Nonlinear Real Exchange Rate Adjustments: Insights from iPad Price Data

E.E. Walker, G. du Rand, H. Hollander and D. van Lill

ERSA working paper 897

November 2024

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E. E. Walker[*], G. du Rand[†], H. Hollander[‡], and D. van lill[§]

November 15, 2024

Abstract

We investigate nonlinear real exchange rate (RER) dynamics using a high-frequency panel dataset of Apple iPad prices across global markets. Our findings challenge the conventional view of slow RER adjustment by demonstrating that larger mispricings are corrected much faster, while smaller deviations persist for longer periods. We identify a valuation threshold effect, where smaller deviations behave like unit root processes, while larger discrepancies are more quickly mean-reverting. Furthermore, the magnitude of these thresholds decrease as the evaluation time horizon increases. Transaction costs play a crucial role in shaping these dynamics, with higher costs associated with wider thresholds for arbitrage activity. Additionally, the results reveal asymmetry in RER adjustments, where undervaluations are corrected more rapidly than overvaluations. These findings provide new insights into the speed and nature of RER adjustments, suggesting that product-specific price data, such as that from iPads, can offer a more granular understanding of international price convergence.

JEL Codes: C22, C23, E31, F31, F41

Keywords: Nonlinear Real Exchange Rate Adjustments, Law of One Price (LOP), High-Frequency Data, Threshold Effects, Apple iPads

[*]Marble Rock Asset Management. Corresponding author: rickw@marblerock.co.za.
[†]South African Reserve Bank
[‡]University of Cape Town
[§]South African Reserve Bank

1 Introduction

The real exchange rate (RER) plays a critical role in understanding international price dynamics and is central to economic concepts like the law of one price (LOP) and purchasing power parity (PPP). According to the LOP, arbitrage should equalize the local and foreign prices of identical goods across countries once nominal exchange rates are factored in. However, despite its theoretical appeal, empirical studies have found persistent deviations from the LOP, suggesting that real exchange rates do not fully adjust in the manner predicted by theory.

Traditional research has focused on long-run RER adjustments, often relying on broad aggregate price indices to test the PPP hypothesis. However, this approach may obscure important product-specific dynamics and fail to capture the nonlinear nature of RER adjustments. In this paper, we focus on a homogeneous, globally traded good — Apple iPads — to explore how real exchange rates adjust in a nonlinear fashion. By employing a new high-frequency dataset and nonlinear econometric techniques, we uncover threshold effects and asymmetries in price adjustments, providing a more nuanced understanding of the factors driving RER deviations and their corrections.

Even if PPP holds in a weaker form allowing for certain frictions, RERs should theoretically be stationary. However, most research finds that RERs are highly persistent, with deviations from PPP lasting so long that statistical tests reject stationarity in many real exchange rates (Rogoff, 1996; Obstfeld and Rogoff, 2000; Vo and Vo, 2023). Rogoff (1996) and Obstfeld and Rogoff (2000) show that the half-lives of these deviations last between three and five years.

These long deviations from PPP have been called the *PPP puzzle* (Rogoff, 1996). Although obvious frictions like transport costs suggest that PPP should only hold in the long run, the extent of these measured frictions is insufficient to explain the estimated half-lives of deviations — unless arbitrage forces are unreasonably weak. Put differently, while PPP might only hold in the long run, the implied length of the "long run" does not seem reasonable, especially in a modern digital economy. For example, Vo and Vo (2023) find in a recent meta-analysis that arbitrage forces and resource allocation overcome many measurable frictions in far less time than studies like Rogoff (1996) and Obstfeld and Rogoff (2000) would suggest.

The empirical evaluation of the PPP hypothesis is further constrained by the appropriateness of the data used in empirical tests. Parsley and Wei (2007) provides strong evidence that most aggregate assessments of PPP are subject to severe data constraints that undermine the conclusiveness of their results. Specifically, Parsley and Wei (2007) identifies four main data-related issues that contribute to slow real exchange rate adjustments. First, aggregate price measures use dissimilar price baskets across countries, differing both in weights and in the goods compared. Second, there is a phenomenon known as *time aggregation bias*, which occurs when nominal prices or exchange rates are averaged over different collection times (Taylor, 2001). Third, broad price measures embed a *product aggregation bias*, resulting from varying adjustment speeds for dissimilar products, as well as differences in transaction costs (Imbs et al., 2005). Finally, nontradable goods, which PPP does not apply to, often represent a significant portion of these price baskets (Balassa, 1964; Samuelson, 1964).

Examining RER adjustments from an LOP perspective can better reveal underlying price and exchange rate dynamics, as highlighted by Vo and Vo (2023). To address these data-related issues, we construct two LOP datasets that comprise a highly tradable and homogeneous good: Apple iPads. By using iPads, we avoid many of the aggregation biases present in previous PPP studies. In addition to these data advantages, this paper addresses the issue of RER adjustments possibly occurring in a nonlinear fashion. Using nonlinear econometric techniques, we show that the speed of RER adjustment depends on the initial degree of mispricing. Larger deviations from LOP are less persistent and corrected faster than smaller deviations, suggesting a closer alignment between theoretical models and real-world price dynamics, particularly for electronic goods rather than broad price baskets.[1]

Some of the main findings of our analyses include the following. First, we find evidence of a valuation *threshold effect* for iPad-derived real exchange rate deviations. Clear asymmetric effects, arising from a 'band of no arbitrage,' are observed, where small deviations from parity are corrected more slowly than larger deviations. Second, the size of these valuation thresholds appears to decline over time. In other words, as the evaluation window increases, even smaller deviations are likely to be corrected due to diminishing information asymmetries and the increasing influence of arbitrage forces. Third, in considering the nonlinearity of RER adjustments, the time required to correct mispricings can be as short as a *few months*. This contrasts with previous findings, which generally estimate RER half-lives to range between three and five years (Rogoff, 1996; Vo and Vo, 2023). Fourth, there is a strong association between the estimated thresholds and the actual transaction costs related to iPad-derived RERs. Countries with higher transaction costs exhibit wider valuation thresholds, meaning more substantial RER deviations are required before arbitrage forces are triggered. Finally, we find that RER adjustments are not only nonlinear but also *asymmetric*. Specifically, undervaluations tend to correct faster than overvaluations, as upward price adjustments are less sticky and better support nominal exchange rate depreciations during RER corrections.

[1]For a detailed review of the LOP and PPP literature, refer to Officer (2012) and Vo and Vo (2023).

2 Dataset

There are several advantages to using a shorter time-frame, higher frequency database. For example, literature that uses very long time series to generate enough statistical power are unavailable for a large number of currencies, which may generate a *survivorship bias* in tests (Froot and Rogoff, 1996).[2] Long historical periods may also include different nominal exchange rate regimes (Taylor et al., 2001). Furthermore, studies using panel datasets to jointly test all of the country-specific time series raise the probability of *Type II* statistical errors.[3] This paper aims to circumvent these issues by utilising a higher frequency dataset of better suited products. This allows one to investigate both the panel dataset and the individual country time series to evaluate our findings. Due to data limitations, very few studies have been able to use the same dataset to focus on both the panel data aspect of the dataset as well as what the individual country time series could convey.

In order to investigate the nonlinearity of product-derived real exchange rates, logarithmic real exchange rates were compiled between 34 countries (i) and the United States (US) as the base country. That is $q_t^{i\text{US},x}$ values are derived from four different Apple iPad devices (x) on a weekly basis since the start of 2016 to end-2021 (i.e. using the *high frequency* dataset scraped from the internet.[4] On average, across all 35 countries and all four iPad varieties, the domestic prices of the devices changed fairly infrequently. More specifically, price changes were observed only about five times, on average, over the six-year period (i.e. price changes occurred slightly less than once per year). These averages however do not reflect the large dispersion between countries. For example, higher CPI inflation countries (e.g. Brazil, Mexico, Russia and Turkey) witnessed about twice the number of price changes compared to the other, lower inflation countries included in the dataset. In fact, the former four countries recorded almost eight price changes on average over the six-year period, compared to only about four price changes for the rest. Finally, price increases occurred more than twice as often as decreases, reinforcing the asymmetry in price adjustments.

Figures 1 (a) to (d) utilises box plots to show the distributions of these real exchange

[2]According to Froot and Rogoff (1996), a *survivorship bias* could potentially overstate the validity of PPP with studies utilising long term datasets. This bias arises because the available long-run PPP data primarily pertains to countries that have consistently been among the world's wealthiest nations. On the other hand, countries that experienced rapid growth from a low economic base (for example Japan) or those that were once prosperous but no longer are (for example Argentina) have not been extensively studied. However, these particular countries might offer significant insights as the relative prices of their nontraded goods are likely to have undergone substantial changes and this is where tests of long-run PPP are most prone to failure.

[3]The use of cross-sectionally augmented Dickey–Fuller (ADF) statistics and cross-sectionally augmented versions of the t-bar test have however been proposed by Pesaran (2007) to overcome this.

[4]The four Apple iPad devices used are: iPad Pros (Large Screen), iPad Pros (Small Screen), iPad Airs and iPad minis.

rates for each country as compiled from the four different products. The average real exchange rate for each device over all the different countries and time periods t are illustrated as dotted vertical blue lines. Interestingly, all these mean product real exchange rates (i.e. average over country and time or $\bar{q}^x$s) for the different iPads are approximately 0.2. This signifies that the different devices cost, on average, 20% more in non-US countries. Meanwhile, the averages for the individual countries (i.e. $\bar{q}^{i\text{US},x}$) are shown as white dots which are located inside each of the grey boxes in the different subplots. The boxes represent the inter-quartile range of real exchange rates observed for each country, while the vertical lines located inside each box represents the country median for each iPad.

From the box plots in Figure 1, it becomes clear that there are frequent departures from the absolute LOP. What's more, the majority of $q_t^{i\text{US},x}$s fluctuate substantially around their respective means. The vast majority of these country means are also notably larger than zero. The exceptions appear to be Canada, Hong Kong, Japan and to some extent, Malaysia. Meanwhile, the Brazilian real exchange rate is the most overvalued versus the greenback over the sample period. Also noteworthy is the persistence and consistency of these biases across the different devices.

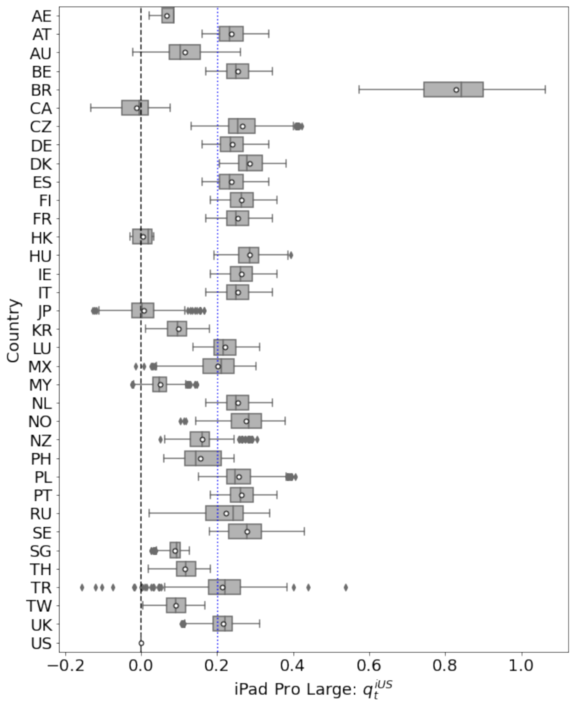
t-value tests were conducted to investigate whether the means of the real exchange rates calculated for different countries for the four products are equal to zero at a 95% confidence level. It was found that for both iPad Pro Large and Small screen devices 30 out of the 34 countries had significant t-values for the country means, while for iPad Air and iPad Minis these averages were significant in 27 and 28 cases respectively out of 34 countries. Similar to the finding of Clements et al. (2012), when evaluating the real exchange rates derived from Big Macs, the real exchange rates obtained from iPad devices appear to be biased indicators of absolute currency values. As with the analyses performed in the literature, we can control for this bias by subtracting the sample means for each country. That is, the bias-adjusted real exchange rate can be calculated by obtaining:

$$\tilde{q}_t^{i\text{US},x} = q_t^{i\text{US},x} - \bar{q}^{i\text{US},x} \ , \tag{1}$$

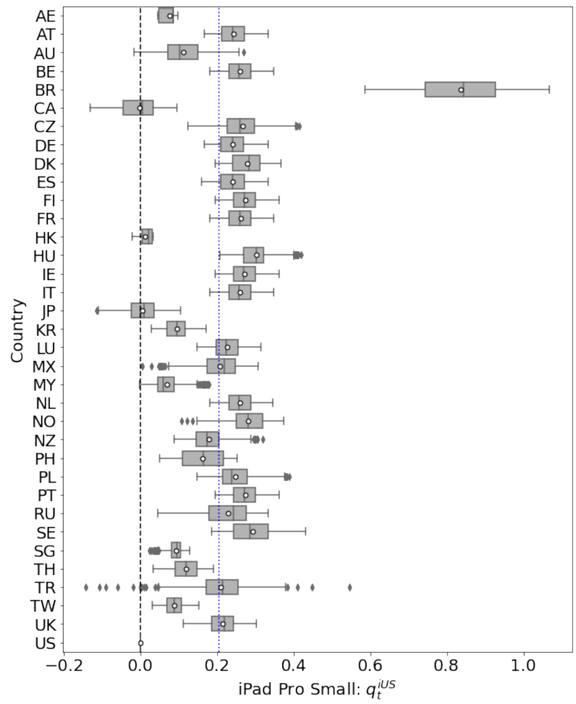
where $\bar{q}^{i\text{US},x} = 1/t \sum_t q_t^{i\text{US},x}$ is the sample (country) mean. From this, the currency is over- (or undervalued) if $\tilde{q}_t^{i\text{US},x} > 0$ ($\tilde{q}_t^{i\text{US},x} < 0$).

3 Real Exchange Rate Convergence and Half-Lives

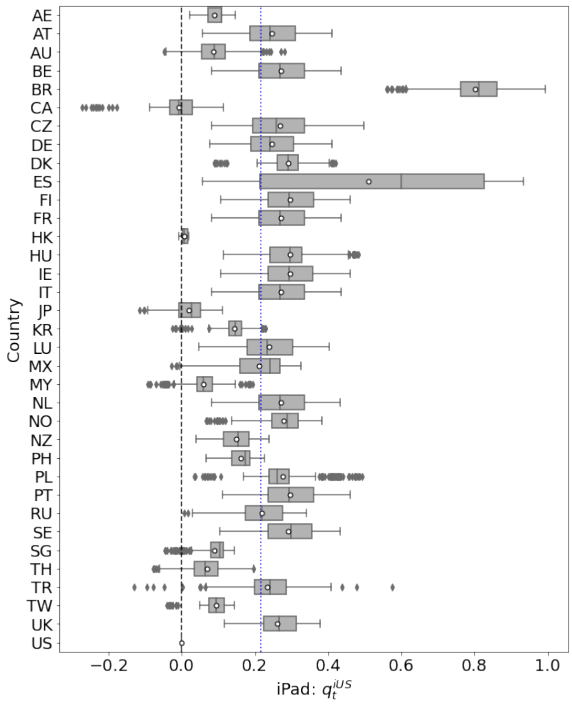
In this section we'll evaluate both the persistence and nonlinearity of real exchange rate deviations as derived from the four iPad products. This is similar to the analyses conducted by Parsley and Wei (2007) on Big Mac hamburgers. We'll first introduce the linear model to evaluate convergence and then expand this to nonlinear techniques. According to Rogoff (1996) and Obstfeld and Rogoff (2000), the PPP literature generally indicates



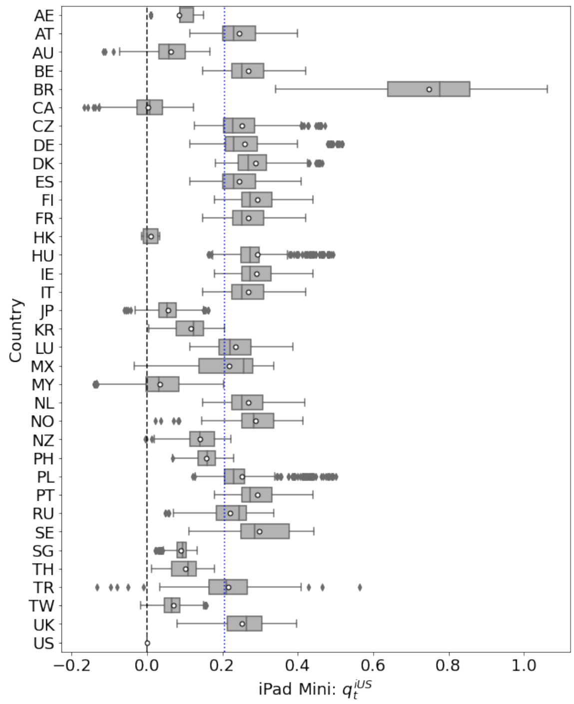
(a) iPad Pro Large Screen



(b) iPad Pro Small Screen



(c) iPad



(d) iPad Mini

Figure 1: Box Plots of Real Exchange Rates by Country

Notes: Box plots of real exchange rates for iPad models across 35 countries (2016-2021), showing notable deviations from the Law of One Price. For the majority of countries, there is also a persistent bias.

a half-life speed of around three- to five years. To calculate the speed of convergence, one estimates $\hat{\rho}_d^{i\mathrm{US},x}$ in Equation 2 in the following AR(1) process:

$$\Delta^{(d)}\tilde{q}_t^{i\mathrm{US},x} = \rho_d^{i\mathrm{US},x}\tilde{q}_{t-d}^{i\mathrm{US},x} + \epsilon_t^{i\mathrm{US},x} \ , \tag{2}$$

Where $\Delta^{(d)}\tilde{q}_t^{i\mathrm{US},x} = \tilde{q}_t^{i\mathrm{US},x} - \tilde{q}_{t-d}^{i\mathrm{US},x}$ and $\tilde{q}_t^{i\mathrm{US},x}$ is the bias-adjusted real exchange rate. One can evaluate the persistence of real exchange rate deviations by analysing how any *initial* real exchange rate deviation (for example at time $t-d$) *subsequently* adjusts over period d. The respective price ratios' half-lives (in years) can then be derived by calculating: $(d/52)\log(0.5)/\log(1+\hat{\rho}_d^{i\mathrm{US},x})$. Since the difference periods are in weeks, the half-lives need to be adjusted by a factor of $d/52$ in order to convert to years. As is evident from this formula, the closer $\hat{\rho}_d^{i\mathrm{US},x}$ gets to -1, the shorter the estimated period half-life will be. Meanwhile, should $\hat{\rho}_d^{i\mathrm{US},x}$ found to be closer to zero, the real exchange rate will appear to follow a random walk since the equation above will approximate $\Delta^{(d)}\tilde{q}_t^{i\mathrm{US},x} = \epsilon_t^{i\mathrm{US},x}$. This model however enforces a hypothesis that real exchange rate adjustments are both continuous and of constant speed, irrespective of the size of the deviation from the LOP (Taylor et al., 2001).

4 The Nonlinearity of Real Exchange Rate Adjustments

According to Taylor et al. (2001), the notion that real exchange rate adjustments may occur in a nonlinear fashion dates back at least to Heckscher (1916) and Cassel (1918).[5] A few publications since that have investigated the nonlinearity of real exchange rates include: Obstfeld and Taylor (1997), Taylor et al. (2001), Chortareas et al. (2002), O'Connell and Wei (2002), Sarno et al. (2004), Cushman and Michael (2011), Chen et al. (2019) and Drissi and Boukhatem (2020). The literature expanded to focus on the nonlinearity of real exchange rate adjustments because only using single parameter estimates incorrectly combines different regimes. For example, a single adjustment coefficient does not distinguish between the low speed of convergence for deviations smaller than the arbitrage costs as well as faster convergence for larger deviations (Parsley and Wei, 2007, p. 1346). In other words, simply using linear estimates result in upwardly biased half-lives.

The real exchange rate, when within a certain (limited) distance from parity, may appear to follow a random walk. In other words, the real exchange rate may not display any convergence tendencies and only becomes mean-reverting once a specific 'threshold' is breached that gives rise to the marginal benefit of arbitrage exceeding the marginal cost thereof. Once this threshold level is crossed, the real exchange rate's gravitational pull

[5]Heckscher (1916) argued that transport costs may see price discrepancies arising without precipitating goods arbitrage.

toward parity may become increasingly strong as the distance from parity increase. This paper employs a variety of techniques to investigate the possibility that real exchange rate adjustments behave in a nonlinear fashion. These includes: 1) locally-weighted scatter-plot smoothing (LOWESS), 2) threshold regressions (TARs) and 3) piecewise regression models.

4.1 Panel and Country Unit Root and Co-integration Tests

Numerous panel statistic as well as individual country time series unit root tests were performed to test the iPad-derived real exchange rates (i.e. $q_t^{i\mathrm{US},x}$s). Contrary to the large number of studies investigating real exchange rate unit root behaviour, we were in most cases able to reject the unit root null hypothesis at conventional significance levels. In fact, the null hypothesis that each of the four iPad-derived real exchange rate panels contained a unit root were rejected at a 90% confidence level when utilising various panel unit root tests. These included the Levin-Lin-Chu, Harris-Tzavalis, Breitung, Im-Pesaran-Shin and Fischer-type (which includes the Augmented Dickey-Fuller and Phillips-Peron) tests. At a 95% confidence level we could reject 23 out of the 24 null hypotheses (i.e. six statistical tests across four product panels) that the data contains a unit root. We could not however reject the Hadri LM stationarity tests that *all* panels are stationary for the individual country $q_t^{i\mathrm{US},x}$s. The same panel autocorrelation tests were also performed on the real exchange rate *changes* for a subset of deltas (i.e $\Delta^{(d)}q_t^{i\mathrm{US},x}$ for $d = 12, 24, 36, 48$). However, as the time difference d increased, fewer null hypotheses of 'no panel unit root' could be rejected. Specifically for $d = 12$, we were able to reject all 24 hypotheses tests of no unit root at a 90% confidence level. Meanwhile, when d increased to 24, only 21 out of 24 hypotheses were rejected, with $d = 36$ this figure declined to 20 rejections. For $d = 48$ only about half of the panels were found not to contain a unit root.

We also performed ADF unit root tests on all the individual country real exchange rate time series.[6] At a 10% significance level, we could only reject 51 out of the 136 hypotheses tests (we tested a number of time series based on four devices across 34 countries) that these individual time series *did not* contain unit roots. My analyses however primarily involved investigating the *change* in real exchange rates. Consequently, we also performed the ADF tests on the $\Delta^{(d)}q_t^{i\mathrm{US},x}$s for each country over $d = 1, 2, ..., 52$. The finding was similar to that of Taylor et al. (2001), the use of differences on the real exchange rate time series appear to induce stationarity. The results of these hypotheses tests are plotted in Figure 2. Each line plot represents the number of null hypotheses that were rejected (out of a total number of 136) that each country real exchange rate change, at a specific d (i.e. $\Delta^{(d)}q_t^{i\mathrm{US},x}$), contained a unit root. For small period changes, for example $d < 30$), most of the hypotheses were generally rejected at a 90% confidence level that

[6] These tests were performed in Python using Seabold and Perktold (2010). The p-values were obtained through regression surface approximation from MacKinnon (1994), but using the updated 2010 tables.

