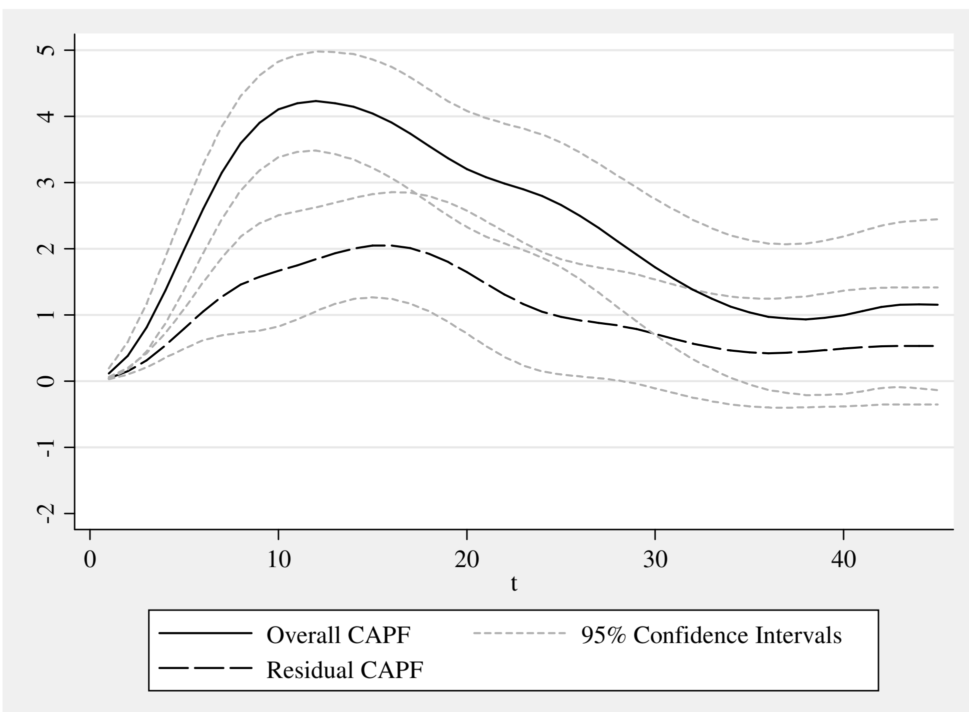

Figure 6: Cumulative Overall and Residual Asymmetric Passthrough

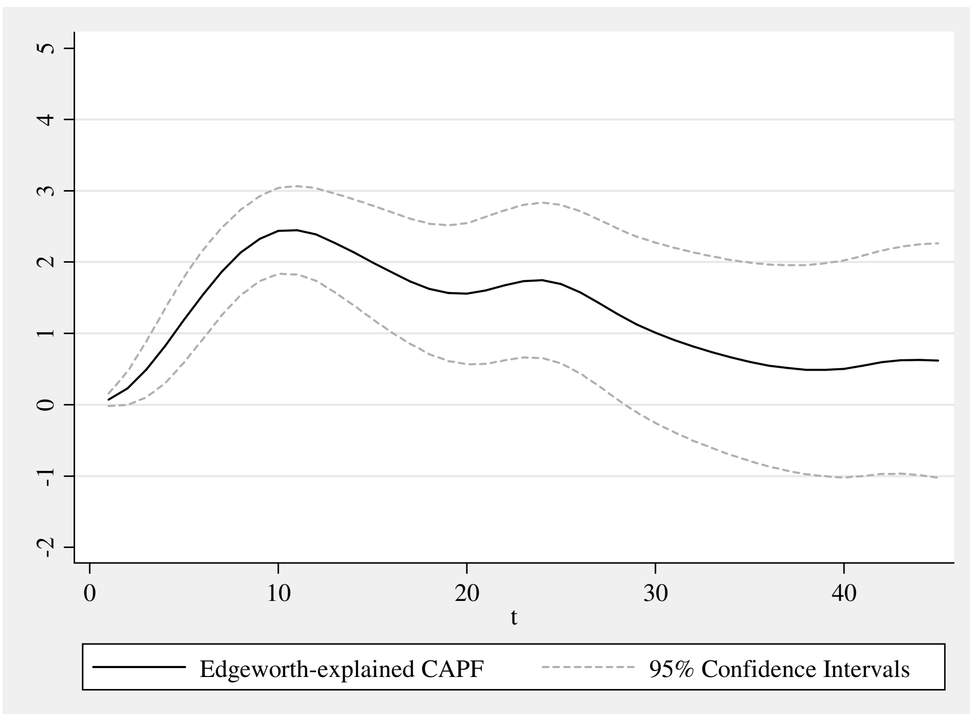

Figure 7: Cumulative Edgeworth-explained Asymmetric Passthrough

Table 1: Edgeworth Cycle Model - Lagged Rack Prices Excluded

Non-Zero Price Changes ($\Delta RETAIL_{st} = X_{st}^i\beta + \varepsilon_{st}^i$)

Specification:	(1)		(2)	
Regime $i =$	R	U	R	U
α^i (expected non-zero price change)	5.576	-0.751		
	(0.083)	(0.008)		
$RETAIL_{st-1}$			-0.887	-0.043
			(0.029)	(0.004)
$RACK_{st}$			0.820	0.052
			(0.028)	(0.005)
σ_i	1.650	0.459	0.729	0.419
	(0.066)	(0.009)	(0.057)	(0.008)

Zero Price Change Probabilities ($\gamma_{st}^i = \exp(V_{st}^i\zeta^i)/(1+\exp(V_{st}^i\zeta^i))$)

Specification:	(1)		(2)	
Regime $i =$	R	U	R	U
γ^i (prob. of zero price change)	0.000	0.429	0.000	
	(0.000)	(0.007)	(0.000)	
$RETAIL_{st-1}$				0.057
				(0.015)
$RACK_{st}$				-0.019
				(0.015)

Switching Probabilities ($\lambda_{st}^{iR} = \exp(W_{st}^i\theta^i)/(1+\exp(W_{st}^i\theta^i))$)

Specification:	(1)		(2)	
Regime $i =$	R	U	R	U
λ^{iR} (prob.of switching i $\rightarrow$ R)	0.008	0.078	0.008	
	(0.004)	(0.001)	(0.004)	
$RETAIL_{st-1}$				-0.749
				(0.036)
$RACK_{st}$				0.777
				(0.037)

α^i is the expected non-zero price change in regime i, σ_i is the standard deviation of ε^i, γ^i is the unconditional probability of a zero price change in regime i, and λ^{iR} is the unconditional probability of switching from regime i to regime R.