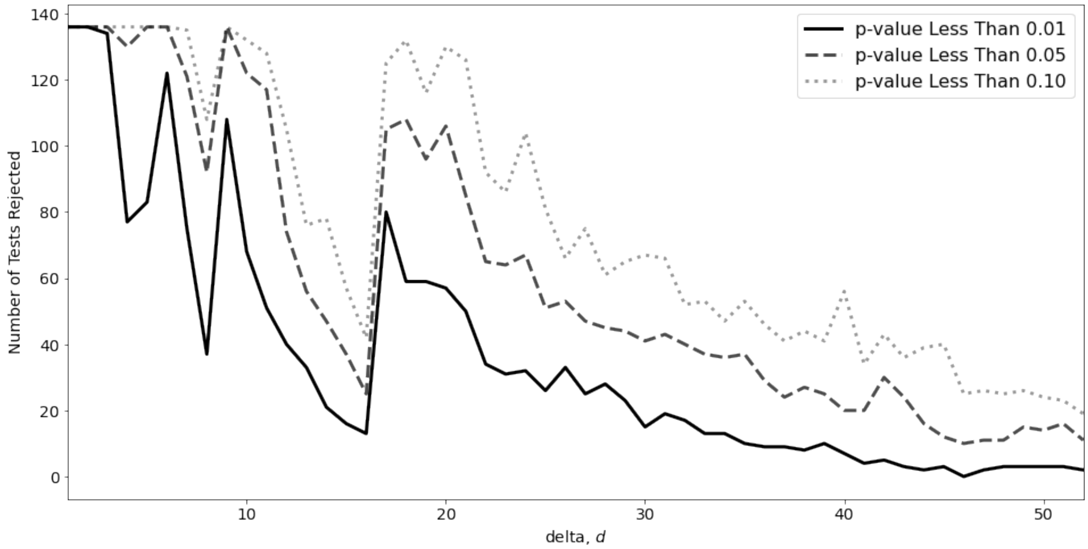


Figure 2: Number of Augmented Dickey Fuller Unit Root Tests Rejected

Notes: Number out of 136 country time series, over various significance levels calculated on $\Delta^{(d)} q_t^{i\mathrm{US},x}$s over deltas ($d$).

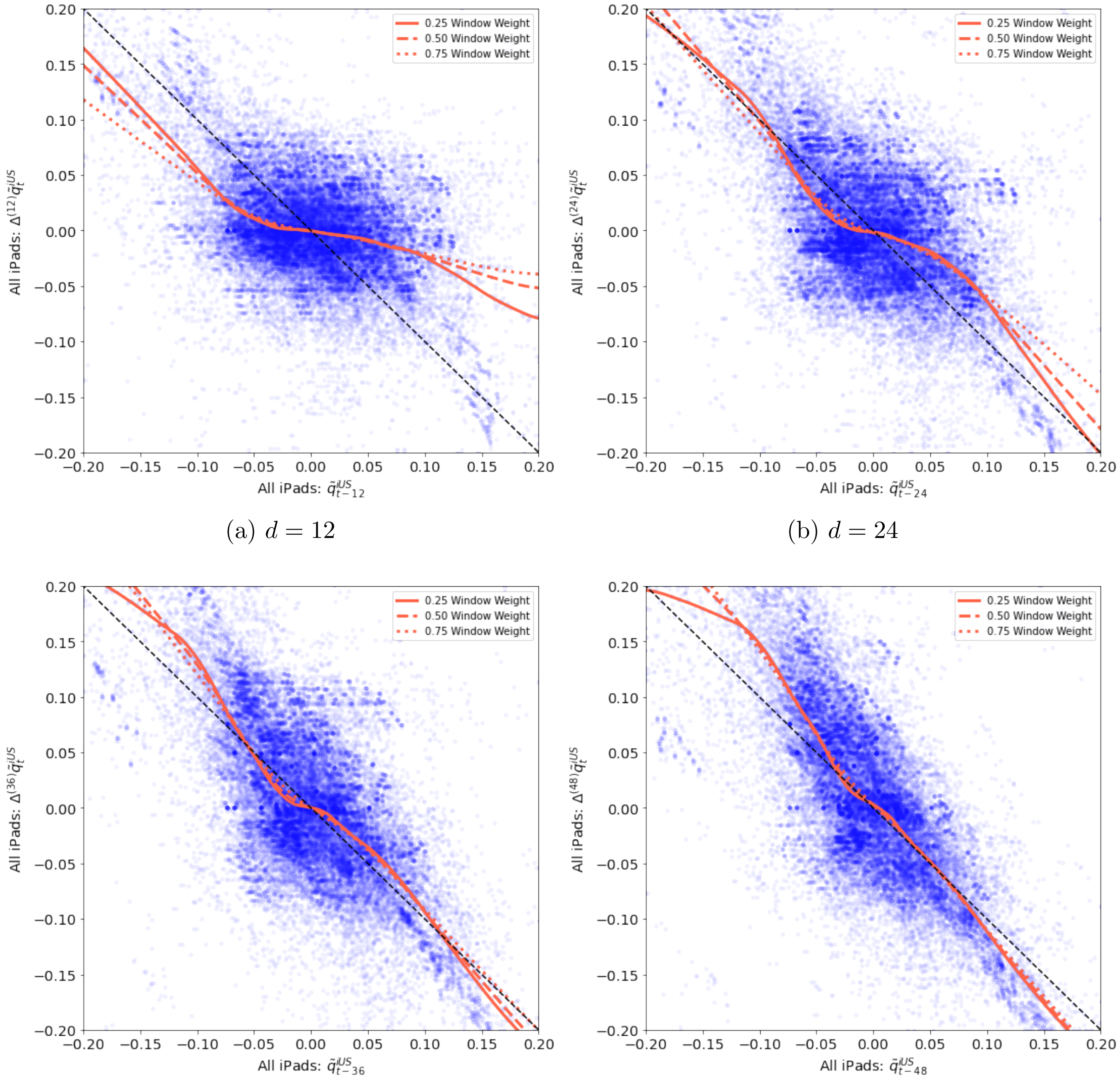
the individual country real exchange rate changes contained unit roots. Most time series however contained unit roots at larger deltas. One should therefore keep in mind that the estimates in my analyses at larger ds may be less efficient. That said, Taylor et al. (2001) demonstrated via Monte Carlo simulations that standard univariate unit root tests have very low power to reject a false null hypothesis of unit root behaviour when the true model is nonlinearly mean reverting.

4.2 Locally-Weighted Scatterplot Smoothing

The first method used to investigate the nonlinearity of real exchange rate adjustments is locally-weighted scatter-plot smoothing (LOWESS or LOESS). This is a non parametric regression method that smooths data by slicing it into smaller sections. More specifically, the technique attempts to fit linear models for datapoints based on local, or nearby, linear fits.[7] The Figures in 3 (a) to (d) illustrates the LOWESS scatter-plot fit for the sample mean adjusted lagged real exchange rates derived from all the iPad devices (i.e. $\tilde{q}_{t-d}^{i\mathrm{US},x}$ $\forall$ x) on the x-axis versus the subsequent d period change in the real exchange rates (i.e. $\Delta^{(d)} \tilde{q}_t^{i\mathrm{US},x}$ for $d = 12, 24, 36, 48$) on the y-axis. Figures A3 to A6 shows the LOWESS plots for the four individual iPad models. The various datapoints are semi-transparent in order to avoid excessive overlapping of observations. This also helps distinguish the distribution of the data. The analyses incorporated different proportional window weights for each

[7] The LOWESS estimations were performed using Python with the statsmodels package by Seabold and Perktold (2010) and the Figures are rendered using Matplotlib by Hunter (2007).

estimation, including 0.25, 0.5 and 0.75 which are represented by the solid, dashed and dotted lines respectively. A 45°-line is also included in each scatter-plot as a reference if the subsequent real exchange rate adjustments occur proportionally to each initial real exchange rate deviations. To make the charts more directly comparable, both the x- and y-axes are cut off at -0.2 and 0.2 respectively.



(a) $d = 12$

(b) $d = 24$

(c) $d = 36$

(d) $d = 48$

Figure 3: LOWESS Scatterplots

Notes: All iPad Derived Lagged Real Exchange Rates vs Subsequent Change in Real Exchange Rates Over Different Horizons (d). Shorter time horizons have more prominent valuation thresholds.

Several interesting patterns emerge from LOWESS analyses. First, as the delta, d, increases, the datapoints appear to converge to the 45°-line. This means that as the window length is increased, the initial deviations are a better indicator of the subsequent real exchange rate adjustment we can expect. Second, there appears to be a valuation 'threshold effect' for real exchange rate deviations. That is, when the valuation deviations are small (i.e. 'close' to zero on the x axis), the subsequent adjustment to eliminate these deviations are basically insignificant. This effect is more prominent over smaller difference periods d. This is evident by the flatter 'inner' slope of the LOWESS estimates around zero. In other words, the mean reverting nature of real exchange rates are noticeably *less* when the associated valuation discrepancy is also *small*. This again supports the notion of stochastic law of one price. Third, after about 12- to 24-weeks, it appears as though the outer deviations (or 'valuation wings') have converged to the 45°-line (i.e. the deviations and subsequent corrections are equivalent).

Meanwhile, inside the 'thresholds', the regression slope has now become slightly negative. This again supports the finding that real exchange rate half-lives are significantly shorter than the literature's three- to five-years; at least when valuation discrepancies are large enough. Meanwhile, when the valuation discrepancies are small, real exchange rate adjustments can take a longer and may even appear to follow a random walk. Fourth, the valuation thresholds or 'area of no arbitrage' appears to decrease as the delta increases. Finally, it also appears as though negative real exchange rate deviations are more inclined to subsequently 'overshoot' than do positive real exchange rate deviations (the LOWESS regressions line for $d > 30$ is parallel to, but *above* the 45°-line).

In summary, it appears that smaller real exchange rate deviations over shorter time differences d can take notably longer to dissipate, while large deviations tend to disappear even over short periods, but even more so as these differences increase. Even though the LOWESS analyses is visually and intuitively appealing, they are not directly interpretable. In other words, one still cannot exactly pinpoint the exact values of these potential valuation thresholds nor the slope of the inner or outer adjustment parameter estimates. In the remaining sections other statistical techniques are employed to derive estimations for these.

4.3 Threshold Regression Models

A threshold regression is an extension of the linear model by allowing estimates to vary across regions. These 'regions' are identified by threshold variable(s) separating the areas.[8] These models are superior at potentially capturing breaks, asymmetries or change points observed in many macroeconomic time series. What's more, one can either specify a known number of thresholds or allow a measure like the Bayesian information criterion (BIC) being minimised to specify the quantity of these breaks. These methods have more recently become popular in order to model the potential nonlinear behaviour of real

[8]The Threshold Autoregression (TAR) was initially proposed by Tong (1980). Also refer to Tong (2012). For a survey of threshold regression models in economics, refer to Hansen (2011).

exchange rates (Obstfeld and Taylor, 1997; O'Connell, 1998; Baum et al., 2001; Taylor, 2001; O'Connell and Wei, 2002; Sarno et al., 2004; Smallwood, 2008; Chen et al., 2019; Vo and Vo, 2023).[9] Formally, we can consider a threshold regression in a similar fashion to the way we evaluated the nonlinearity of real exchange rates via the LOWESS method in Section 4.2. Specifically, the subsequent d-period change in the real exchange rate derived from product x between countries i and j can be formulated by equations in two regions split by the threshold parameter $c_d^{ij,x}$. Mathematically this can be represented as:

$$\Delta^{(d)}\tilde{q}_t^{ij,x} = \begin{cases} \rho_{1,d}^{ij,x}(|\tilde{q}_{t-d}^{ij,x}| - c_d^{ij,x}) + \epsilon_t^{ij,x}\Phi[|\tilde{q}_{t-d}^{ij,x}| > c_d^{ij,x}] \\ \rho_{0,d}^{ij,x}|\tilde{q}_{t-d}^{ij,x}| + \epsilon_t^{ij,x}\Phi[|\tilde{q}_{t-d}^{ij,x}| \leq c_d^{ij,x}] \end{cases} \tag{3}$$

The lagged explanatory variables (in this case lagged real exchange rate) have different parameters depending on the region applicable to the equation. The $\Phi[.]$ represents an indicator function whether or not the equation applicable is within the threshold (i.e. $\leq c_d^{ij,x}$) or outside of it (i.e. $> c_d^{ij,x}$). After specifying the equation, a grid search was performed to find both the potential thresholds as well as the applicable parameter estimates.

4.3.1 Panel Threshold Regressions

The output of the fixed effect panel threshold regressions are shown in Table 1.[10] Again, the United States (US) was used as the base country $j =$ US. From this analysis, several points of interest emerge. First, a 'threshold effect' again appears to emerge for the real exchange rate adjustments. The thresholds also tend to vary by device and difference period (or delta, d). For example, the average threshold across the four devices when $d = 12$ is 11.5%, while only 6% when $d = 24$. Overall, for three of the devices it appears as though the thresholds $c_d^{i\text{US},x}$ tend to decline (at least initially) as d increase. This makes sense since there most likely exist various lags and information asymmetries before arbitrage forces can kick in, which implies as more time passes, the likelier even smaller deviations will be eliminated.

Second, especially over smaller difference periods (ds), the inner adjustment estimates (i.e. $\hat{\rho_0}$) are only about one third of the outer regressive parameters (i.e. $\hat{\rho_1}$). Accordingly, the derived half-lives of the inner estimates also tend to be notably longer than in

[9]Other nonlinear techniques to evaluate RER adjustments that are also explored by some of these papers include Smooth Transition Autoregressive (STAR), Exponential STAR (ESTAR) and logistic STAR (LSTAR) models. These allow for smooth transitions between regimes. An alternative suggestion to these approaches has been to use nonlinear Vector Error Correcting (VEC) models and threshold co-integration analyses. Overall, the literature mentioned generally appears to be in agreement that RERs adjust in a nonlinear fashion. We have not discovered any papers evaluating the nonlinearity of product-derived RERs.

[10]The panel Threshold regressions were performed by using Stata's fixed effect panel model 'xthreg' and are based on the method proposed by Hansen (1999) (Wang, 2015).

the outer regimes. Again, faster adjustments for larger deviations are supportive of the stochastic LOP theory. Third, as the time difference (d) increase, *both* the inner and outer adjustment parameters tend to decline, or equivalently, the half-lives tend to decrease. When the difference window reaches 36 weeks, the half-lives of the outer parameters for three of the four Apple devices are approximately zero. This implies that larger deviations are eliminated within 36 weeks. At the same delta, the half-lives inside the thresholds (deviations that are on average less than 9.6% across all the devices) still record half-lives close to six months on average. Fourth, the panel TAR models' fit appear to improve as the time difference increase. These findings also support the observations from the LOWESS analyses.

Finally, the half-lives in both the inner and outer thresholds are significantly shorter than the literature's finding of 'three to five years'.[11] In fact, even over shorter deltas (or time differences), the half-lives derived for the outer thresholds are merely between 0.16 to 0.26 years. Also, by using a higher frequency database one can delve into notably more detail regarding real exchange rate adjustments and perform more analyses without losing too much degrees of freedom on the dataset. More detail is provided by also evaluating some of the findings emerging from the evaluation of individual countries.

4.3.2 Individual Country Threshold Regressions

Threshold regressions were performed on all the *individual* countries over different deltas. The results of these regressions are summarised (that is, the mean and median of the parameters of the various countries) in Table 2.[12] For these regressions, the Bayesian Information Criterion (BIC) was used to determine whether a threshold exists, and if an optimal threshold was found, it is reported in the table under the c_i parameter. For the vast majority of countries and deltas, thresholds appear to exist for real exchange rate adjustments.

Figure 4 illustrates, via the use of box plots, the ranges of the derived thresholds for the various devices over different deltas. It appears that the thresholds can actually vary notably for the different countries and devices. For example, for both iPod Pro Large Screen and Small screen devices the thresholds average around 5% when $d = 12$ and declines to around 4% when d reaches 48. For these devices, the inter-quartile ranges of these $\hat{c}_d^{i\mathrm{US},x}$s over the different countries are fairly small; i.e. approximately two to three percentage points. Meanwhile, the average threshold levels for the two cheaper variants, the iPads and iPad minis, are found to be notably larger and more varied. For example, for these two devices the estimated thresholds are 9.5% and 7.4% respectively when $d = 12$

[11] Refer to Rogoff (1996) for a meta study on adjustment speeds and half-lives captured by the literature. One of the findings was that the speed of convergence to PPP is extremely slow, with deviations appearing to damp out at a rate of only 15% per year, consistent with half-lives of three to five years.

[12] All individual country and product regressions are recorded in Appendix B Tables B1 to B16.

Table 1: Panel Threshold Regression Persistence Estimates

	Panel Threshold Regressions Over Different Devices and Deltas						
Product	Delta d	Inner $\hat{\rho}_0$	Outer $\hat{\rho}_1$	Threshold c_i	Half-life $\hat{\rho}_0$	Half-life $\hat{\rho}_1$	Overall R^2
iPad Pro L	12	-0.33 (0.01)***	-0.64 (0.02)***	0.12	0.40	0.16	0.22
iPad Pro S	12	-0.32 (0.01)***	-0.58 (0.02)***	0.12	0.41	0.18	0.20
iPad	12	-0.17 (0.01)***	-0.46 (0.01)***	0.10	0.84	0.26	0.26
iPad Mini	12	-0.19 (0.01)***	-0.48 (0.01)***	0.11	0.78	0.24	0.20
Average	12	-0.25 (0.01)	-0.54 (0.01)	0.12	0.61	0.21	0.22
iPad Pro L	24	-0.40 (0.02)***	-0.77 (0.01)***	0.05	0.63	0.22	0.37
iPad Pro S	24	-0.43 (0.02)***	-0.74 (0.01)***	0.05	0.56	0.24	0.35
iPad	24	-0.17 (0.02)***	-0.66 (0.01)***	0.07	1.74	0.30	0.37
iPad Mini	24	-0.29 (0.02)***	-0.75 (0.01)***	0.08	0.94	0.23	0.34
Average	24	-0.32 (0.02)	-0.73 (0.01)	0.06	0.97	0.25	0.36
iPad Pro L	36	-0.73 (0.02)***	-1.06 (0.01)***	0.05	0.36	0.00	0.51
iPad Pro S	36	-0.69 (0.03)***	-1.02 (0.01)***	0.04	0.42	0.00	0.49
iPad	36	-0.84 (0.01)***	-0.56 (0.02)***	0.22	0.26	0.59	0.43
iPad Mini	36	-0.49 (0.02)***	-1.00 (0.01)***	0.08	0.72	0.06	0.46
Average	36	-0.69 (0.02)	-0.91 (0.01)	0.10	0.44	0.16	0.47
iPad Pro L	48	-0.76 (0.04)***	-1.18 (0.01)***	0.03	0.44	0.00	0.58
iPad Pro S	48	-1.23 (0.01)***	-1.04 (0.02)***	0.09	0.00	0.00	0.59
iPad	48	-1.10 (0.01)***	-0.54 (0.01)***	0.17	0.00	0.83	0.52
iPad Mini	48	-1.16 (0.01)***	-0.78 (0.02)***	0.17	0.00	0.42	0.56
Average	48	-1.06 (0.02)	-0.89 (0.02)	0.11	0.11	0.31	0.56

Note: Standard Errors in Parenthesis $^{*}p<0.10$; $^{**}p<0.05$; $^{***}p<0.01$

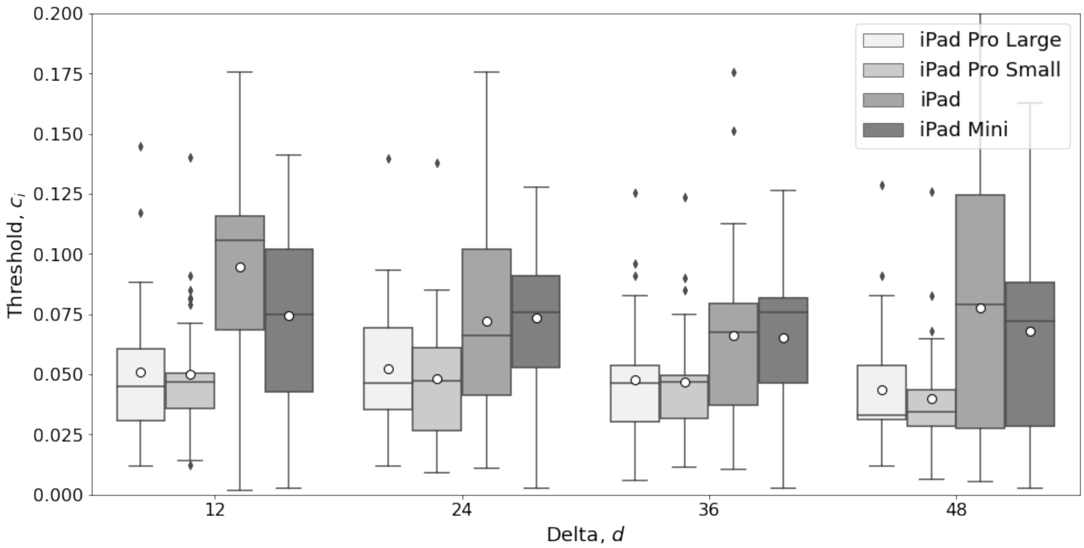


Figure 4: Box Plots of Country Thresholds

Notes: Country Thresholds $c_d^{i\text{US}}$ from TAR Estimates for the Different Devices over Various Deltas (d).

while only declining to 7.8% and 6.8% each when the time difference reaches almost one year (or more precisely 48 weeks). It does however make sense that the thresholds for the cheaper devices should be larger.[13] If several of the transaction costs (for example transportation, etc) are fixed — and assuming they do not vary notably between these different variants — then larger real exchange rate deviations are consequently required on lower priced goods before these fixed costs are offset enough for the arbitraging forces to kick in. Also, since there are various lags and rigidities inhibiting arbitrage, it also seems appropriate that the thresholds tend to decline as d increase. In other words, given the same initial deviation, when evaluated over a longer timeframe d, is more likely to be eliminated.

Next, Figure 5 employs violin plots to show the distributions for the 'inner' $\hat{\rho}_0$ and 'outer' $\hat{\rho}_1$ estimates. Again, as was found with the panel threshold regressions, the $\hat{\rho}_1$s are notably *smaller* than the $\hat{\rho}_0$s. This again implies *shorter* half-lives when the initial deviations exceed the various thresholds $c_d^{i\text{US}}$. The threshold effect also again tends to decrease as d increases (i.e. both the inner and outer parameter estimates converge, at least to some extent, as the time difference lengthens). What's more, the outer coefficients are fairly stable (i.e. narrowly distributed) across the different countries and time differences, especially compared to the $\hat{\rho}_0$s which appear notably more volatile and have a wider distribution across the different deltas. Also noteworthy is that one observes non-mean reverting real exchange rates (i.e. $\hat{\rho}_0$s that are larger or equal to zero) only for the inner parameter estimates. In other words, in several cases when the real exchange

[13]Note that the iPads and iPad Minis tend to cost less than half of the iPad Pro devices.

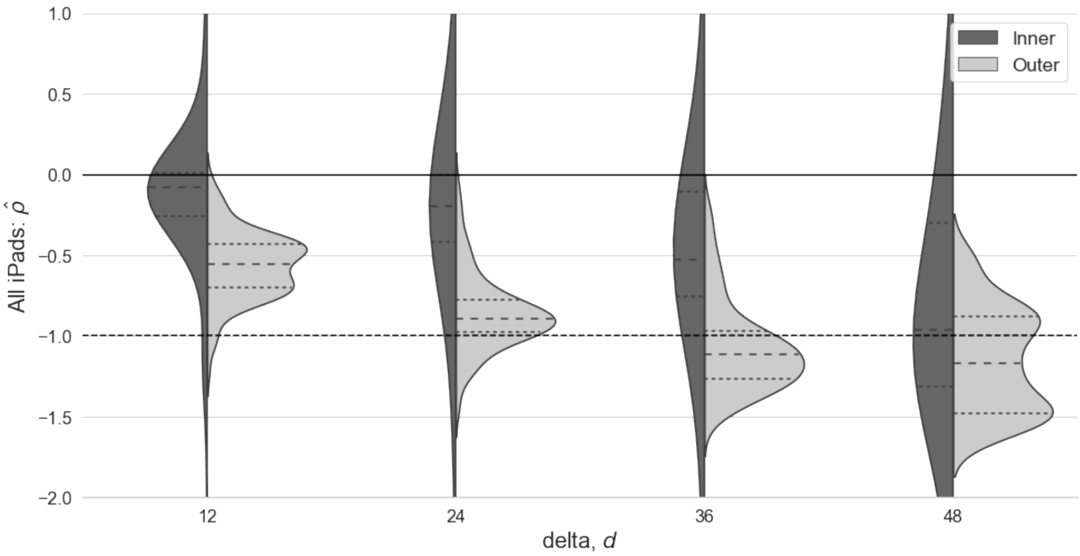


Figure 5: Violin Plots of Inner Adjustment Parameters

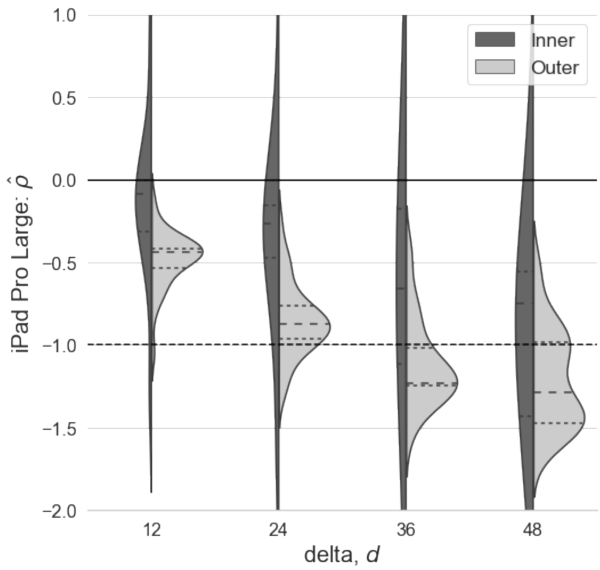
Notes: Adjustment Parameters $\hat{\rho}_0$ and Outer $\hat{\rho}_1$ TAR Estimates for all Devices over Various Deltas (d).

rate deviations are small, they do not mean revert but sometimes appear to follow a random walk. In these cases, the half-lives are infinite. In the other cases, pertaining to the inner threshold, they do mean revert, but at noticeably slower speeds than in the outer threshold regions. Meanwhile, in the outer thresholds, the real exchange rates are almost always mean reverting. Also, real exchange rate adjustment speeds in the outer thresholds are generally significantly quicker and the half-lives are shorter.

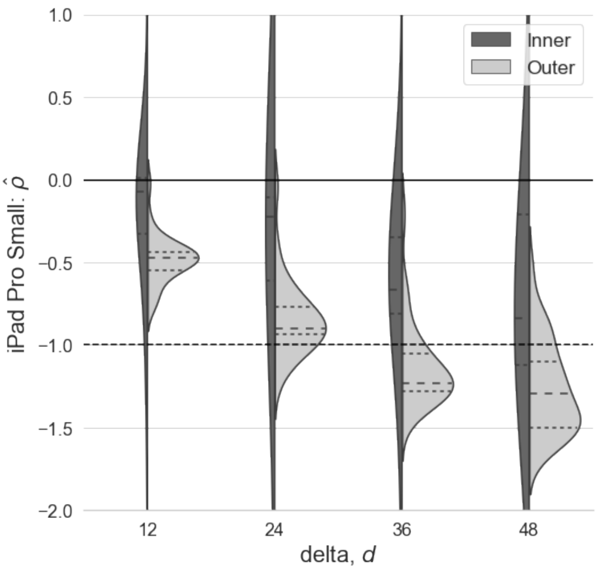
For example, taking the 99% confidence bands for each country's inner and outer adjustment estimates over the various devices and deltas, it was found that for 242 out of the 565 (or 42%) threshold regressions, the $\hat{\rho}_0$s included zero. Meanwhile, only four out of the 510 regressions confidence bands for $\hat{\rho}_1$s, or less than 1% of the number of regressions, included zero.[14] This again validates the stochastic LOP that for several countries small real exchange rate deviations either do not correct (i.e. follow a random walk), or they take notably longer to adjust. Large deviations however tend to quickly mean revert.

Next, both the $\hat{\rho}_0$s and $\hat{\rho}_1$s decline (or equivalently, the half-lives decrease) as the delta increases. In fact, when d reaches 36, almost three quarters of the outer adjustment coefficients tend to be smaller than -1. This either implies negligible half-lives, or that *complete convergence* for the vast majority of countries occurs within 36 weeks. Again, real exchange rate convergence (at least for ones derived from iPads) appears to be notably quicker than the literature's finding that half-lives are around three- to five years. Finally, after around $d = 36$, it appears as though the $\hat{\rho}_1$s reached their optimum adjustment, and

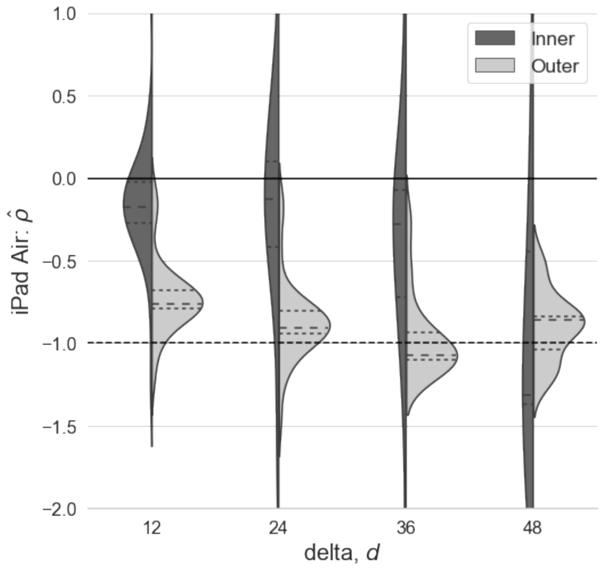
[14]There are 565 threshold regressions in total, but the Bayesian Information Criterion found that only 510 of these contained thresholds.



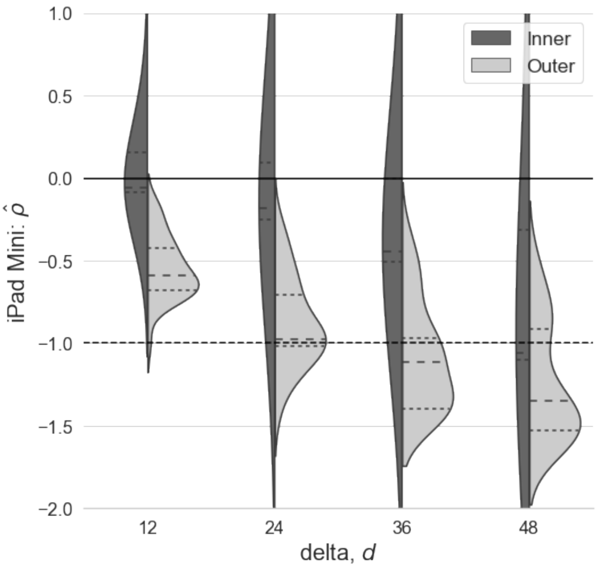
(a) iPad Pro Large



(b) iPad Pro Small



(c) iPad Air



(d) iPad Mini

Figure 6: Violin Plots of Adjustment Parameters

Notes: Adjustment Parameters for Inner $\hat{\rho}_0$ and Outer $\hat{\rho}_1$ TAR Estimates for Individual Devices over Various Deltas (d).

the subsequent coefficients estimated at $d = 48$ become somewhat more varied or less concentrated around the median. Overall, from the regression estimates, there again appears to be strong support that the 'stochastic LOP' holds.

Table 2: Summary Statistics of Country Threshold Regression Persistence Estimates

Product	Averages of Country Estimates, Tables B3 to B16								
Product	Delta d	Inner $\hat{\rho}_0$	Inner SE	Outer $\hat{\rho}_1$	Outer SE	Threshold c_i	Half-life $\hat{\rho}_0$	Half-life $\hat{\rho}_1$
iPad Pro Large	12	-0.104	(0.113)	-0.483	(0.051)***	0.051	1.454	0.243
iPad Pro Small	12	-0.108	(0.138)	-0.481	(0.054)***	0.050	1.396	0.244
iPad	12	-0.154	(0.076)**	-0.723	(0.048)***	0.095	0.957	0.124
iPad Mini	12	0.152	(0.115)	-0.543	(0.050)***	0.074	∞	0.204
iPad Pro Large	24	-0.250	(0.139)*	-0.852	(0.063)***	0.053	1.112	0.168
iPad Pro Small	24	-0.609	(0.233)***	-0.842	(0.064)***	0.048	0.340	0.173
iPad	24	-0.302	(0.124)**	-0.869	(0.052)***	0.072	0.888	0.158
iPad Mini	24	0.214	(0.196)	-0.876	(0.059)***	0.073	∞	0.153
iPad Pro Large	36	-0.827	(0.198)***	-1.113	(0.064)***	0.048	0.273	0.000
iPad Pro Small	36	-0.758	(0.184)***	-1.130	(0.068)***	0.047	0.338	0.000
iPad	36	-0.408	(0.124)***	-0.970	(0.054)***	0.066	0.916	0.137
iPad Mini	36	-0.012	(0.180)	-1.084	(0.063)***	0.065	39.946	0.000
iPad Pro Large	48	-0.853	(0.169)***	-1.208	(0.063)***	0.043	0.334	0.000
iPad Pro Small	48	-0.738	(0.236)***	-1.262	(0.064)***	0.040	0.477	0.000
iPad	48	-0.780	(0.221)***	-0.897	(0.063)***	0.078	0.423	0.281
iPad Mini	48	-0.395	(0.199)**	-1.238	(0.067)***	0.068	1.274	0.000
	Medians Country of Estimates, Tables B3 to B16							
Product	Delta d	Inner $\hat{\rho}_0$	Inner SE	Outer $\hat{\rho}_1$	Outer SE	Threshold c_i	Half-life $\hat{\rho}_0$	Half-life $\hat{\rho}_1$
iPad Pro Large	12	-0.088	(0.073)	-0.435	(0.050)***	0.045	1.726	0.280
iPad Pro Small	12	-0.075	(0.066)	-0.472	(0.052)***	0.047	2.052	0.250
iPad	12	-0.173	(0.058)***	-0.759	(0.046)***	0.106	0.842	0.112
iPad Mini	12	-0.056	(0.066)	-0.587	(0.052)***	0.075	2.750	0.181
iPad Pro Large	24	-0.264	(0.094)***	-0.870	(0.064)***	0.046	1.046	0.157
iPad Pro Small	24	-0.224	(0.083)***	-0.898	(0.063)***	0.048	1.261	0.140
iPad	24	-0.129	(0.088)	-0.905	(0.053)***	0.066	2.316	0.136
iPad Mini	24	-0.185	(0.083)**	-0.974	(0.062)***	0.076	1.564	0.088
iPad Pro Large	36	-0.659	(0.110)***	-1.232	(0.068)***	0.046	0.447	0.000
iPad Pro Small	36	-0.664	(0.102)***	-1.232	(0.070)***	0.047	0.440	0.000
iPad	36	-0.281	(0.106)***	-1.071	(0.054)***	0.068	1.455	0.000
iPad Mini	36	-0.446	(0.102)	-1.116	(0.064)***	0.076	0.813	0.000
iPad Pro Large	48	-0.749	(0.153)***	-1.284	(0.060)***	0.033	0.463	0.000
iPad Pro Small	48	-0.840	(0.136)***	-1.296	(0.063)***	0.034	0.349	0.000
iPad	48	-1.314	(0.104)***	-0.862	(0.056)***	0.079	0.000	0.323
iPad Mini	48	-1.056	(0.090)**	-1.352	(0.066)***	0.072	0.000	0.000

Note: Standard Errors in Parenthesis *p<0.10; **p<0.05; ***p<0.01

4.3.3 Threshold Levels and Transaction Costs

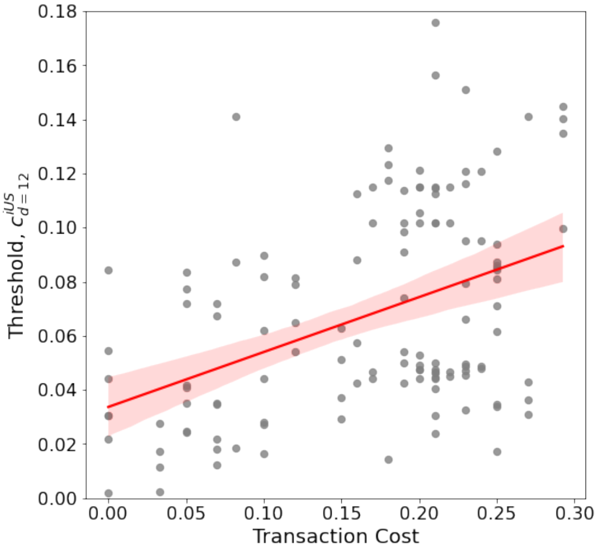
According to several authors, frictions due to transaction costs and uncertainties are responsible for the resulting thresholds that inhibits real exchange rate adjustment (Obstfeld and Taylor, 1997; Baum et al., 2001; Taylor et al., 2001; O'Connell and Wei, 2002; Chari et al., 2002; Sarno et al., 2004; Chen et al., 2019; Drissi and Boukhatem, 2020). These transaction costs include ones that can be measured, for example tariffs or non-tariff barriers and different local tax rates on products; as well as frictions that are more difficult to quantify: for example information costs or lack of labour mobility (Rogoff, 1996). One of the main benefits of using Apple devices in a LOP analyses is that one is able to control for a notable amount price heterogeneity, specifically regarding the transaction costs embedded in these devices' prices. One of these 'input costs' controlled for, is that of local taxes imposed on the prices of these devices. Using various years of KPMG's *Indirect Tax Rate Survey* publications, the applicable value added tax (VAT) or general sales tax (GST) rate was extracted for each of the various countries evaluated in this paper. The exact week any VAT or GST rate was changed from 2016 to 2021 was recorded in the dataset (KPMG, 2022). For the United States, the average tax rate on of all the states were used, excluding Puerto Rico.

Second, since all of the Apple devices are shipped from a single origin China to the various importing countries, it's also important to account for the different import tariffs that each country levies on these products. Specifically, using the applicable harmonised system (HS) of tariff codes applicable to each of the devices for each of the importing countries, we can also control for any import duties embedded in these products' prices. All of the applied tariff rates were sourced from the International Trace Centre's Market Access Map (International Trade Centre, 2022). iPads were associated with the HS code 847130 which applies to all "data-processing machines, automatic, portable, weighing less than 10kg, consisting of a central processing unit, a keyboard and a display."[15] The total transaction cost used in this analyses was simply the average VAT or GST rate plus the average import tariff on iPads over the dataset period.

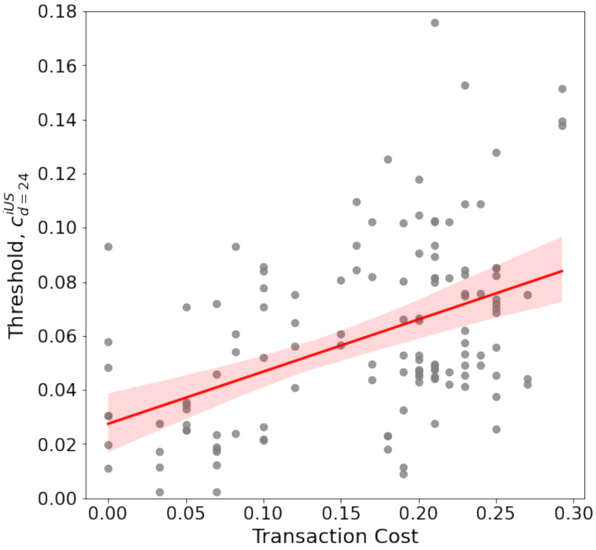
Figure 7 uses scatterplots with robust regressions to plot transaction costs versus the estimated threshold levels from Section 4.3.2 over various deltas (d). Overall, it appears as though the thresholds levels increase (are larger) for countries with higher average transaction costs. Again, this makes sense, since countries with higher transaction costs would need to see more substantial real exchange rate deviations before any actual arbitrage forces can kick in. Even though a large section of the real exchange rate literature has attributed the resulting thresholds to transaction costs, none could be found that have directly compared the estimated thresholds with transaction costs.[16]

[15] Refer to `trade.gov/harmonized-system-hs-codes` for more information on the HS codes.

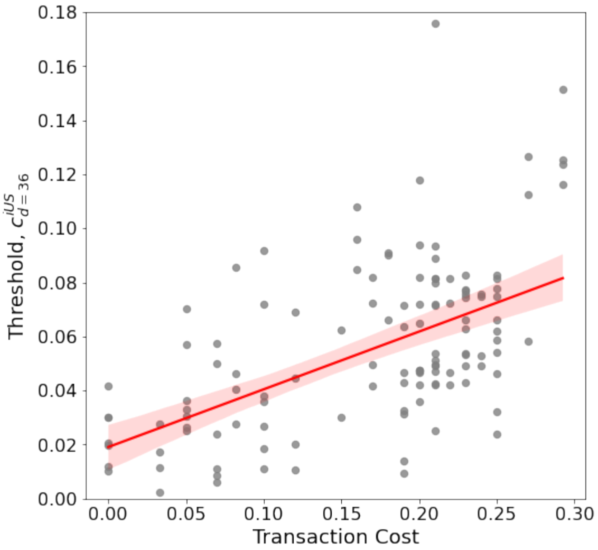
[16] Refer to Obstfeld and Taylor (1997); Michael et al. (1997); Baum et al. (2001); Taylor et al. (2001); O'Connell and Wei (2002); Chari et al. (2002); Sarno et al. (2004); Chen et al. (2019); Drissi and



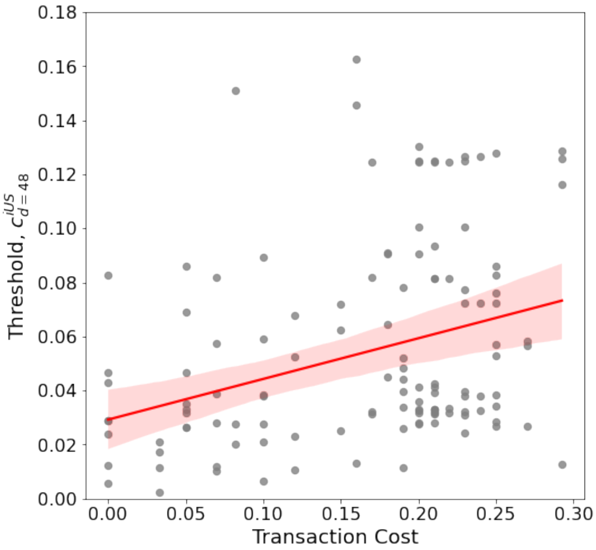
(a) $d = 12$



(b) $d = 24$



(c) $d = 36$



(d) $d = 48$

Figure 7: Transaction Costs vs Estimated Threshold Levels

Notes: Robust Regression Scatterplots of Transaction Costs vs Estimated Threshold Levels over Various Deltas, (d).

The threshold regressions in this section have enriched our understanding regarding the nonlinear adjustment of iPad derived real exchange rates. However, from the specification above *symmetrical* thresholds were assumed as well as the same adjustment parameters for both over and under-valuations. What's more, one also cannot derive confidence bands for the threshold estimates. The paper therefore also employed piecewise-linear estimation techniques in order to evaluate real exchange rate nonlinearity. This method imposes the least number of restrictions on the models being estimated. In fact, the only hyper-parameter used is to define the number of break points.

4.4 Piecewise Regressions Model with Unknown Break Points

Muggeo (2003) has developed a nonlinear regression technique whereby piecewise terms in the regression models are fit *simultaneously* along with the break- or change-point(s). This method therefore incorporates the change-points parameters as part of the estimation model itself.[17] More specifically, the technique reduces the investigation to a linear framework, where the regression function is continuous, but the first derivatives of the function are not. The two, or more, line segments along with the switch-points are estimated at the same time via iterative fitting of linear models. From this multi-phase model, Pilgrim (2021) compiled a Python package utilising Muggeo's algorithms. Within this package, confidence bands for all the model estimates are derived.

The general form of the model for two change points (or three segmented areas, i.e. 'left', 'middle' and 'right') using the real exchange rate specification from Equation 4. In order to simplify the expression, the iUS-country and x-product superscripts for all the different real exchange rate variables are omitted:

$$\Delta^{(d)}\tilde{q}_t = \delta_d + \rho_{l,d}\tilde{q}_{t-d} + \rho_{m,d}(\tilde{q}_{t-d} - \psi_0)H(\tilde{q}_{t-d} - \psi_0) + \rho_{r,d}(\tilde{q}_{t-d} - \psi_1)H(\tilde{q}_{t-d} - \psi_1) + \epsilon_t \ , \quad (4)$$

From this equation, δ_d represents the intercept and $\rho_{l,d}$, $\rho_{m,d}$ and $\rho_{r,d}$ are the estimated slope coefficients for the left, middle and right areas of the two change-point model. The ψ_0 and ψ_1 parameters indicate the break-point positions while the $H(.)$ function is the Heaviside step function (similar to the indicator function $\Phi[.]$ in the threshold regressions).[18] Finally, ϵ_t is the error term. Since this equation cannot be solved directly via linear estimation techniques, a linear approximation via a multivariate Taylor expansion

Boukhatem (2020).

[17] Note, the terms thresholds, change-points, break-points, switch-points and transition-points are often interchangeably used to indicate the area where an 'abrupt' change occurs between the dependent and explanatory variables. Similarly, the piecewise regression model is also frequently referred to as a broken-line, multi-phase or segmented regression model.

[18] The Heaviside function assigns a value of zero for negative arguments and one for positive arguments.

which is derived around initial guesses for the breakpoints ψ_0 and ψ_1 is used:

$$\Delta^{(d)}\tilde{q}_t \approx \delta_d + \rho_{l,d}\tilde{q}_{t-d} + \rho_{m,d}(\tilde{q}_{t-d} - \psi_0^{(0)})H(\tilde{q}_{t-d} - \psi_0^{(0)}) - \rho_{m,d}(\psi_0 - \psi_0^{(0)})H(\tilde{q}_{t-d} - \psi_0^{(0)}) + \rho_{r,d}(\tilde{q}_{t-d} - \psi_1^{(0)})H(\tilde{q}_{t-d} - \psi_1^{(0)}) - \rho_{r,d}(\psi_1 - \psi_1^{(0)})H(\tilde{q}_{t-d} - \psi_1^{(0)}) + ... + \epsilon_t \ , \quad (5)$$

This Taylor expansion then becomes a linear expression that can be estimated and an iterative process can then be used until the breakpoint estimates converge. As Pilgrim (2021) however explains, the "Muggeo method" is not guaranteed to converge to a global optimum (i.e. the technique can also produce a local optimum, or might not converge at all). To address this problem, a bootstrap restarting method is used that generates a non-parametric bootstrap of the data via resampling to discover new changepoint values that may represent a better global solution. By repeating this process several times, the algorithm attempts to converge as well as escape local optima. The number of times this process runs can be controlled in Python with the *nboot* parameter. Though this raises the likelihood of convergence, it comes at the cost of computation time.

4.4.1 Panel Piecewise Regressions: All Countries including all iPad devices

Figure 8 illustrates the piecewise regression output derived from the nonlinear real exchange rate analyses. The four scatterplots show the sample mean adjusted lagged real exchange rates derived from all the iPad devices (i.e. $\tilde{q}_{t-d}^{i\mathrm{US},x}$ $\forall$ x) on the x-axis versus the subsequent d-period change in the real exchange rates (i.e. $\Delta^{(d)}\tilde{q}_t^{i\mathrm{US},x}$ for four samples of $d = 1, 12, 24, 30$) on the y-axis. (Note, though a sample of only four deltas are shown, the piecewise regression analyses was performed for every $d = 1, 2, ..., 30$). This is similar to the LOWESS analyses conducted in Section 4.2 on a smaller sample of deltas. The segmented regression fit is represented by the 'kinked' solid red lines in each scatterplot. Additionally, the various change points are included as vertical blue lines while their respective confidence intervals are illustrated as translucent blue bands. Similar to the LOWESS analyses, it again appears as though there exists valuation thresholds for real exchange rate adjustments. These become more evident (i.e. 'flatter' inner slope vs 'steeper' outer slopes) as well as increasingly certain (i.e. narrower confidence bands) as the evaluation period d increases. Contrary to the LOWESS analyses, it is possible to derive parameter estimates with confidence bands for each coefficient of the various regressions.

The left, middle and right area adjustment parameter estimates (i.e. $\hat{\rho}_{l,d}$, $\hat{\rho}_{m,d}$ and $\hat{\rho}_{r,d}$) as well as their respective 95% confidence bands over various deltas from $d = 1, 2, ...30$ are plotted in Figure 9 (a).[19] Again, it is clear that the middle adjustment coefficients (or

[19]The change-points surrounding the inner threshold became more unstable to estimate as the delta increased. For large deltas, the piecewise regression model discovered nonsensical "kinks" at significant undervaluations (i.e. far to the left of zero). As a result, the deltas for 26, 27 and 29 were omitted and

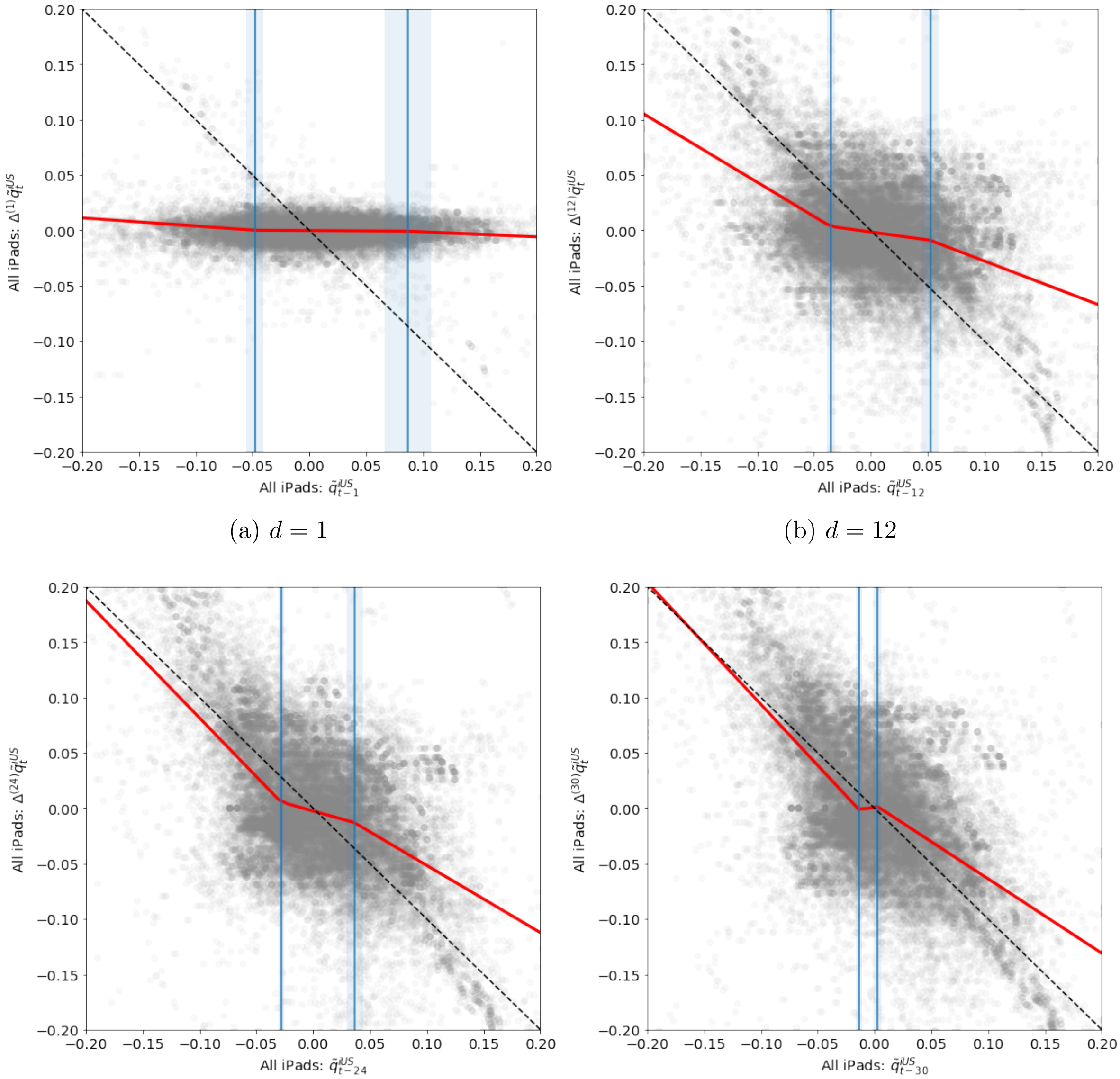
$\hat{\rho}_{m,d}$s) are basically zero for $d < 5$ while only declining slightly over larger deltas. That said, the uncertainty of this parameter again increases to around naught over $d > 25$. This once more supports the notion of the stochastic LOP; that is that small real exchange rate deviations may follow a random walk, or at least, take notably longer to correct. Meanwhile, both the outer parameter estimates (i.e. $\hat{\rho}_{l,d}$ and $\hat{\rho}_{r,d}$) imply significantly quicker adjustments; or equivalently, shorter half-lives. After around $d = 20$, the 95% confidence interval for $\hat{\rho}_{l,d}$ includes -1. Meanwhile for $\hat{\rho}_{r,d}$ at $d = 30$, the 95% confidence band, at -0.65 to -0.69, is somewhat larger than $\hat{\rho}_{l,d}$. Nonetheless, this larger estimate still implies a very short half-life of only 0.36 years when the difference period is 30 weeks.

In addition to the finding that real exchange rate adjustments exhibit nonlinear behaviour, the analyses also imply that the subsequent adjustments are *asymmetric*. That is, changes attributable to undervaluations (i.e. $\tilde{q}_t < 0$) seem to occur notably quicker relative to overvaluations. Upon closer investigation, this finding is perhaps not all that surprising. For example, given a notably large real exchange rate undervaluation shock it implies that either the nominal exchange rate needs to appreciate (i.e. $e_t^{ij,x}$ decrease), and/or the local price relative to the US price is required to increase (i.e. $p_t^{i,x} - p^{US,x}$ rises). From economic theory we'd expect that price adjustments can more easily occur upward rather than downward.[20] Thus, the local prices of iPads may be more fluid when it comes to price increases and more sticky to downward pressure. This phenomenon also seems to be supported by my Apple product price dataset. For example, for the different devices over the 35 countries we've recorded, 470 domestic price increases (i.e. $\Delta p_t^{i,x} > 0$) were recorded over the various devices; more than double the number of decreases (i.e. $\Delta p_t^{i,x} < 0$) which came in at 198. What's more, the average price increase over all the devices came in at 15% versus only -7% for the downward price adjustments. In other words, in the database the frequency of recorded price increases was more than twice that of declines and the average absolute size of such price hikes were more than double the size of price decreases.

Subplot (b) in Figure 9 shows the estimated change-point parameters along with their associated confidence bands derived from the piecewise regressions. Theses change-points get closer to zero as the difference period d increases. Also, the confidence bands around these estimates also appear to narrow over d. Finally, even though the threshold estimates for overvaluations (i.e. $\hat{\psi}_1$) appear slightly more volatile than the threshold coefficients for undervaluations, $\hat{\psi}_0$, the change-points are still fairly symmetrical around naught. Thus larger deviations for both under- and overvaluations have to be of approximately of similar absolute size before the more significant adjustment parameters kick in. Finally, the change-points derived from the piece-wise model mostly concurs with those derived

the regressions for $d > 30$ excluded.

[20] This is also observed empirically. For example, Cavallo (2018) presents several findings on 'price stickiness' using scraped data from online retailers.



(a) $d = 1$

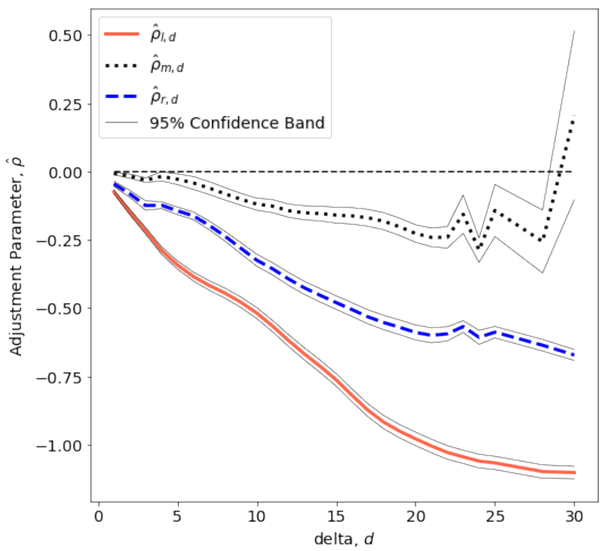
(b) $d = 12$

(c) $d = 24$

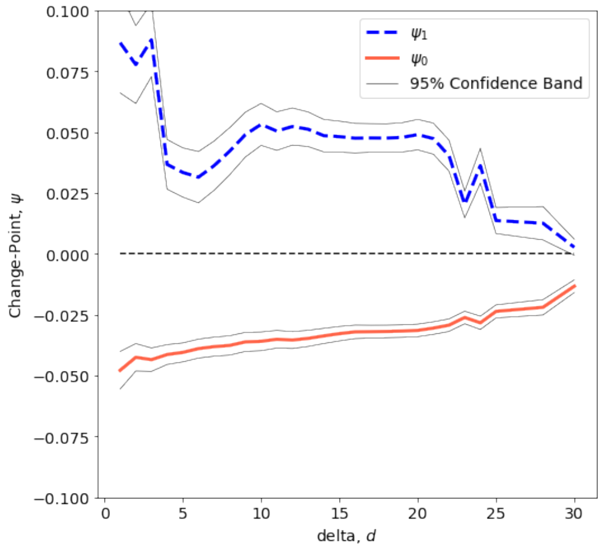
(d) $d = 30$

Figure 8: Panel Piecewise Regressions Over Different Horizons (d)

from the threshold regression (TAR) analyses in Section 4.3.1 where the thresholds are around 5% at lower deltas. The convergence of the change point estimates, $\hat{\psi}_0$ and $\hat{\psi}_1$, to zero as d increases is however significantly more noticeable in the piecewise regressions. Or, similarly, the absolute decline in thresholds over d are more apparent in the segmented regressions.



(a) Adjustment Parameters



(b) Change-point Parameters

Figure 9: Panel Piecewise Regression Parameters

Notes: 95% Confidence Bands Over Different Horizons (d).

4.4.2 Piecewise Regressions: Individual Countries and Devices

The piecewise regression analysis was also performed over the various deltas for all of the individual countries included. Figure 10 utilises box plots to show the distributions of the $\hat{\psi}_0$s and $\hat{\psi}_1$s break-point parameters for all the individual countries over all of the iPad devices. The averages are again included as white dots and the medians via the horizontal lines inside the grey inter-quartile boxes. Similar to the aggregate panel, it appears as though both thresholds for the individual countries converge to naught over d (i.e. the average, median and range of change-points decline over the size of the difference period). One interesting finding that became more apparent in the individual country analyses is that the real exchange rate overvalaution thresholds (i.e. $\hat{\psi}_1$s) appears to be larger in absolute size than the $\hat{\psi}_0$s, especially over shorter deltas. The distributions of $\hat{\psi}_0$s and $\hat{\psi}_1$s however do appear to become more symmetrical over larger ds. The reason for this could be similar to my argument regarding the asymmetry observed between the 'left' and 'right' adjustment parameters (i.e. $\hat{\rho}_{l,d}$ vs $\hat{\rho}_{r,d}$) outlined in Section 4.4.1 above. That is, due to sticky domestic prices and fluid nominal exchange rates, one could be witnessing more upward domestic price adjustments during real exchange rate undervaluations than price decreases during overvaluations. As a result, we could therefore also witness a potentially larger threshold for overvaluations before real exchange rate adjustments can rapidly occur.

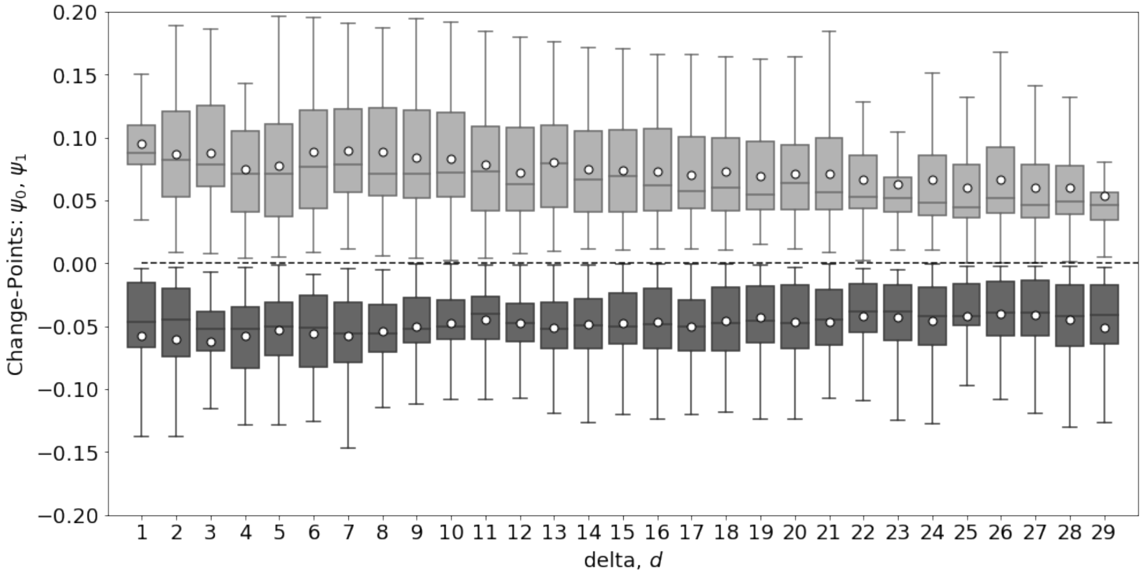


Figure 10: Box Plots of Country Change-Points derived from Piecewise Linear Regressions over Various Deltas (d)

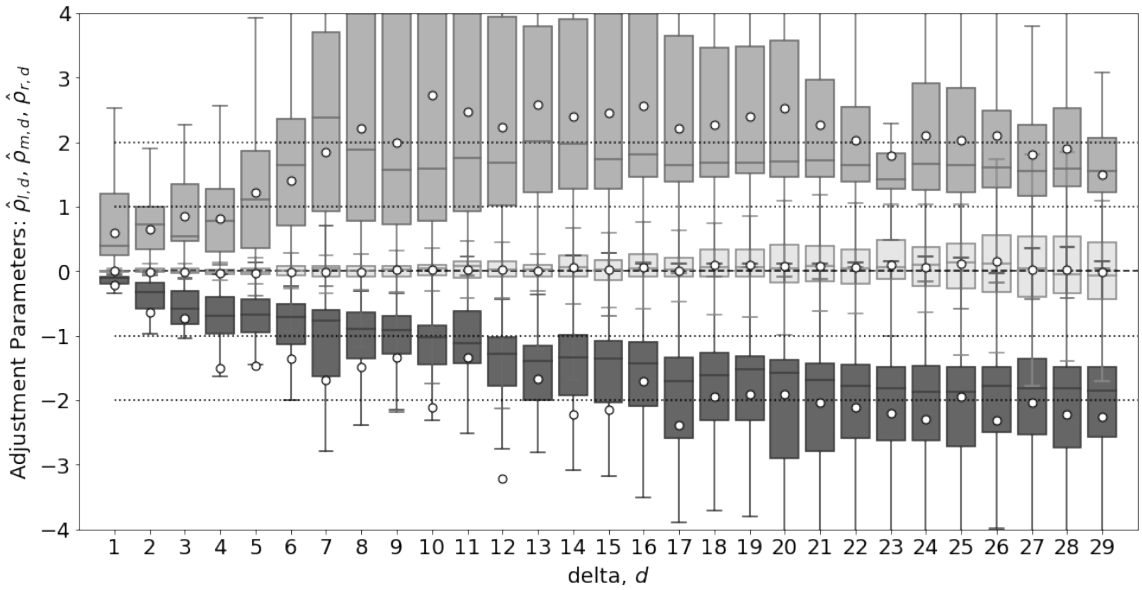


Figure 11: Box Plots of Country Adjustment Parameter Estimates from Piecewise Linear Regressions over Various Deltas (d)

Finally, Figure 11 shows the individual adjustment parameters for the three regions over d. The darkest shaded box-plots represent the leftmost region adjustment parameter, $\hat{\rho}_{l,d}$, while the lightest shade denotes the distributions of the countries' middle adjustment coefficients $\hat{\rho}_{m,d}$. In order to plot all the box-plots onto one chart, the absolute value of the right region's adjustment parameters (i.e. $|\hat{\rho}_{r,d}|$) are included as the uppermost boxes. First to note is that the average and median of the inner parameters, $\hat{\rho}_{m,d}$s, are close to zero. The inter-quartile range of these parameters are also significantly closer to zero than the 'outer' adjustment parameters. This is again supportive of stochastic LOP. Meanwhile, though the $\hat{\rho}_{l,d}$s appear to be smaller than the $\hat{\rho}_{r,d}$s at lower deltas, the potential asymmetry between the two parameters is less noticeable than in the panel dataset. The distribution of the $\hat{\rho}_{r,d}$s are however notably wider than the $\hat{\rho}_{l,d}$s.[21]

5 Conclusion

This study's use of iPad prices to explore the nonlinearity of real exchange rate adjustments provides fresh insights into the mechanics of price dynamics in global markets. Our results challenge the long-held notion of slow RER adjustment, suggesting instead that mispricing corrections may occur over much shorter time horizons, particularly for larger deviations. These findings open up new opportunities to investigate other product-specific RER behaviours, which could further refine our understanding of international price dynamics.

To investigate this, we have constructed a new dataset, consisting of iPad prices, as well as their associated transaction or input costs, in order to evaluate what relationships and dynamics (that have not been explored in existing publications) can be revealed. Specifically, by using a more suitable product from a global conglomerate, like Apple, on which to conduct these LOP investigations, compared to the existing literature, we have found notably less sticky real exchange rates.

Similar to other studies using product-derived RERs, we found that the real exchange rates implied by Apple iPads exhibit a persistent bias. We therefore used mean-adjusted RERs to account for these biases. The various estimation techniques support the following main findings: First, real exchange rate adjustments derived from iPad products appear to embed a 'threshold effect'. Specifically, the real exchange rate adjustments appear to behave more like unit root processes when they do not deviate too far from fair value. Meanwhile, more prominent valuation discrepancies become significantly more mean-reverting. Second, the size of these thresholds appears to decline as our evaluation window or difference period increases. Third, given the non-linearity of RER adjustments, the correction of mispricings may only take a few months compared to the literature's finding that RER half-lives last from three to five years. Fourth, there seems to be a strong association between the estimated thresholds from the analyses and the actual transaction costs particular to iPads. Finally, the analyses imply that real exchange rate

[21]The same box plot analyses for the individual countries over the individual iPad devices are also given in Figures A7 to A10 in Appendix A.

adjustments may be *asymmetric*. That is, changes attributed to undervaluations seem to occur quicker — i.e. have larger adjustment parameters — relative to overvaluations.

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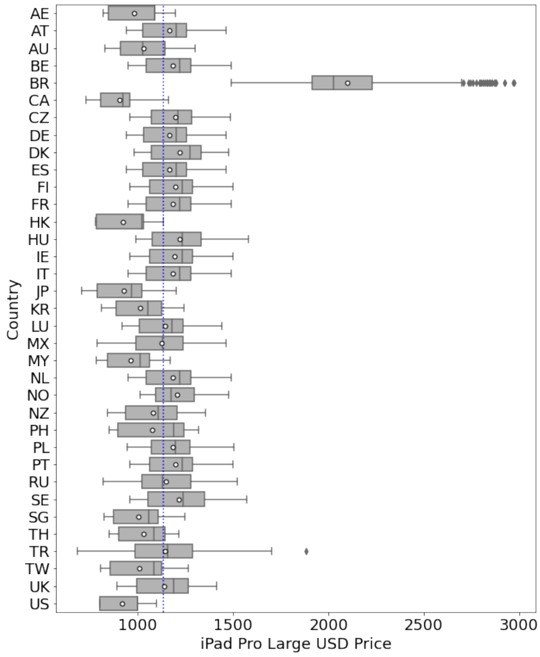
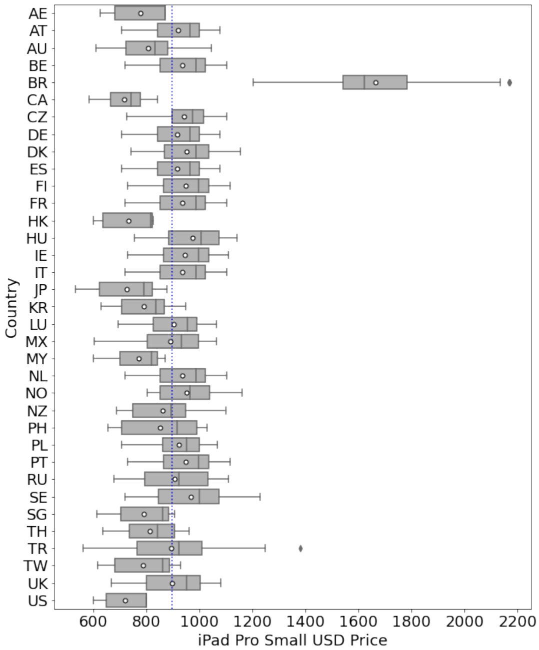
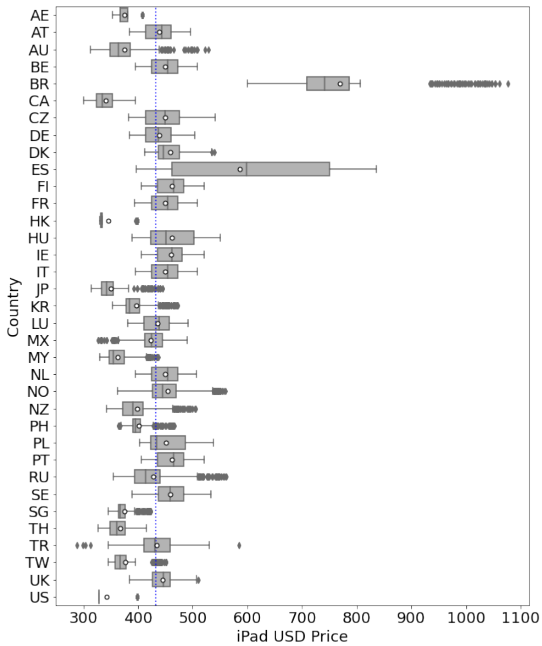
A Appendix Figures



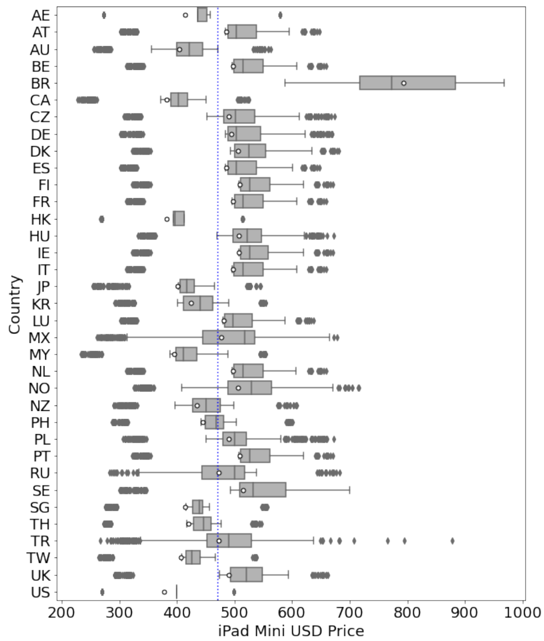
(a) iPad Pro Large Screen



(b) iPad Pro Small Screen

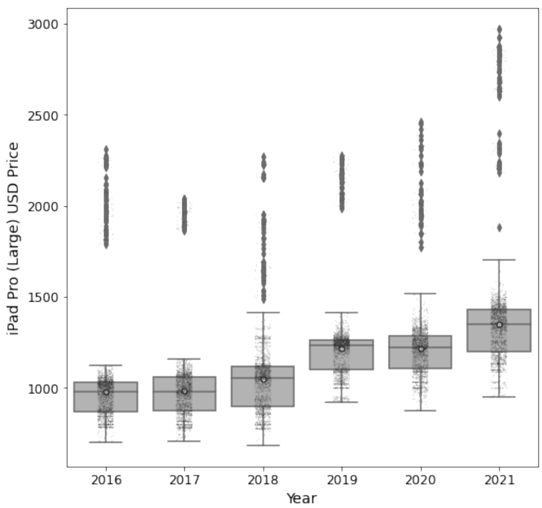


(c) iPad

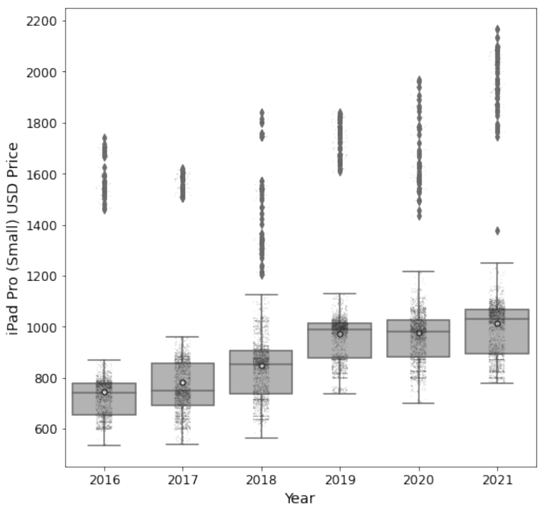


(d) iPad Mini

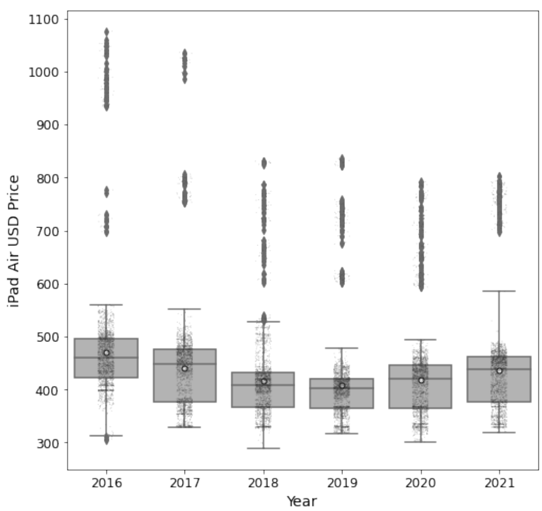
Figure A1: Box Plots of USD Converted Prices of iPads in 35 Countries from 2016 to 2021



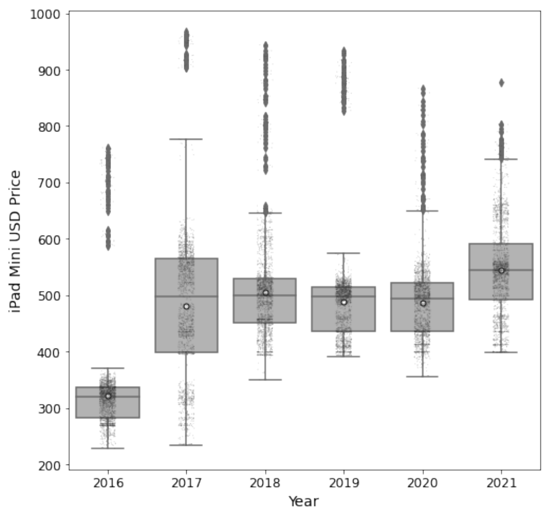
(a) iPad Pro Large Screen



(b) iPad Pro Small Screen

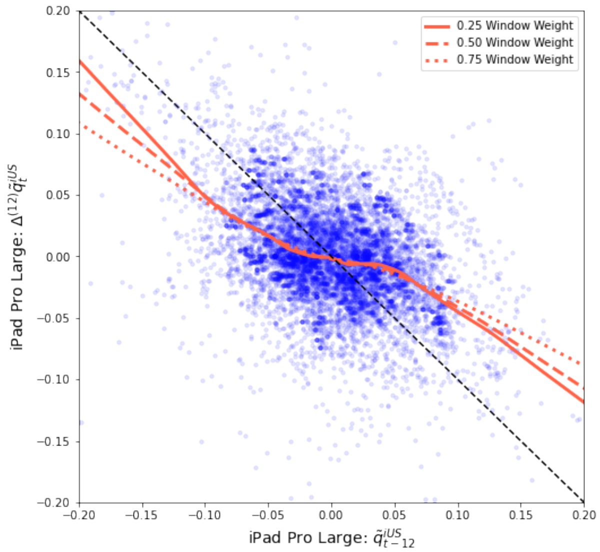


(c) iPad Pro Air

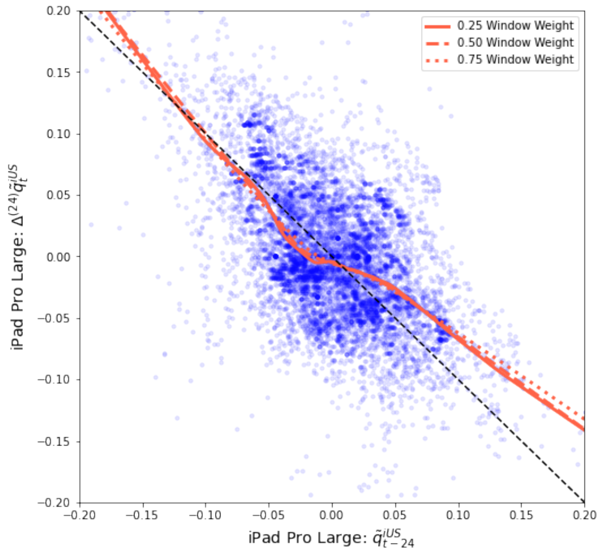


(d) iPad Mini

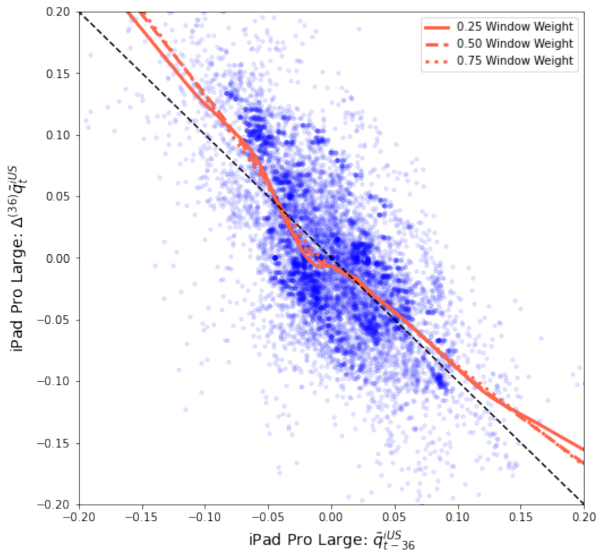
Figure A2: Box Plots of USD Prices of iPad Devices in 35 Countries from 2016 to 2021



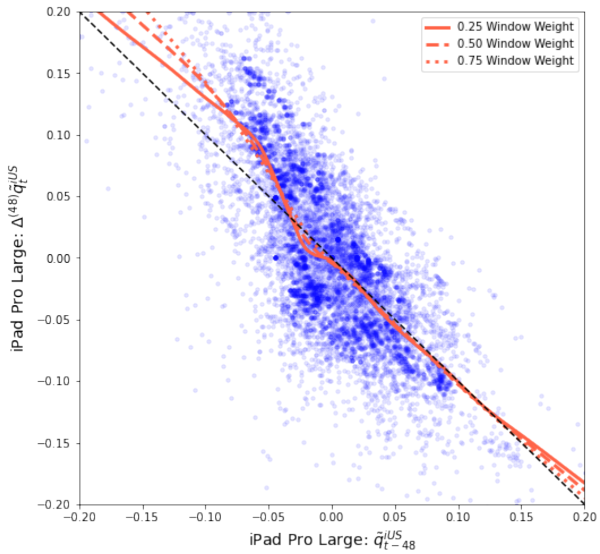
(a) $d = 12$



(b) $d = 24$

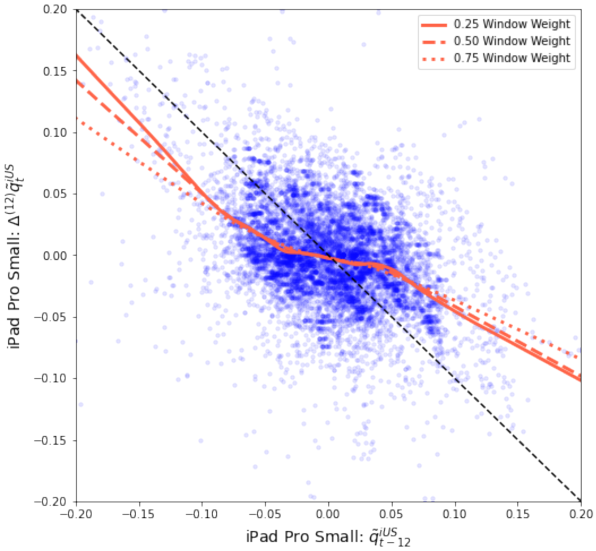


(c) $d = 36$



(d) $d = 48$

Figure A3: LOWESS Scatterplots on iPad Pro Large Screen Devices Lagged RERs vs Subsequent Change in RERs Over Different Horizons (d)



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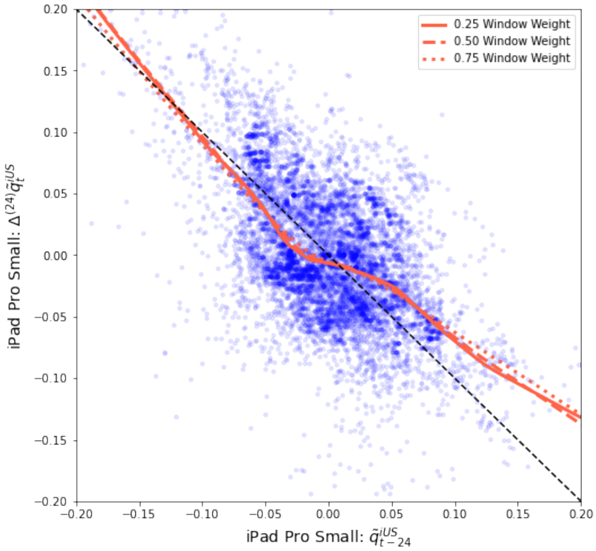

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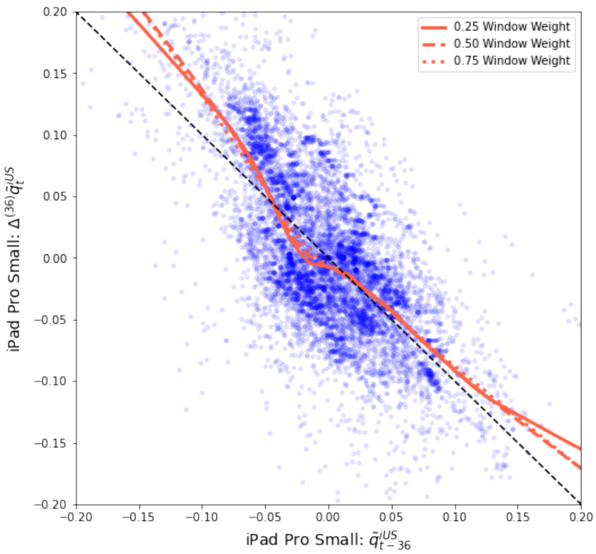

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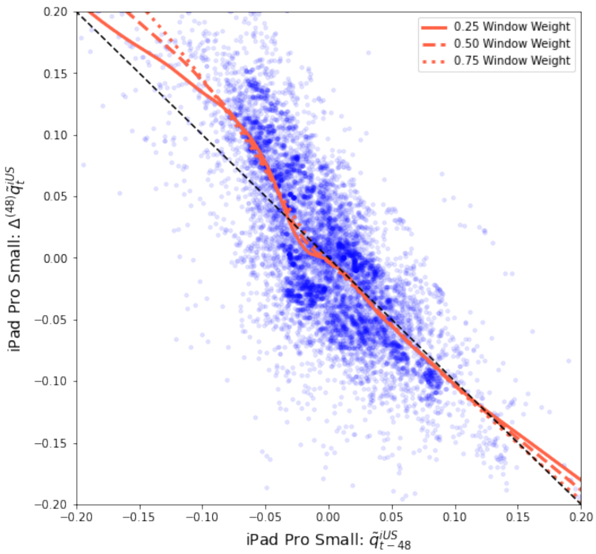

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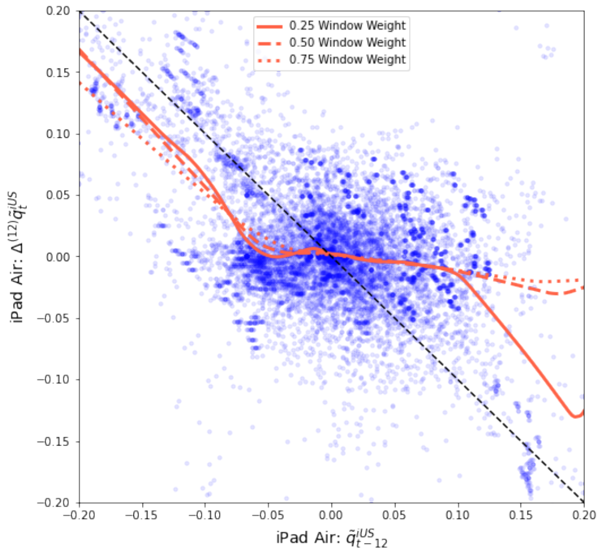
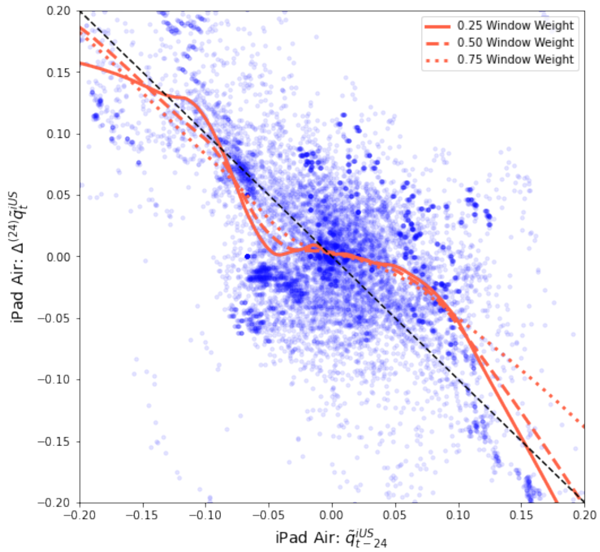
Figure A4: LOWESS Scatterplots on iPad Pro Small Screen Devices Lagged RERs vs Subsequent Change in RERs Over Different Horizons (d)



(a) $d = 12$



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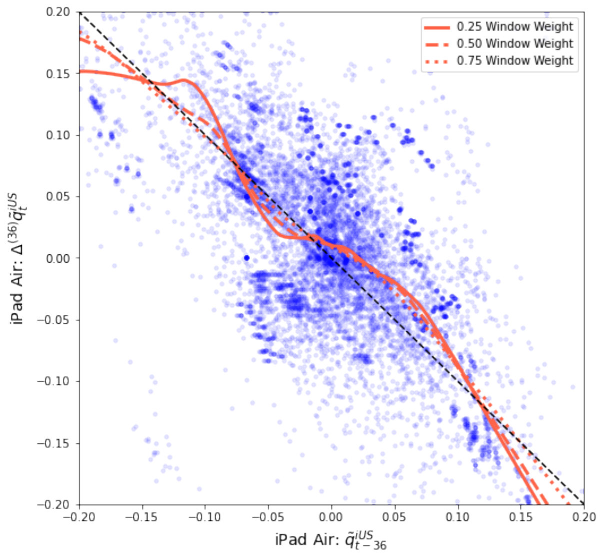
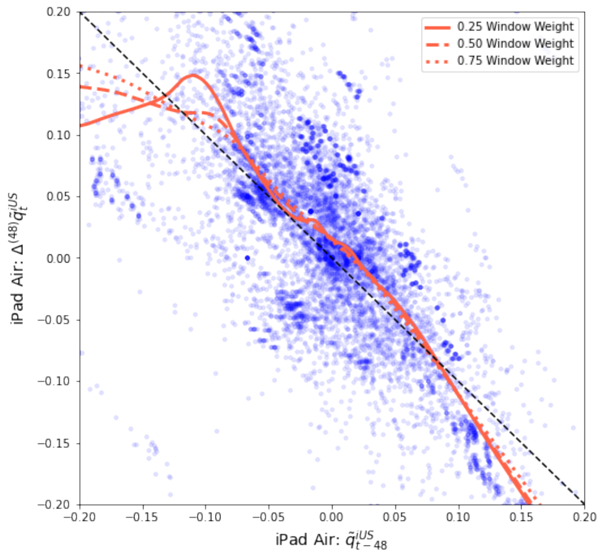
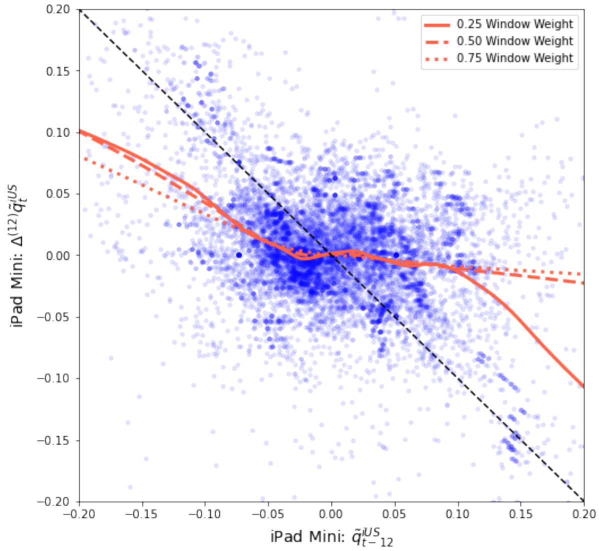


(c) $d = 36$

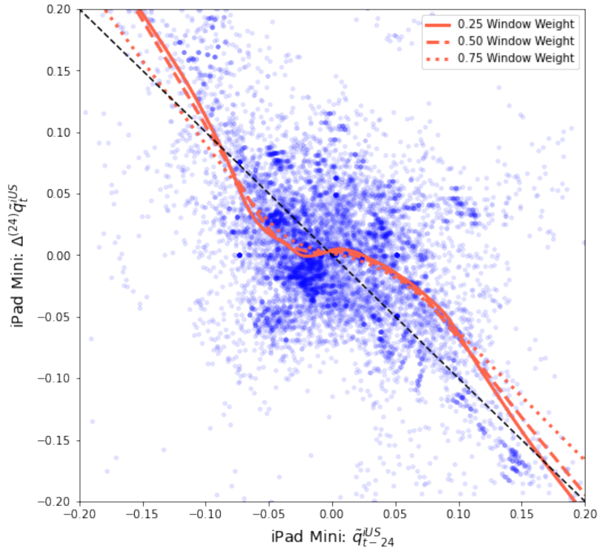


(d) $d = 48$

Figure A5: LOWESS Scatterplots on iPad Air Devices Lagged RERs vs Subsequent Change in RERs Over Different Horizons (d)



(a) $d = 12$



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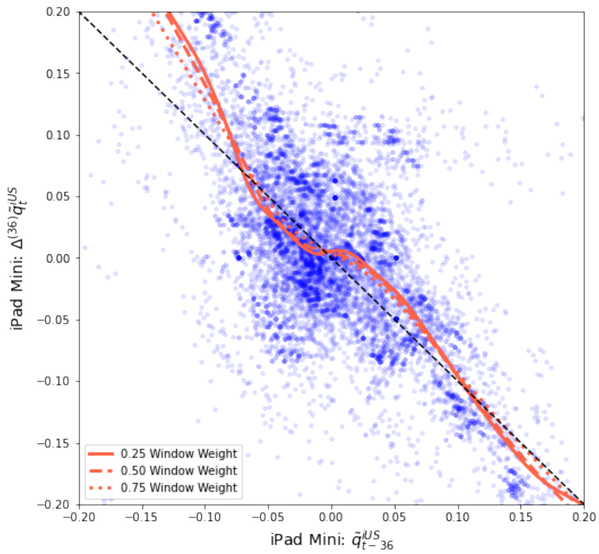

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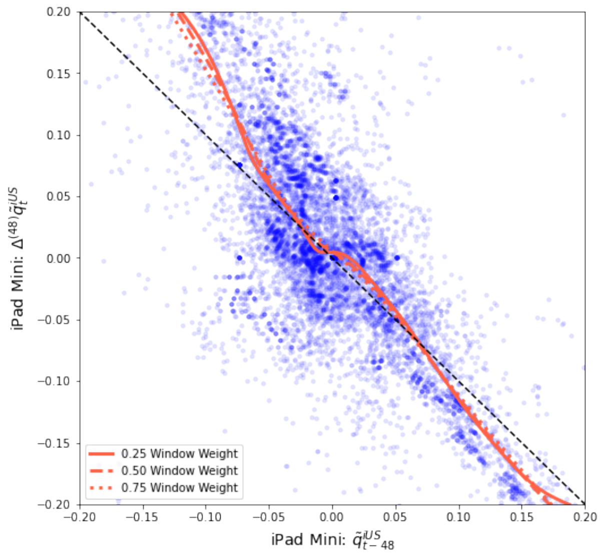

(d) $d = 48$

Figure A6: LOWESS Scatterplots on iPad Mini Devices Lagged RERs vs Subsequent Change in RERs Over Different Horizons (d)

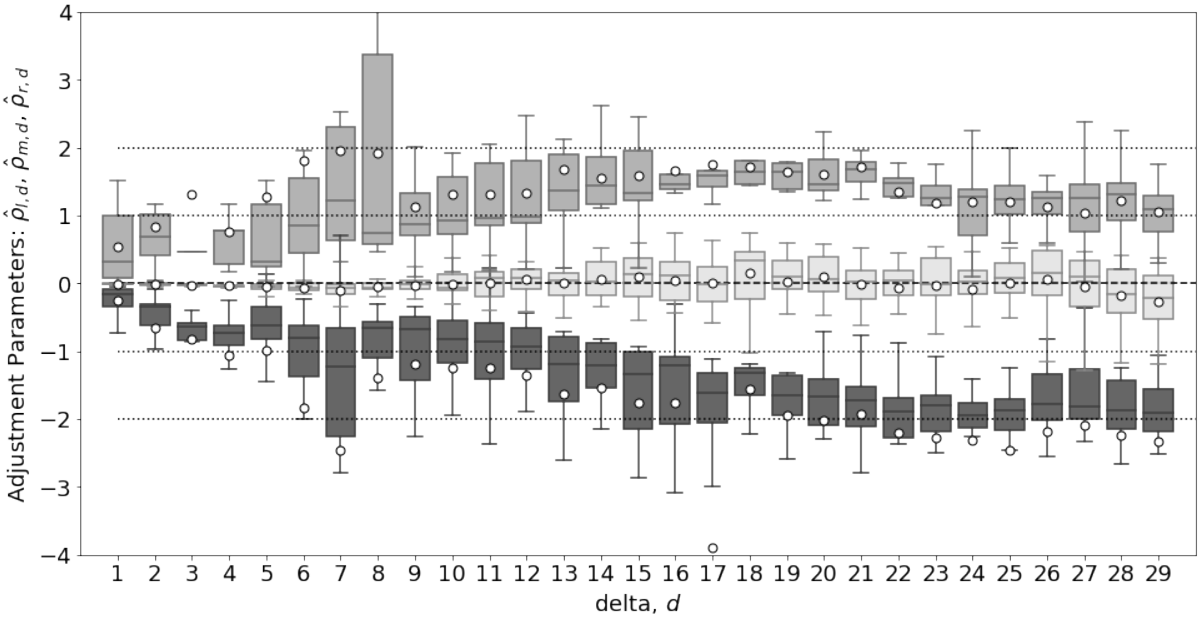

Figure A7: Box Plots of Country Adjustment Parameter Estimates from Piecewise Linear Regressions on iPad Pro Large Screen Devices over Various Deltas (d)

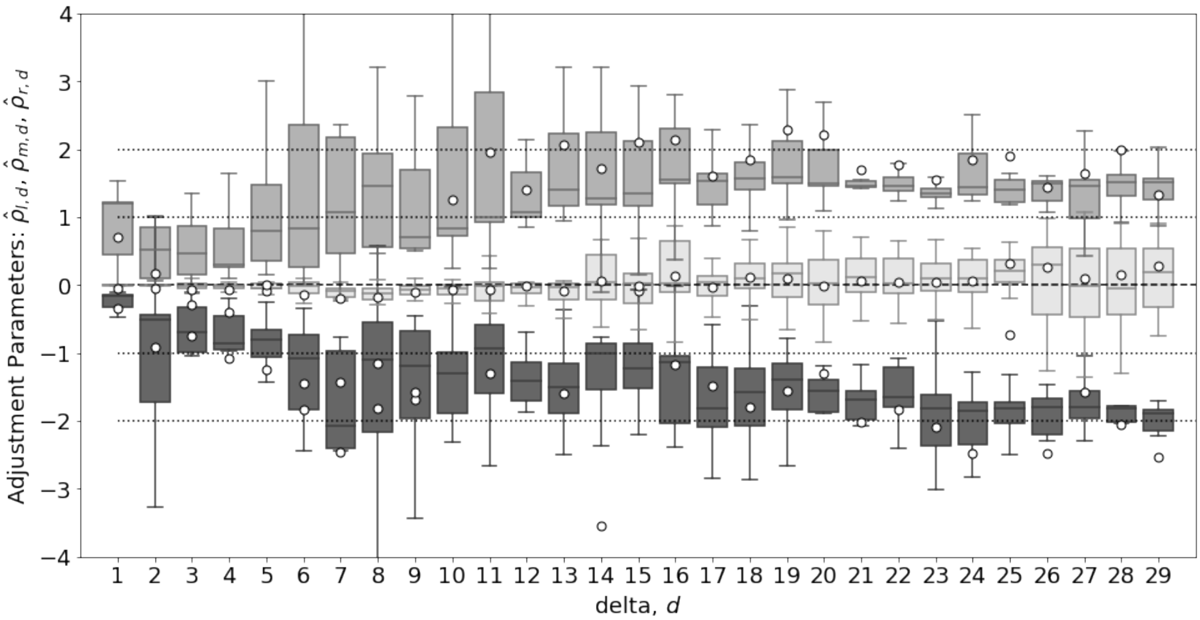

Figure A8: Box Plots of Country Adjustment Parameter Estimates from Piecewise Linear Regressions on iPad Pro Small Screen Devices over Various Deltas (d)

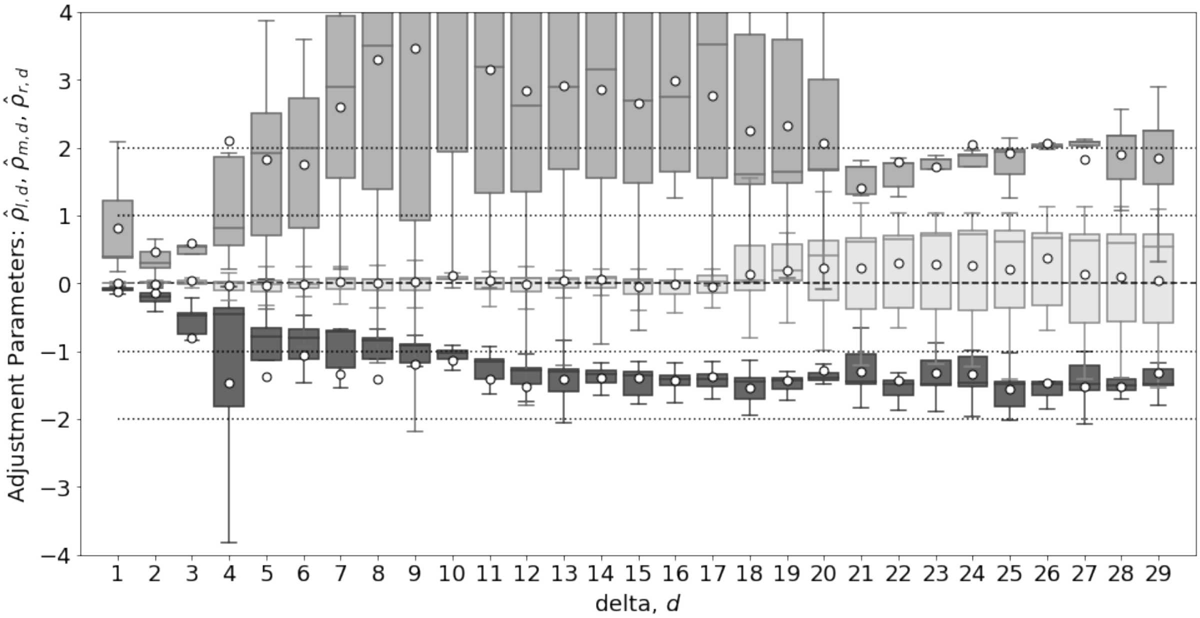

Figure A9: Box Plots of Country Adjustment Parameter Estimates from Piecewise Linear Regressions on iPad Air Devices over Various Deltas (d)

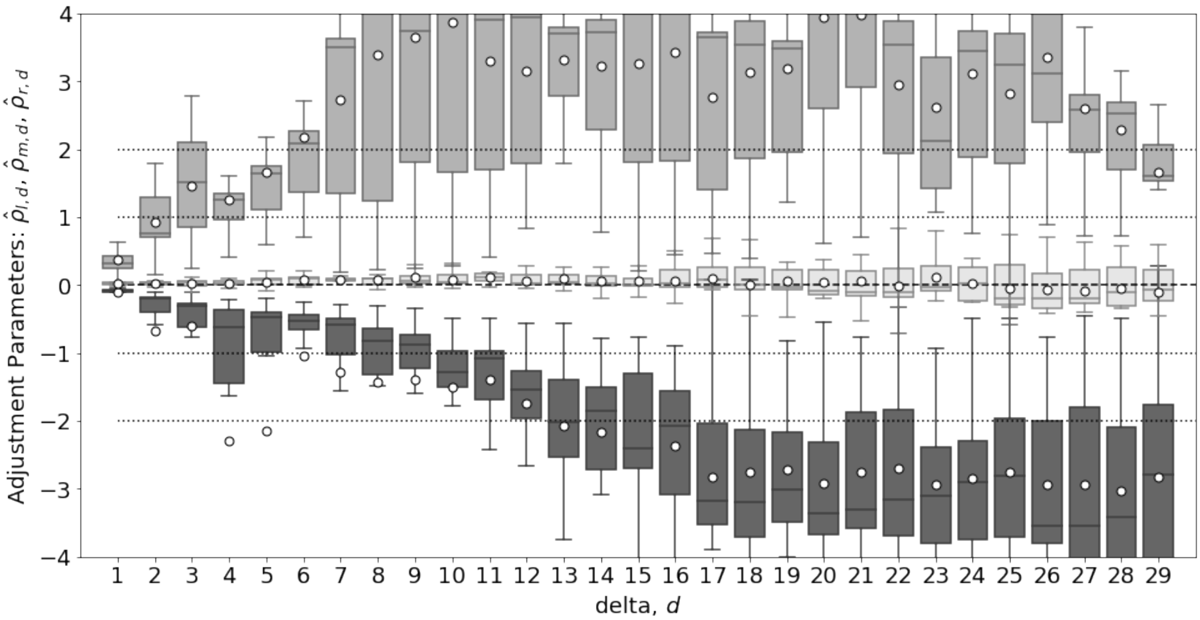

Figure A10: Box Plots of Country Adjustment Parameter Estimates from Piecewise Linear Regressions on iPad Mini Devices over Various Deltas (d)

B Appendix Tables

Table B1: Threshold Autoregression Persistence Estimates for iPad Pro Large Devices, $d = 12$

	i =iPad Pro Large, $d = 12$, No. Observations: 302						
Country	Inner $\hat{\rho}_0$	Inner SE	Outer $\hat{\rho}_1$	Outer SE	Threshold c_i	Half-life $\hat{\rho}_0$	Half-life $\hat{\rho}_1$
AE	0.947	(0.145)***	-0.132	(0.025)***	0.012	∞	1.13
AT	-0.097	(0.066)	-0.423	(0.050)***	0.048	1.568	0.291
AU	0.694	(0.254)***	-0.437	(0.046)***	0.028	∞	0.278
BE	-0.047	(0.074)	-0.429	(0.049)***	0.044	3.323	0.285
BR	-0.042	(0.055)	-0.572	(0.055)***	0.145	3.728	0.188
CA	-1.324	(0.207)***	-0.341	(0.043)***	0.025	0	0.384
CZ	0.821	(0.217)***	-0.348	(0.041)***	0.030	∞	0.374
DE	-0.134	(0.059)**	-0.458	(0.056)***	0.054	1.112	0.261
DK	0.174	(0.112)	-0.399	(0.046)***	0.035	∞	0.314
ES	-0.099	(0.067)	-0.420	(0.050)***	0.048	1.534	0.294
FI	-0.088	(0.069)	-0.441	(0.051)***	0.048	1.736	0.275
FR	-0.047	(0.074)	-0.429	(0.049)***	0.044	3.323	0.285
HK	0.012	(0.022)	-0.522	(0.047)***	0.031	∞	0.217
HU	-1.264	(0.167)***	-0.411	(0.051)***	0.031	0	0.302
IE	-0.089	(0.070)	-0.443	(0.051)***	0.046	1.716	0.273
IT	-0.052	(0.073)	-0.430	(0.049)***	0.045	2.995	0.285
JP	-0.317	(0.073)***	-0.679	(0.067)***	0.084	0.42	0.141
KR	-0.491	(0.047)***				0.237	
LU	-0.044	(0.073)	-0.429	(0.049)***	0.044	3.555	0.285
MX	-0.270	(0.066)***	-0.669	(0.065)***	0.088	0.508	0.145
MY	-1.228	(0.247)***	-0.540	(0.052)***	0.018	0	0.206
NL	-0.042	(0.073)	-0.433	(0.049)***	0.045	3.728	0.282
NO	-0.169	(0.066)**	-0.481	(0.058)***	0.084	0.864	0.244
NZ	-0.316	(0.087)***	-0.622	(0.061)***	0.063	0.421	0.164
PH	0.022	(0.041)	-0.668	(0.052)***	0.079	∞	0.145
PL	-0.357	(0.045)***				0.362	
PT	-0.086	(0.067)	-0.444	(0.052)***	0.049	1.779	0.273
RU	-0.225	(0.082)***	-1.044	(0.056)***	0.074	0.628	0
SE	1.664	(0.614)***	-0.350	(0.043)***	0.017	∞	0.371
SG	-0.541	(0.047)***				0.205	
TH	0.253	(0.200)	-0.433	(0.053)***	0.022	∞	0.282
TR	-0.483	(0.096)***	-0.796	(0.073)***	0.117	0.242	0.101
TW	0.091	(0.129)	-0.255	(0.038)***	0.024	∞	0.543
UK	-0.368	(0.045)***				0.349	
Average	-0.104	0.113	-0.483	0.051	0.051	1.454	0.243
Median	-0.088	0.073	-0.435	0.050	0.045	1.726	0.280
Std Dev	0.565	0.106	0.166	0.009	0.030		

Note: Standard Errors in Parenthesis $^{*}p<0.10$; $^{**}p<0.05$; $^{***}p<0.01$

Average and Median Half-Life calculated from Average and Median Estimates

Table B2: Threshold Autoregression Persistence Estimates for iPad Pro Small Devices, $d = 12$

	i =iPad Pro Small, $d = 12$, No. Observations: 290						
Country	Inner $\hat{\rho}_0$	Inner SE	Outer $\hat{\rho}_1$	Outer SE	Threshold c_i	Half-life $\hat{\rho}_0$	Half-life $\hat{\rho}_1$
AE	-0.303	(0.037)***	-0.020	(0.037)	0.028	0.443	7.918
AT	-0.029	(0.064)	-0.470	(0.052)***	0.049	5.435	0.252
AU	-0.183	(0.064)***	-0.636	(0.065)***	0.082	0.791	0.158
BE	0.013	(0.069)	-0.463	(0.050)***	0.046	∞	0.257
BR	-0.016	(0.055)	-0.497	(0.049)***	0.140	9.917	0.233
CA	-1.036	(0.134)***	-0.239	(0.041)***	0.035	0	0.586
CZ	0.368	(0.150)**	-0.359	(0.043)***	0.041	∞	0.36
DE	-0.113	(0.062)*	-0.435	(0.054)***	0.050	1.334	0.28
DK	-0.110	(0.048)**	-0.558	(0.065)***	0.071	1.373	0.196
ES	-0.024	(0.063)	-0.537	(0.054)***	0.050	6.585	0.208
FI	-0.012	(0.065)	-0.483	(0.051)***	0.049	13.25	0.242
FR	-0.019	(0.068)	-0.472	(0.051)***	0.048	8.339	0.25
HK	0.032	(0.033)	-0.436	(0.046)***	0.031	∞	0.279
HU	-0.977	(0.156)***	-0.356	(0.052)***	0.036	0.042	0.363
IE	-0.040	(0.066)	-0.485	(0.052)***	0.047	3.918	0.241
IT	0.013	(0.068)	-0.465	(0.050)***	0.047	∞	0.256
JP	-0.445	(0.050)***				0.272	
KR	-1.742	(0.267)***	-0.455	(0.052)***	0.017	0	0.264
LU	0.013	(0.069)	-0.463	(0.050)***	0.046	∞	0.257
MX	-1.145	(0.191)***	-0.490	(0.053)***	0.042	0	0.238
MY	-0.436	(0.046)***				0.279	
NL	0.015	(0.069)	-0.467	(0.050)***	0.046	∞	0.254
NO	-0.254	(0.059)***	-0.650	(0.070)***	0.085	0.546	0.152
NZ	-0.258	(0.108)**	-0.561	(0.057)***	0.051	0.536	0.194
PH	0.034	(0.041)	-0.745	(0.054)***	0.082	∞	0.117
PL	-0.192	(0.065)***	-0.492	(0.065)***	0.079	0.75	0.236
PT	-0.012	(0.065)	-0.483	(0.051)***	0.049	13.25	0.242
RU	-0.385	(0.068)***	-0.770	(0.080)***	0.091	0.329	0.109
SE	0.290	(0.190)	-0.383	(0.045)***	0.034	∞	0.331
SG	-0.796	(0.144)***	-0.406	(0.052)***	0.018	0.101	0.307
TH	1.471	(0.438)***	-0.389	(0.049)***	0.012	∞	0.325
TR	3.175	(1.518)**	-0.694	(0.060)***	0.014	∞	0.135
TW	-0.243	(0.063)***	-0.567	(0.070)***	0.042	0.575	0.191
UK	-0.334	(0.043)***				0.394	
Average	-0.108	0.138	-0.481	0.054	0.050	1.396	0.244
Median	-0.075	0.066	-0.472	0.052	0.047	2.052	0.250
Std Dev	0.769	0.253	0.140	0.009	0.026		

Note: Standard Errors in Parenthesis *p<0.10; **p<0.05; ***p<0.01
Average and Median Half-Life calculated from Average and Median Estimates

Table B3: Threshold Autoregression Persistence Estimates for iPad Devices, $d = 12$

	i =iPad, $d = 12$, No. Observations: 302						
Country	Inner $\hat{\rho}_0$	Inner SE	Outer $\hat{\rho}_1$	Outer SE	Threshold c_i	Half-life $\hat{\rho}_0$	Half-life $\hat{\rho}_1$
AE	-0.826	(0.132)***	-0.091	(0.023)***	0.017	0.091	1.677
AT	-0.041	(0.042)	-0.762	(0.046)***	0.115	3.821	0.111
AU	-0.352	(0.058)***	-0.809	(0.060)***	0.090	0.369	0.097
BE	-0.025	(0.041)	-0.759	(0.045)***	0.115	6.318	0.112
BR	-0.225	(0.063)***	-0.900	(0.055)***	0.135	0.628	0.069
CA	-0.218	(0.054)***	-0.764	(0.037)***	0.084	0.65	0.111
CZ	-0.177	(0.050)***	-0.705	(0.059)***	0.156	0.821	0.131
DE	-0.022	(0.045)	-0.789	(0.047)***	0.114	7.19	0.103
DK	-0.237	(0.060)***	-0.848	(0.044)***	0.081	0.591	0.085
ES	0.295	(0.120)**	-0.247	(0.033)***	0.176	∞	0.564
FI	-0.033	(0.039)	-0.785	(0.045)***	0.121	4.767	0.104
FR	-0.025	(0.041)	-0.759	(0.045)***	0.115	6.318	0.112
HK	1.159	(0.458)**	-0.154	(0.026)***	0.002	∞	0.956
HU	-0.250	(0.059)***	-0.759	(0.060)***	0.141	0.556	0.112
IE	-0.020	(0.042)	-0.748	(0.044)***	0.116	7.918	0.116
IT	-0.024	(0.041)	-0.759	(0.044)***	0.115	6.585	0.112
JP	-0.493	(0.083)***	-0.906	(0.061)***	0.054	0.235	0.068
KR	-0.463	(0.058)***	-0.747	(0.048)***	0.062	0.257	0.116
LU	-0.024	(0.041)	-0.759	(0.044)***	0.115	6.585	0.112
MX	-0.277	(0.066)***	-0.695	(0.057)***	0.113	0.493	0.135
MY	-0.169	(0.077)**	-0.857	(0.053)***	0.087	0.864	0.082
NL	-0.027	(0.041)	-0.757	(0.045)***	0.115	5.844	0.113
NO	-0.241	(0.063)***	-1.011	(0.052)***	0.086	0.58	0
NZ	-1.252	(0.203)***	-0.566	(0.052)***	0.030	0	0.192
PH	-0.090	(0.060)	-0.743	(0.052)***	0.054	1.696	0.118
PL	-0.241	(0.062)***	-0.720	(0.051)***	0.151	0.58	0.126
PT	-0.033	(0.039)	-0.784	(0.046)***	0.121	4.767	0.104
RU	-0.417	(0.058)***	-1.217	(0.068)***	0.098	0.296	0
SE	0.209	(0.071)***	-0.639	(0.040)***	0.087	∞	0.157
SG	-0.076	(0.046)*	-0.614	(0.039)***	0.067	2.024	0.168
TH	-0.303	(0.056)***	-0.585	(0.052)***	0.072	0.443	0.182
TR	-0.412	(0.081)***	-1.044	(0.075)***	0.123	0.301	0
TW	-0.269	(0.052)***	-0.675	(0.039)***	0.041	0.51	0.142
UK	0.366	(0.096)***	-0.638	(0.041)***	0.053	∞	0.157
Average	-0.154	0.076	-0.723	0.048	0.095	0.957	0.124
Median	-0.173	0.058	-0.759	0.046	0.106	0.842	0.112
Std Dev	0.369	0.074	0.216	0.011	0.039		

Note: Standard Errors in Parenthesis *p<0.10; **p<0.05; ***p<0.01

Average and Median Half-Life calculated from Average and Median Estimates

Table B4: Threshold Autoregression Persistence Estimates for iPad Mini Devices, $d = 12$

	i =iPad Mini, $d = 12$, No. Observations: 302						
Country	Inner $\hat{\rho}_0$	Inner SE	Outer $\hat{\rho}_1$	Outer SE	Threshold c_i	Half-life $\hat{\rho}_0$	Half-life $\hat{\rho}_1$
AE	3.095	(0.665)***	-0.184	(0.030)***	0.003	∞	0.787
AT	-0.043	(0.048)	-0.712	(0.055)***	0.106	3.639	0.129
AU	0.249	(0.102)**	-0.516	(0.043)***	0.044	∞	0.22
BE	-0.085	(0.049)*	-0.681	(0.058)***	0.102	1.801	0.14
BR	0.495	(0.132)***	-0.159	(0.039)***	0.100	∞	0.924
CA	-0.112	(0.053)**	-0.486	(0.043)***	0.078	1.347	0.24
CZ	1.921	(0.474)***	-0.381	(0.042)***	0.024	∞	0.333
DE	0.249	(0.078)***	-0.684	(0.047)***	0.102	∞	0.139
DK	0.042	(0.081)	-0.385	(0.043)***	0.062	∞	0.329
ES	-0.067	(0.048)	-0.679	(0.056)***	0.112	2.307	0.141
FI	-0.132	(0.055)**	-0.584	(0.059)***	0.095	1.13	0.182
FR	-0.078	(0.049)	-0.690	(0.058)***	0.102	1.97	0.137
HK	0.084	(0.032)***	-0.193	(0.029)***	0.022	∞	0.746
HU	0.136	(0.182)	-0.317	(0.043)***	0.043	∞	0.42
IE	-0.060	(0.073)	-0.486	(0.050)***	0.066	2.585	0.24
IT	-0.085	(0.049)*	-0.681	(0.058)***	0.102	1.801	0.14
JP	-0.293	(0.107)***	-0.638	(0.056)***	0.044	0.461	0.157
KR	0.346	(0.177)*	-0.263	(0.038)***	0.027	∞	0.524
LU	-0.085	(0.049)*	-0.681	(0.058)***	0.102	1.801	0.14
MX	-0.064	(0.160)	-0.473	(0.042)***	0.057	2.418	0.25
MY	-0.020	(0.052)	-0.751	(0.053)***	0.141	7.918	0.115
NL	-0.087	(0.049)*	-0.678	(0.058)***	0.102	1.757	0.141
NO	-0.171	(0.059)***	-0.639	(0.061)***	0.094	0.853	0.157
NZ	-0.053	(0.129)	-0.517	(0.051)***	0.037	2.937	0.22
PH	-0.036	(0.048)	-0.732	(0.057)***	0.065	4.363	0.121
PL	0.701	(0.296)**	-0.336	(0.041)***	0.032	∞	0.391
PT	-0.132	(0.055)**	-0.584	(0.059)***	0.095	1.13	0.182
RU	0.293	(0.144)**	-0.702	(0.048)***	0.043	∞	0.132
SE	-0.096	(0.045)**	-0.591	(0.058)***	0.128	1.585	0.179
SG	-0.339	(0.075)***	-0.600	(0.057)***	0.035	0.386	0.175
TH	0.163	(0.119)	-0.427	(0.041)***	0.035	∞	0.287
TR	-0.435	(0.077)***	-0.989	(0.079)***	0.129	0.28	0.035
TW	-0.089	(0.042)**	-0.425	(0.043)***	0.072	1.716	0.289
UK	-0.049	(0.047)	-0.622	(0.053)***	0.121	3.184	0.164
Average	0.152	0.115	-0.543	0.050	0.074	∞	0.204
Median	-0.056	0.066	-0.587	0.052	0.075	2.750	0.181
Std Dev	0.645	0.128	0.185	0.010	0.036		

Note: Standard Errors in Parenthesis $^{*}p<0.10$; $^{**}p<0.05$; $^{***}p<0.01$

Average and Median Half-Life calculated from Average and Median Estimates

Table B5: Threshold Autoregression Persistence Estimates for iPad Pro Large Devices, $d = 24$

	i =iPad Pro Large, $d = 24$, No. Observations: 290						
Country	Inner $\hat{\rho}_0$	Inner SE	Outer $\hat{\rho}_1$	Outer SE	Threshold c_i	Half-life $\hat{\rho}_0$	Half-life $\hat{\rho}_1$
AE	1.893	(0.182)***	-0.271	(0.031)***	0.012	∞	1.012
AT	-0.262	(0.090)***	-0.826	(0.064)***	0.047	1.053	0.183
AU	-0.439	(0.070)***	-1.189	(0.079)***	0.086	0.553	0
BE	-0.196	(0.094)**	-0.874	(0.063)***	0.045	1.466	0.154
BR	-0.236	(0.072)***	-0.751	(0.067)***	0.140	1.188	0.23
CA	-1.925	(0.245)***	-0.495	(0.049)***	0.025	0	0.468
CZ	0.867	(0.326)***	-0.580	(0.051)***	0.028	∞	0.369
DE	-0.265	(0.092)***	-0.839	(0.065)***	0.047	1.039	0.175
DK	-0.193	(0.099)*	-0.963	(0.066)***	0.046	1.492	0.097
ES	-0.290	(0.089)***	-0.809	(0.065)***	0.048	0.934	0.193
FI	-0.393	(0.080)***	-0.944	(0.073)***	0.053	0.641	0.111
FR	-0.196	(0.094)**	-0.874	(0.063)***	0.045	1.466	0.154
HK	0.044	(0.023)*	-1.076	(0.047)***	0.031	∞	0
HU	-0.635	(0.078)***	-0.965	(0.087)***	0.075	0.317	0.095
IE	-0.304	(0.090)***	-0.877	(0.066)***	0.046	0.883	0.153
IT	-0.152	(0.100)	-0.859	(0.061)***	0.042	1.94	0.163
JP	-0.729	(0.082)***	-1.285	(0.076)***	0.093	0.245	0
KR	-1.479	(0.179)***	-0.858	(0.058)***	0.027	0	0.164
LU	-0.147	(0.095)	-0.866	(0.062)***	0.044	2.012	0.159
MX	-0.374	(0.073)***	-1.018	(0.074)***	0.093	0.683	0
MY	-1.454	(0.083)***	-0.963	(0.064)***	0.054	0	0.097
NL	-0.172	(0.094)*	-0.879	(0.063)***	0.045	1.695	0.151
NO	-0.245	(0.100)**	-0.680	(0.062)***	0.074	1.138	0.281
NZ	-0.481	(0.100)***	-1.005	(0.068)***	0.061	0.488	0
PH	0.517	(0.094)***	-0.711	(0.046)***	0.056	∞	0.258
PL	-0.392	(0.076)***	-0.726	(0.073)***	0.084	0.643	0.247
PT	-0.366	(0.079)***	-0.943	(0.072)***	0.053	0.702	0.112
RU	-0.741	(0.090)***	-1.029	(0.063)***	0.080	0.237	0
SE	-0.869	(0.083)***	-0.484	(0.071)***	0.072	0.157	0.484
SG	-1.493	(0.171)***	-0.857	(0.058)***	0.017	0	0.164
TH	0.236	(0.212)	-0.919	(0.071)***	0.024	∞	0.127
TR	2.681	(1.031)***	-1.205	(0.060)***	0.018	∞	0
TW	-0.117	(0.126)	-0.486	(0.054)***	0.033	2.571	0.481
UK	-0.191	(0.126)	-0.856	(0.060)***	0.046	1.509	0.165
Average	-0.250	0.139	-0.852	0.063	0.053	1.112	0.168
Median	-0.264	0.094	-0.870	0.064	0.046	1.046	0.157
Std Dev	0.838	0.166	0.210	0.010	0.026		

Note: Standard Errors in Parenthesis *$^{*}p<0.10$; $^{**}p<0.05$; $^{***}p<0.01$*
Average and Median Half-Life calculated from Average and Median Estimates

Table B6: Threshold Autoregression Persistence Estimates for iPad Pro Small Devices, $d = 24$

	i =iPad Pro Small, $d = 24$, No. Observations: 278						
Country	Inner $\hat{\rho}_0$	Inner SE	Outer $\hat{\rho}_1$	Outer SE	Threshold c_i	Half-life $\hat{\rho}_0$	Half-life $\hat{\rho}_1$
AE	-0.621	(0.047)***	-0.040	(0.047)	0.028	0.33	7.837
AT	-0.342	(0.075)***	-0.914	(0.076)***	0.053	0.764	0.13
AU	-0.373	(0.079)***	-1.061	(0.075)***	0.078	0.685	0
BE	-0.159	(0.082)*	-0.934	(0.066)***	0.050	1.847	0.118
BR	-0.206	(0.069)***	-0.658	(0.057)***	0.138	1.387	0.298
CA	-1.480	(0.158)***	-0.409	(0.050)***	0.036	0	0.608
CZ	0.134	(0.166)	-0.586	(0.054)***	0.044	∞	0.363
DE	-3.876	(0.915)***	-0.623	(0.055)***	0.011	0	0.328
DK	-0.415	(0.070)***	-0.938	(0.085)***	0.069	0.597	0.115
ES	-0.242	(0.091)***	-0.820	(0.066)***	0.048	1.155	0.187
FI	-0.190	(0.081)**	-0.932	(0.067)***	0.049	1.518	0.119
FR	-0.147	(0.087)*	-0.926	(0.065)***	0.048	2.012	0.123
HK	0.083	(0.039)**	-0.895	(0.054)***	0.031	∞	0.142
HU	-0.696	(0.060)***				0.269	
IE	-0.052	(0.097)	-0.842	(0.061)***	0.042	5.991	0.173
IT	-0.101	(0.089)	-0.898	(0.063)***	0.047	3.005	0.14
JP	-0.803	(0.059)***				0.197	
KR	-2.445	(0.230)***	-0.820	(0.059)***	0.021	0	0.187
LU	-0.159	(0.082)*	-0.934	(0.066)***	0.050	1.847	0.118
MX	-0.465	(0.084)***	-1.074	(0.074)***	0.084	0.511	0
MY	0.220	(0.200)	-0.945	(0.056)***	0.024	∞	0.11
NL	-0.161	(0.083)*	-0.932	(0.066)***	0.049	1.822	0.119
NO	-0.273	(0.062)***	-1.047	(0.073)***	0.085	1.003	0
NZ	-0.585	(0.082)***	-1.038	(0.080)***	0.081	0.364	0
PH	-0.028	(0.055)	-1.106	(0.063)***	0.075	11.265	0
PL	-0.350	(0.083)***	-0.738	(0.074)***	0.075	0.743	0.239
PT	-0.190	(0.081)**	-0.932	(0.067)***	0.049	1.518	0.119
RU	-8.639	(2.600)***	-0.794	(0.059)***	0.009	0	0.202
SE	0.313	(0.397)	-0.700	(0.057)***	0.025	∞	0.266
SG	-1.473	(0.177)***	-0.815	(0.062)***	0.018	0	0.19
TH	2.653	(0.512)***	-0.783	(0.062)***	0.012	∞	0.209
TR	1.147	(0.723)	-1.220	(0.062)***	0.023	∞	0
TW	-0.668	(0.058)***				0.29	
UK	-0.128	(0.141)	-0.750	(0.060)***	0.043	2.336	0.231
Average	-0.609	0.233	-0.842	0.064	0.048	0.340	0.173
Median	-0.224	0.083	-0.898	0.063	0.048	1.261	0.140
Std Dev	1.709	0.455	0.220	0.009	0.027		

Note: Standard Errors in Parenthesis $^{*}p<0.10$; $^{**}p<0.05$; $^{***}p<0.01$

Average and Median Half-Life calculated from Average and Median Estimates

Table B7: Threshold Autoregression Persistence Estimates for iPad Devices, $d = 24$

	i =iPad, $d = 24$, No. Observations: 290						
Country	Inner $\hat{\rho}_0$	Inner SE	Outer $\hat{\rho}_1$	Outer SE	Threshold c_i	Half-life $\hat{\rho}_0$	Half-life $\hat{\rho}_1$
AE	-1.467	(0.157)***	-0.194	(0.029)***	0.017	0	1.483
AT	0.385	(0.100)***	-0.831	(0.044)***	0.066	∞	0.18
AU	-0.358	(0.063)***	-0.933	(0.060)***	0.084	0.722	0.118
BE	-0.128	(0.067)*	-0.923	(0.054)***	0.102	2.336	0.125
BR	-0.698	(0.066)***	-1.135	(0.074)***	0.151	0.267	0
CA	0.398	(0.179)**	-0.785	(0.038)***	0.035	∞	0.208
CZ	0.009	(0.096)	-0.899	(0.054)***	0.090	∞	0.14
DE	0.562	(0.112)***	-0.865	(0.045)***	0.066	∞	0.16
DK	0.083	(0.164)	-0.856	(0.043)***	0.037	∞	0.165
ES	0.630	(0.150)***	-0.457	(0.043)***	0.176	∞	0.524
FI	-0.159	(0.064)**	-0.948	(0.055)***	0.109	1.847	0.108
FR	0.302	(0.105)***	-0.784	(0.046)***	0.067	∞	0.209
HK	-0.384	(0.047)***	-0.144	(0.052)***	0.011	0.66	2.058
HU	-1.510	(0.252)***	-0.720	(0.052)***	0.042	0	0.251
IE	0.019	(0.077)	-0.876	(0.049)***	0.083	∞	0.153
IT	-0.129	(0.067)*	-0.923	(0.054)***	0.102	2.316	0.125
JP	-0.828	(0.082)***	-1.447	(0.063)***	0.058	0.182	0
KR	-1.821	(0.252)***	-0.864	(0.043)***	0.022	0	0.16
LU	-0.129	(0.067)*	-0.923	(0.054)***	0.102	2.316	0.125
MX	-0.422	(0.081)***	-1.043	(0.064)***	0.109	0.584	0
MY	-0.237	(0.106)**	-1.179	(0.054)***	0.061	1.183	0
NL	-0.128	(0.067)*	-0.924	(0.054)***	0.102	2.336	0.124
NO	-0.436	(0.079)***	-0.968	(0.057)***	0.082	0.559	0.093
NZ	-0.403	(0.093)***	-0.935	(0.065)***	0.057	0.62	0.117
PH	0.148	(0.084)*	-0.769	(0.048)***	0.041	∞	0.218
PL	-0.404	(0.070)***	-0.911	(0.060)***	0.152	0.618	0.132
PT	-0.159	(0.064)**	-0.951	(0.056)***	0.109	1.847	0.106
RU	0.106	(0.295)	-0.929	(0.049)***	0.033	∞	0.121
SE	0.612	(0.122)***	-0.810	(0.044)***	0.070	∞	0.193
SG	-0.038	(0.072)	-0.806	(0.044)***	0.046	8.258	0.195
TH	-0.516	(0.070)***	-0.880	(0.064)***	0.072	0.441	0.151
TR	-3.547	(0.636)***	-1.160	(0.059)***	0.023	0	0
TW	-0.088	(0.096)	-0.805	(0.041)***	0.027	3.473	0.196
UK	0.451	(0.114)***	-0.959	(0.047)***	0.051	∞	0.1
Average	-0.302	0.124	-0.869	0.052	0.072	0.888	0.158
Median	-0.129	0.088	-0.905	0.053	0.066	2.316	0.136
Std Dev	0.796	0.107	0.235	0.009	0.040		

Note: Standard Errors in Parenthesis $^{*}p<0.10$; $^{**}p<0.05$; $^{***}p<0.01$

Average and Median Half-Life calculated from Average and Median Estimates

Table B8: Threshold Autoregression Persistence Estimates for iPad Mini Devices, $d = 24$

	i =iPad Mini, $d = 24$, No. Observations: 290						
Country	Inner $\hat{\rho}_0$	Inner SE	Outer $\hat{\rho}_1$	Outer SE	Threshold c_i	Half-life $\hat{\rho}_0$	Half-life $\hat{\rho}_1$
AE	5.269	(0.842)***	-0.380	(0.038)***	0.003	∞	0.669
AT	-0.285	(0.065)***	-1.150	(0.069)***	0.105	0.954	0
AU	-0.059	(0.104)	-0.744	(0.054)***	0.052	5.261	0.235
BE	-0.240	(0.080)***	-0.985	(0.064)***	0.082	1.166	0.076
BR	-0.005	(0.085)	-0.408	(0.062)***	0.204	63.823	0.61
CA	-0.194	(0.088)**	-0.730	(0.051)***	0.070	1.483	0.244
CZ	-0.048	(0.110)	-0.870	(0.058)***	0.080	6.504	0.157
DE	0.084	(0.091)	-1.217	(0.063)***	0.102	∞	0
DK	0.096	(0.118)	-0.760	(0.055)***	0.056	∞	0.224
ES	-0.176	(0.077)**	-0.996	(0.062)***	0.094	1.653	0.058
FI	-0.290	(0.083)***	-0.974	(0.066)***	0.076	0.934	0.088
FR	-0.236	(0.077)***	-1.011	(0.065)***	0.090	1.188	0
HK	0.263	(0.061)***	-0.276	(0.035)***	0.020	∞	0.991
HU	0.115	(0.225)	-0.595	(0.054)***	0.044	∞	0.354
IE	-0.144	(0.100)	-0.922	(0.060)***	0.057	2.058	0.125
IT	-0.240	(0.080)***	-0.985	(0.064)***	0.082	1.166	0.076
JP	-0.394	(0.106)***	-1.203	(0.066)***	0.048	0.639	0
KR	-0.200	(0.070)***	-0.613	(0.064)***	0.071	1.434	0.337
LU	-0.240	(0.080)***	-0.985	(0.064)***	0.082	1.166	0.076
MX	-0.718	(0.048)***				0.253	
MY	0.328	(0.074)***	-1.035	(0.045)***	0.093	∞	0
NL	-0.239	(0.080)***	-0.986	(0.064)***	0.081	1.171	0.075
NO	-0.103	(0.074)	-0.863	(0.062)***	0.085	2.943	0.161
NZ	-0.619	(0.055)***				0.332	
PH	-0.254	(0.061)***	-1.033	(0.075)***	0.065	1.092	0
PL	0.136	(0.171)	-0.640	(0.054)***	0.062	∞	0.313
PT	-0.290	(0.083)***	-0.974	(0.066)***	0.076	0.934	0.088
RU	-0.431	(0.133)***	-1.006	(0.059)***	0.053	0.567	0
SE	-0.235	(0.060)***	-1.111	(0.072)***	0.128	1.194	0
SG	6.698	(2.708)**	-0.866	(0.054)***	0.002	∞	0.159
TH	0.646	(0.296)**	-0.599	(0.047)***	0.019	∞	0.35
TR	-0.934	(0.087)***	-1.412	(0.078)***	0.125	0.118	0
TW	0.270	(0.139)*	-0.489	(0.044)***	0.025	∞	0.476
UK	-0.069	(0.051)	-1.212	(0.055)***	0.118	4.475	0
Average	0.214	0.196	-0.876	0.059	0.073	∞	0.153
Median	-0.185	0.083	-0.974	0.062	0.076	1.564	0.088
Std Dev	1.482	0.458	0.264	0.010	0.039		

Note: Standard Errors in Parenthesis *p<0.10; **p<0.05; ***p<0.01
Average and Median Half-Life calculated from Average and Median Estimates

Table B9: Threshold Autoregression Persistence Estimates for iPad Pro Large Devices, $d = 36$

	i =iPad Pro Large, $d = 36$, No. Observations: 278						
Country	Inner $\hat{\rho}_0$	Inner SE	Outer $\hat{\rho}_1$	Outer SE	Threshold c_i	Half-life $\hat{\rho}_0$	Half-life $\hat{\rho}_1$
AE	2.840	(0.186)***	-0.416	(0.032)***	0.012	∞	0.892
AT	-0.663	(0.100)***	-1.233	(0.072)***	0.047	0.441	0
AU	0.525	(0.361)	-1.194	(0.057)***	0.027	∞	0
BE	-0.659	(0.116)***	-1.235	(0.069)***	0.042	0.446	0
BR	-0.395	(0.086)***	-0.785	(0.065)***	0.126	0.955	0.312
CA	-2.149	(0.202)***	-0.712	(0.057)***	0.031	0	0.386
CZ	-0.155	(0.166)	-1.010	(0.062)***	0.054	2.849	0
DE	-0.677	(0.106)***	-1.239	(0.071)***	0.046	0.425	0
DK	-0.113	(0.317)	-1.242	(0.061)***	0.024	4.002	0
ES	0.131	(0.249)	-1.100	(0.060)***	0.025	∞	0
FI	-0.875	(0.089)***	-1.320	(0.079)***	0.053	0.231	0
FR	-0.658	(0.116)***	-1.236	(0.069)***	0.042	0.447	0
HK	0.069	(0.016)***	-1.534	(0.032)***	0.030	∞	0
HU	-1.251	(0.107)***	-0.929	(0.077)***	0.058	0	0.181
IE	-0.865	(0.091)***	-1.279	(0.079)***	0.054	0.24	0
IT	-0.654	(0.114)***	-1.243	(0.069)***	0.042	0.452	0
JP	-1.271	(0.048)***				0	
KR	-1.136	(0.056)***				0	
LU	-0.628	(0.115)***	-1.232	(0.068)***	0.042	0.485	0
MX	-0.656	(0.074)***	-1.464	(0.080)***	0.096	0.45	0
MY	-1.796	(0.077)***	-1.245	(0.051)***	0.046	0	0
NL	-0.752	(0.096)***	-1.285	(0.075)***	0.051	0.344	0
NO	-0.532	(0.092)***	-1.136	(0.075)***	0.083	0.632	0
NZ	-1.041	(0.059)***				0	
PH	1.234	(0.168)***	-0.802	(0.048)***	0.045	∞	0.296
PL	-0.586	(0.097)***	-1.019	(0.075)***	0.074	0.544	0
PT	-0.852	(0.089)***	-1.319	(0.079)***	0.053	0.251	0
RU	-8.189	(1.966)***	-1.241	(0.050)***	0.009	0	0
SE	-1.384	(0.100)***	-0.836	(0.074)***	0.066	0	0.265
SG	-2.991	(0.694)***	-1.088	(0.058)***	0.006	0	0
TH	0.026	(0.217)	-1.324	(0.073)***	0.024	∞	0
TR	-1.867	(0.119)***	-1.141	(0.067)***	0.091	0	0
TW	0.078	(0.119)	-0.498	(0.053)***	0.033	∞	0.696
UK	-0.237	(0.129)*	-1.163	(0.062)***	0.048	1.774	0
Average	-0.827	0.198	-1.113	0.064	0.048	0.273	0
Median	-0.659	0.110	-1.232	0.068	0.046	0.447	0
Std Dev	1.610	0.330	0.254	0.012	0.026		

Note: Standard Errors in Parenthesis *p<0.10; **p<0.05; ***p<0.01
Average and Median Half-Life calculated from Average and Median Estimates

Table B10: Threshold Autoregression Persistence Estimates for iPad Pro Small Devices, $d = 36$

	i =iPad Pro Small, $d = 36$, No. Observations: 266						
Country	Inner $\hat{\rho}_0$	Inner SE	Outer $\hat{\rho}_1$	Outer SE	Threshold c_i	Half-life $\hat{\rho}_0$	Half-life $\hat{\rho}_1$
AE	-0.817	(0.057)***	-0.210	(0.056)***	0.028	0.283	2.036
AT	-0.669	(0.103)***	-1.226	(0.075)***	0.047	0.434	0
AU	-0.285	(0.214)	-1.237	(0.061)***	0.038	1.43	0
BE	-0.665	(0.096)***	-1.290	(0.077)***	0.050	0.439	0
BR	-0.334	(0.094)***	-0.710	(0.060)***	0.124	1.181	0.388
CA	-1.869	(0.183)***	-0.666	(0.058)***	0.036	0	0.438
CZ	0.077	(0.213)	-0.952	(0.062)***	0.043	∞	0.158
DE	-3.436	(0.735)***	-1.031	(0.061)***	0.014	0	0
DK	-0.686	(0.097)***	-1.302	(0.075)***	0.054	0.414	0
ES	-0.638	(0.104)***	-1.259	(0.073)***	0.047	0.472	0
FI	-0.684	(0.094)***	-1.286	(0.078)***	0.049	0.417	0
FR	-0.690	(0.101)***	-1.282	(0.075)***	0.048	0.41	0
HK	0.115	(0.040)***	-1.274	(0.053)***	0.030	∞	0
HU	-0.948	(0.064)***				0.162	
IE	-0.604	(0.107)***	-1.220	(0.074)***	0.043	0.518	0
IT	-0.621	(0.103)***	-1.263	(0.074)***	0.047	0.495	0
JP	-3.121	(0.920)***	-0.895	(0.064)***	0.012	0	0.213
KR	-3.159	(0.549)***	-1.113	(0.061)***	0.011	0	0
LU	-0.665	(0.096)***	-1.290	(0.077)***	0.050	0.439	0
MX	-0.785	(0.085)***	-1.447	(0.071)***	0.085	0.312	0
MY	0.115	(0.189)	-1.279	(0.054)***	0.028	∞	0
NL	-0.663	(0.096)***	-1.290	(0.077)***	0.049	0.441	0
NO	-0.523	(0.082)***	-1.244	(0.069)***	0.075	0.648	0
NZ	-0.398	(0.244)	-1.138	(0.062)***	0.030	0.946	0
PH	-0.210	(0.074)***	-1.118	(0.071)***	0.069	2.036	0
PL	-0.549	(0.104)***	-1.029	(0.076)***	0.066	0.603	0
PT	-0.684	(0.094)***	-1.286	(0.078)***	0.049	0.417	0
RU	-0.168	(0.213)	-1.283	(0.061)***	0.043	2.609	0
SE	-1.110	(0.061)***				0	
SG	-1.197	(0.061)***				0	
TH	2.504	(0.636)***	-1.157	(0.065)***	0.011	∞	0
TR	-1.786	(0.120)***	-1.130	(0.070)***	0.090	0	0
TW	-0.548	(0.055)***				0.604	
UK	-0.077	(0.179)	-0.998	(0.060)***	0.036	5.989	0.077
Average	-0.758	0.184	-1.130	0.068	0.047	0.338	0
Median	-0.664	0.102	-1.232	0.070	0.047	0.440	0
Std Dev	1.028	0.204	0.244	0.008	0.024		

Note: Standard Errors in Parenthesis *$^{*}p<0.10$; $^{**}p<0.05$; $^{***}p<0.01$*
Average and Median Half-Life calculated from Average and Median Estimates

Table B11: Threshold Autoregression Persistence Estimates for iPad Devices, $d = 36$

	i =iPad, $d = 36$, No. Observations: 278						
Country	Inner $\hat{\rho}_0$	Inner SE	Outer $\hat{\rho}_1$	Outer SE	Threshold c_i	Half-life $\hat{\rho}_0$	Half-life $\hat{\rho}_1$
AE	-2.106	(0.159)***	-0.306	(0.029)***	0.017	0	1.314
AT	0.098	(0.124)	-1.068	(0.052)***	0.065	∞	0
AU	-0.686	(0.072)***	-0.927	(0.071)***	0.092	0.414	0.183
BE	-0.087	(0.107)	-1.089	(0.054)***	0.072	5.272	0
BR	-0.776	(0.064)***	-1.097	(0.071)***	0.151	0.321	0
CA	-1.278	(0.093)***	-0.814	(0.047)***	0.070	0	0.285
CZ	-0.304	(0.109)***	-1.186	(0.060)***	0.089	1.324	0
DE	0.162	(0.139)	-1.106	(0.054)***	0.064	∞	0
DK	-0.116	(0.221)	-1.021	(0.046)***	0.032	3.892	0
ES	0.799	(0.153)***	-0.552	(0.045)***	0.176	∞	0.598
FI	-0.152	(0.101)	-1.098	(0.055)***	0.075	2.911	0
FR	-0.066	(0.108)	-1.091	(0.054)***	0.072	7.028	0
HK	-0.656	(0.063)***	-0.226	(0.056)***	0.010	0.45	1.873
HU	-0.574	(0.094)***	-1.163	(0.064)***	0.112	0.562	0
IE	-0.234	(0.088)***	-1.161	(0.057)***	0.083	1.8	0
IT	-0.109	(0.106)	-1.092	(0.054)***	0.072	4.158	0
JP	-2.429	(0.331)***	-1.074	(0.052)***	0.020	0	0
KR	-1.482	(0.161)***	-0.927	(0.046)***	0.036	0	0.183
LU	-0.109	(0.106)	-1.092	(0.054)***	0.072	4.158	0
MX	-0.713	(0.093)***	-1.171	(0.067)***	0.108	0.384	0
MY	-0.258	(0.166)	-1.130	(0.054)***	0.041	1.608	0
NL	-0.099	(0.106)	-1.091	(0.054)***	0.072	4.603	0
NO	-0.658	(0.087)***	-1.100	(0.064)***	0.081	0.447	0
NZ	-0.725	(0.057)***				0.372	
PH	1.206	(0.201)***	-0.607	(0.043)***	0.020	∞	0.514
PL	-0.905	(0.051)***				0.204	
PT	0.204	(0.139)	-1.034	(0.052)***	0.063	∞	0
RU	0.394	(0.295)	-1.059	(0.048)***	0.033	∞	0
SE	0.648	(0.167)***	-1.025	(0.050)***	0.059	∞	0
SG	-0.375	(0.072)***	-0.856	(0.054)***	0.058	1.021	0.248
TH	-0.991	(0.051)***				0.102	
TR	-1.165	(0.061)***				0	
TW	-0.306	(0.110)***	-0.974	(0.048)***	0.026	1.314	0.131
UK	-0.014	(0.159)	-0.955	(0.056)***	0.046	34.036	0.155
Average	-0.408	0.124	-0.970	0.054	0.066	0.916	0.137
Median	-0.281	0.106	-1.071	0.054	0.068	1.455	0
Std Dev	0.733	0.063	0.239	0.008	0.037		

Note: Standard Errors in Parenthesis *p<0.10; **p<0.05; ***p<0.01
Average and Median Half-Life calculated from Average and Median Estimates

Table B12: Threshold Autoregression Persistence Estimates for iPad Mini Devices, $d = 36$

	i =iPad Mini, $d = 36$, No. Observations: 278						
Country	Inner $\hat{\rho}_0$	Inner SE	Outer $\hat{\rho}_1$	Outer SE	Threshold c_i	Half-life $\hat{\rho}_0$	Half-life $\hat{\rho}_1$
AE	7.221	(0.921)***	-0.569	(0.040)***	0.003	∞	0.57
AT	-0.482	(0.082)***	-1.410	(0.066)***	0.094	0.73	0
AU	1.194	(0.523)**	-0.967	(0.058)***	0.018	∞	0.141
BE	-0.508	(0.086)***	-1.399	(0.066)***	0.082	0.677	0
BR	-1.015	(0.173)***	-0.346	(0.057)***	0.116	0	1.13
CA	-0.427	(0.149)***	-0.966	(0.055)***	0.057	0.862	0.142
CZ	-0.203	(0.118)*	-1.292	(0.060)***	0.080	2.115	0
DE	-0.167	(0.140)	-1.421	(0.089)***	0.072	2.626	0
DK	0.043	(0.170)	-1.074	(0.058)***	0.046	∞	0
ES	-0.465	(0.084)***	-1.400	(0.064)***	0.094	0.767	0
FI	-0.553	(0.090)***	-1.405	(0.068)***	0.076	0.596	0
FR	-0.504	(0.087)***	-1.394	(0.066)***	0.082	0.684	0
HK	0.399	(0.072)***	-0.445	(0.043)***	0.020	∞	0.815
HU	-0.574	(0.102)***	-0.975	(0.073)***	0.126	0.562	0.13
IE	-0.490	(0.094)***	-1.393	(0.066)***	0.077	0.713	0
IT	-0.508	(0.086)***	-1.399	(0.066)***	0.082	0.677	0
JP	-0.469	(0.122)***	-1.006	(0.069)***	0.042	0.758	0
KR	-0.420	(0.076)***	-0.730	(0.073)***	0.072	0.881	0.367
LU	-0.508	(0.086)***	-1.399	(0.066)***	0.082	0.677	0
MX	-0.918	(0.050)***				0.192	
MY	0.001	(0.102)	-1.040	(0.055)***	0.086	∞	0
NL	-0.510	(0.086)***	-1.400	(0.066)***	0.081	0.673	0
NO	-0.271	(0.137)**	-1.046	(0.067)***	0.062	1.518	0
NZ	-0.697	(0.080)***	-1.116	(0.090)***	0.062	0.402	0
PH	3.274	(0.715)***	-0.684	(0.057)***	0.011	∞	0.417
PL	-0.382	(0.157)**	-0.915	(0.062)***	0.077	0.997	0.195
PT	-0.553	(0.090)***	-1.405	(0.068)***	0.076	0.596	0
RU	0.013	(0.303)	-1.263	(0.055)***	0.032	∞	0
SE	0.042	(0.140)	-1.144	(0.058)***	0.078	∞	0
SG	0.167	(0.467)	-1.051	(0.058)***	0.009	∞	0
TH	-1.157	(0.087)***	-0.530	(0.057)***	0.050	0	0.636
TR	-0.640	(0.200)***	-1.206	(0.064)***	0.066	0.47	0
TW	-0.005	(0.164)	-0.662	(0.058)***	0.025	95.734	0.442
UK	-0.334	(0.065)***	-1.315	(0.067)***	0.118	1.181	0
Average	-0.012	0.180	-1.084	0.063	0.065	39.946	0
Median	-0.446	0.102	-1.116	0.064	0.076	0.813	0
Std Dev	1.460	0.191	0.318	0.010	0.031		

Note: Standard Errors in Parenthesis *p<0.10; **p<0.05; ***p<0.01
Average and Median Half-Life calculated from Average and Median Estimates

Table B13: Threshold Autoregression Persistence Estimates for iPad Pro Large Devices, $d = 48$

	i =iPad Pro Large, $d = 48$, No. Observations: 266						
Country	Inner $\hat{\rho}_0$	Inner SE	Outer $\hat{\rho}_1$	Outer SE	Threshold c_i	Half-life $\hat{\rho}_0$	Half-life $\hat{\rho}_1$
AE	2.923	(0.200)***	-0.588	(0.035)***	0.012	∞	0.722
AT	-0.663	(0.166)***	-1.435	(0.061)***	0.033	0.588	0
AU	-1.000	(0.102)***	-1.627	(0.072)***	0.059	0.0	0
BE	-0.726	(0.157)***	-1.488	(0.060)***	0.032	0.494	0
BR	-0.538	(0.087)***	-0.993	(0.070)***	0.128	0.829	0.129
CA	-1.711	(0.168)***	-0.916	(0.065)***	0.035	0	0.258
CZ	-0.248	(0.206)	-1.242	(0.061)***	0.041	2.245	0
DE	-0.743	(0.155)***	-1.468	(0.061)***	0.034	0.471	0
DK	-1.460	(0.059)***				0	
ES	-0.684	(0.165)***	-1.429	(0.061)***	0.033	0.555	0
FI	-0.935	(0.152)***	-1.497	(0.060)***	0.033	0.234	0
FR	-0.725	(0.157)***	-1.489	(0.060)***	0.032	0.496	0
HK	0.095	(0.030)***	-1.380	(0.045)***	0.029	∞	0
HU	-1.633	(0.104)***	-0.953	(0.074)***	0.058	0	0.209
IE	-0.944	(0.170)***	-1.455	(0.060)***	0.031	0.222	0
IT	-0.729	(0.158)***	-1.489	(0.060)***	0.032	0.49	0
JP	-1.431	(0.086)***	-1.057	(0.063)***	0.083	0	0
KR	-1.630	(0.117)***	-1.020	(0.066)***	0.038	0	0
LU	-0.743	(0.158)***	-1.486	(0.060)***	0.031	0.471	0
MX	-4.013	(1.032)***	-1.092	(0.056)***	0.013	0	0
MY	-0.613	(0.221)***	-1.417	(0.047)***	0.020	0.674	0
NL	-0.755	(0.159)***	-1.486	(0.060)***	0.031	0.455	0
NO	-0.306	(0.128)**	-1.346	(0.066)***	0.057	1.752	0
NZ	-1.427	(0.096)***	-0.968	(0.093)***	0.072	0	0.186
PH	0.393	(0.145)***	-0.851	(0.057)***	0.052	∞	0.336
PL	-0.060	(0.367)	-1.149	(0.062)***	0.024	10.341	0
PT	-0.946	(0.154)***	-1.499	(0.060)***	0.032	0.219	0
RU	-1.947	(0.140)***	-1.210	(0.053)***	0.052	0	0
SE	-1.568	(0.087)***	-0.899	(0.091)***	0.072	0	0.279
SG	-1.037	(0.061)***				0	
TH	-1.320	(0.126)***	-0.888	(0.093)***	0.039	0	0.292
TR	-1.976	(0.125)***	-0.990	(0.067)***	0.091	0	0.139
TW	0.287	(0.106)***	-0.539	(0.052)***	0.033	∞	0.826
UK	-0.188	(0.211)	-1.325	(0.058)***	0.028	3.072	0
Average	-0.853	0.169	-1.208	0.063	0.043	0.334	0
Median	-0.749	0.153	-1.284	0.060	0.033	0.463	0
Std Dev	1.033	0.161	0.285	0.012	0.024		

Note: Standard Errors in Parenthesis *$^{*}p<0.10$; $^{**}p<0.05$; $^{***}p<0.01$*
Average and Median Half-Life calculated from Average and Median Estimates

Table B14: Threshold Autoregression Persistence Estimates for iPad Pro Small Devices, $d = 48$

	i =iPad Pro Small, $d = 48$, No. Observations: 254						
Country	Inner $\hat{\rho}_0$	Inner SE	Outer $\hat{\rho}_1$	Outer SE	Threshold c_i	Half-life $\hat{\rho}_0$	Half-life $\hat{\rho}_1$
AE	-0.260	(0.081)***	-0.854	(0.052)***	0.021	2.125	0.333
AT	-0.924	(0.118)***	-1.503	(0.063)***	0.041	0.248	0
AU	0.329	(0.319)	-1.543	(0.058)***	0.028	∞	0
BE	-0.826	(0.144)***	-1.500	(0.059)***	0.032	0.366	0
BR	-0.481	(0.097)***	-0.930	(0.065)***	0.126	0.976	0.241
CA	-1.392	(0.140)***	-0.861	(0.069)***	0.047	0	0.324
CZ	-0.193	(0.219)	-1.228	(0.061)***	0.043	2.984	0
DE	-1.076	(0.106)***	-1.466	(0.068)***	0.044	0	0
DK	-1.067	(0.092)***	-1.630	(0.072)***	0.053	0	0
ES	-0.674	(0.202)***	-1.430	(0.059)***	0.028	0.571	0
FI	-0.962	(0.120)***	-1.513	(0.063)***	0.038	0.196	0
FR	-0.901	(0.141)***	-1.505	(0.059)***	0.033	0.277	0
HK	0.176	(0.067)***	-1.124	(0.060)***	0.029	∞	0
HU	-1.756	(0.112)***	-0.909	(0.069)***	0.057	0	0.267
IE	-1.010	(0.114)***	-1.485	(0.065)***	0.040	0	0
IT	-0.845	(0.138)***	-1.510	(0.060)***	0.033	0.343	0
JP	-1.301	(0.133)***	-0.866	(0.066)***	0.043	0	0.318
KR	-5.847	(1.405)***	-1.250	(0.062)***	0.006	0	0
LU	-0.826	(0.144)***	-1.500	(0.059)***	0.032	0.366	0
MX	-1.205	(0.048)***				0	
MY	-0.076	(0.184)	-1.340	(0.052)***	0.028	8.095	0
NL	-0.835	(0.142)***	-1.502	(0.060)***	0.033	0.355	0
NO	0.262	(0.207)	-1.228	(0.057)***	0.034	∞	0
NZ	-0.143	(0.333)	-1.374	(0.069)***	0.025	4.146	0
PH	-0.314	(0.084)***	-1.115	(0.075)***	0.068	1.698	0
PL	-1.138	(0.063)***				0	
PT	-0.962	(0.120)***	-1.513	(0.063)***	0.038	0.196	0
RU	2.683	(1.575)*	-1.280	(0.062)***	0.012	∞	0
SE	-1.490	(0.075)***	-1.178	(0.099)***	0.083	0	0
SG	-1.296	(0.052)***				0	
TH	2.059	(0.825)**	-1.092	(0.067)***	0.010	∞	0
TR	-2.101	(0.172)***	-1.050	(0.064)***	0.065	0	0
TW	-0.088	(0.091)	-0.553	(0.063)***	0.032	6.946	0.795
UK	-0.617	(0.166)***	-1.296	(0.060)***	0.036	0.667	0
Average	-0.738	0.236	-1.262	0.064	0.040	0.477	0
Median	-0.840	0.136	-1.296	0.063	0.034	0.349	0
Std Dev	1.283	0.341	0.265	0.008	0.022		

Note: Standard Errors in Parenthesis *$^{*}p<0.10$; $^{**}p<0.05$; $^{***}p<0.01$*
Average and Median Half-Life calculated from Average and Median Estimates

Table B15: Threshold Autoregression Persistence Estimates for iPad Devices, $d = 48$

	i =iPad, $d = 48$, No. Observations: 266						
Country	Inner $\hat{\rho}_0$	Inner SE	Outer $\hat{\rho}_1$	Outer SE	Threshold c_i	Half-life $\hat{\rho}_0$	Half-life $\hat{\rho}_1$
AE	-2.263	(0.183)***	-0.484	(0.034)***	0.017	0	0.967
AT	-1.316	(0.069)***	-0.857	(0.084)***	0.125	0	0.329
AU	-0.813	(0.081)***	-1.152	(0.073)***	0.090	0.382	0
BE	-1.315	(0.068)***	-0.853	(0.084)***	0.125	0	0.334
BR	4.292	(2.015)**	-0.988	(0.047)***	0.013	∞	0.145
CA	-1.782	(0.093)***	-0.877	(0.043)***	0.069	0	0.305
CZ	0.800	(0.564)	-1.242	(0.056)***	0.039	∞	0
DE	-0.002	(0.273)	-1.225	(0.056)***	0.040	319.594	0
DK	-1.646	(0.085)***	-0.893	(0.049)***	0.076	0	0.286
ES	0.380	(0.142)***	-0.590	(0.051)***	0.233	∞	0.718
FI	-1.319	(0.068)***	-0.837	(0.083)***	0.126	0	0.353
FR	-1.313	(0.068)***	-0.857	(0.084)***	0.125	0	0.329
HK	-1.392	(0.144)***	-0.492	(0.051)***	0.006	0	0.945
HU	0.335	(0.511)	-1.138	(0.056)***	0.027	∞	0
IE	-1.345	(0.068)***	-0.842	(0.081)***	0.125	0	0.347
IT	-1.316	(0.068)***	-0.852	(0.084)***	0.124	0	0.335
JP	-1.195	(0.115)***	-0.715	(0.058)***	0.047	0	0.51
KR	-1.503	(0.145)***	-0.867	(0.048)***	0.038	0	0.317
LU	-1.316	(0.068)***	-0.852	(0.084)***	0.124	0	0.335
MX	-1.235	(0.080)***	-0.895	(0.075)***	0.146	0	0.284
MY	-1.044	(0.053)***				0	
NL	-1.314	(0.068)***	-0.849	(0.084)***	0.125	0	0.338
NO	-0.776	(0.088)***	-1.197	(0.068)***	0.086	0.428	0
NZ	-0.840	(0.063)***				0.349	
PH	0.017	(0.174)	-0.565	(0.047)***	0.023	∞	0.769
PL	-1.645	(0.119)***	-0.922	(0.055)***	0.101	0	0.251
PT	-1.320	(0.068)***	-0.843	(0.084)***	0.127	0	0.346
RU	-0.545	(0.177)***	-1.170	(0.051)***	0.048	0.813	0
SE	2.087	(0.574)***	-1.112	(0.053)***	0.027	∞	0
SG	-2.277	(0.583)***	-0.752	(0.045)***	0.012	0	0.459
TH	-1.378	(0.070)***	-0.718	(0.066)***	0.082	0	0.505
TR	-1.508	(0.135)***	-0.968	(0.070)***	0.091	0	0.186
TW	-0.411	(0.117)***	-1.019	(0.051)***	0.026	1.209	0
UK	-0.293	(0.308)	-1.092	(0.056)***	0.028	1.845	0
Average	-0.780	0.221	-0.897	0.063	0.078	0.423	0.281
Median	-1.314	0.104	-0.862	0.056	0.079	0	0.323
Std Dev	1.243	0.348	0.200	0.015	0.052		

Note: Standard Errors in Parenthesis *p<0.10; **p<0.05; ***p<0.01

Average and Median Half-Life calculated from Average and Median Estimates

Table B16: Threshold Autoregression Persistence Estimates for iPad Mini Devices, $d = 48$

	i =iPad Mini, $d = 48$, No. Observations: 266						
Country	Inner $\hat{\rho}_0$	Inner SE	Outer $\hat{\rho}_1$	Outer SE	Threshold c_i	Half-life $\hat{\rho}_0$	Half-life $\hat{\rho}_1$
AE	8.546	(0.971)***	-0.808	(0.040)***	0.003	∞	0.388
AT	-1.061	(0.082)***	-1.546	(0.068)***	0.100	0	0
AU	-1.204	(0.063)***				0	
BE	-1.095	(0.090)***	-1.528	(0.066)***	0.082	0	0
BR	-1.098	(0.181)***	-0.489	(0.061)***	0.116	0	0.953
CA	-1.387	(0.073)***	-0.923	(0.067)***	0.086	0	0.25
CZ	0.374	(0.363)	-1.392	(0.055)***	0.033	∞	0
DE	-1.035	(0.135)***	-1.624	(0.098)***	0.078	0	0
DK	0.809	(0.424)*	-1.273	(0.056)***	0.028	∞	0
ES	-1.071	(0.088)***	-1.515	(0.065)***	0.094	0	0
FI	-1.119	(0.094)***	-1.538	(0.066)***	0.072	0	0
FR	-1.113	(0.088)***	-1.524	(0.067)***	0.090	0	0
HK	-0.074	(0.045)	-1.461	(0.091)***	0.024	8.322	0
HU	-1.052	(0.063)***				0	
IE	-1.101	(0.097)***	-1.527	(0.065)***	0.077	0	0
IT	-1.095	(0.090)***	-1.528	(0.066)***	0.082	0	0
JP	1.340	(0.600)**	-0.735	(0.062)***	0.012	∞	0.482
KR	0.757	(0.450)*	-0.689	(0.055)***	0.021	∞	0.548
LU	-1.095	(0.090)***	-1.528	(0.066)***	0.082	0	0
MX	-1.244	(0.069)***	-0.839	(0.070)***	0.163	0	0.35
MY	-0.711	(0.069)***	-1.350	(0.077)***	0.151	0.515	0
NL	-1.095	(0.090)***	-1.529	(0.066)***	0.081	0	0
NO	-0.457	(0.239)*	-1.277	(0.068)***	0.038	1.048	0
NZ	-0.759	(0.082)***	-1.352	(0.093)***	0.062	0.45	0
PH	2.836	(0.736)***	-0.846	(0.061)***	0.011	∞	0.342
PL	-1.099	(0.060)***				0	
PT	-1.119	(0.094)***	-1.538	(0.066)***	0.072	0	0
RU	-2.779	(0.400)***	-1.326	(0.053)***	0.026	0	0
SE	-1.052	(0.073)***	-1.548	(0.084)***	0.128	0	0
SG	-1.361	(0.137)***	-0.969	(0.064)***	0.028	0	0.184
TH	-1.038	(0.074)***	-0.555	(0.066)***	0.057	0	0.79
TR	0.281	(0.320)	-1.173	(0.062)***	0.045	∞	0
TW	-0.262	(0.167)	-0.907	(0.071)***	0.026	2.106	0.269
UK	-0.793	(0.064)***	-1.542	(0.073)***	0.130	0.406	0
Average	-0.395	0.199	-1.238	0.067	0.068	1.274	0
Median	-1.056	0.090	-1.352	0.066	0.072	0	0
Std Dev	1.834	0.214	0.344	0.012	0.041		

Note: Standard Errors in Parenthesis $^{*}p<0.10$; $^{**}p<0.05$; $^{***}p<0.01$
Average and Median Half-Life calculated from Average and Median Estimates