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Asymmetry – Resurrecting the Roots

Abstract

This note attempts to reconcile a range of primary methods for dealing with price asymmetry, such as the approaches proposed by Tweeten and Quance (1969), Wolffram (1971) and Houk(1977). Using Wolffram's stylized example, we first illustrate that the notion of asymmetry can be captured in a straightforward and highly intuitive manner in terms of first differences. While this asymmetry definition is more readily interpretable than the alternatives proposed by Wolffram and Houk, we demonstrate that, theoretically, these definitions are equivalent. This conclusion also turns out to be true for Wolfframs's stylized example. Using data on coffee consumption, however, we illustrate that, in practice, these approaches may yield divergent conclusions with respect to asymmetry. We argue that in such situations the asymmetry notion based on first differences should be preferred.

JEL Classification: D13, Q41

Keywords: Irreversibility; decomposition approaches

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1 Manuel Frondel, RWI and Ruhr University Bochum; Christoph M. Schmidt, RWI and Ruhr University Bochum; Colin Vance, RWI and Jacobs University Bremen. *– This work has been partly supported by the Collaborative Research Center "Statistical Modeling of Nonlinear Dynamic Processes" (SFB 823) of the German Research Foundation (DFG), within the framework of Project A3, "Dynamic Technology Modeling".**– All correspondence to: Manuel Frondel, RWI, Hohenzollernstr. 1-3, 45128 Essen, Germany. E-Mail: frondel@rwi-essen.de.*

1 Introduction

The estimation of so-called irreversible supply and demand functions that allow for asymmetric price responses has been a subject of ongoing research across a range of fields in economics, including agriculture (TRAILL, COLMAN, YOUNG, 1978) and energy (GRIFFIN, SCHULMAN, 2005). While theoretical arguments in favor of asymmetric responses to rising or falling agricultural input prices were advanced by JOHNSON (1958), the empirical work on the topic was pushed with an analysis of aggregate farm output by TWEETEN and QUANCE (1969a, b). Their approach, which employs dummy variables that split up the price variable into two complementing explanatory terms capturing either increasing or decreasing input prices, is criticized by WOLFFRAM (1971:356).

WOLFFRAM (1971) proposes an alternative technique based on cumulated price differences that, in their reply to his criticism, TWEETEN and QUANCE (1971:359) concede is superior to their approach, even though the application of the technique to their own data suggests otherwise (TWEETEN, QUANCE, 1971:360). In the aftermath of this exchange, WOLFFRAM's technique, henceforth called the W technique, became the most popular method of partitioning an explanatory variable to allow for the estimation of a non-reversible function (TRAILL, COLMAN, and YOUNG, 1978:528), and has since been expanded upon using more sophisticated approaches, such as error-correction models (for helpful surveys, see MEYER, VON CRAMON-TAUBADEL, 2004, and FREY, MANERA, 2007). Despite WOLFFRAM's (1971) and TWEETEN and QUANCE's (1971) common belief of the superiority of the W technique, however, a number of articles have pointed to several weaknesses in its application, including the high dependence on the starting point of the data (GRIFFIN, SCHULMAN, 2005:7) and its proneness to multi-collinearity problems (SAYLOR, 1974).

Using WOLFFRAM's (1971) example originally conceived to demonstrate the superiority of his method over the TWEETEN and QUANCE – henceforth TQ – approach, this note resurrects WOLFFRAM's (1971) critique and argues that the notion of asymmetry can be captured in a straightforward and highly intuitive manner in terms of first differences. We prove that, in a deterministic context without stochastic influences, this asymmetry definition is equivalent to WOLFFRAM's alternative, but more readily interpretable. Using an empirical example originating from the real world, however, we demonstrate that, in practice, these approaches may yield divergent conclusions with respect to asymmetry. We argue that in such situations the asymmetry notion based on first differences should be preferred.

2 A Reassessment of WOLFFRAM's Example

WOLFFRAM (1971:357) criticizes that any irreversible relationship $y = f(x)$ between a dependent variable y and an explanatory variable x cannot be determined exactly with the TQ approach, which splits x into two complementary variables, x^+ and x^-. Variable x^+ is defined as $x_1^+ = x_1$ and for $i > 1$ by

$$x_i^+ := x_i, \quad \text{if} \quad x_i > x_{i-1}, \tag{1}$$

and $x_i^+ := 0$ otherwise, where subscript i is used to denote the observation, while x^- is defined in a similar way: $x_1^- := 0$, and for $i > 1$

$$x_i^- := x_i, \quad \text{if} \quad x_i \leq x_{i-1}, \tag{2}$$

and $x_i^- := 0$ otherwise. By definition, $x_i^+ + x_i^- = x_i$ for all i.[1]

As an alternative to the TQ decomposition of x, WOLFFRAM (1971) suggests taking cumulated increases and decreases of the explanatory variable x, denoted here by w_i^+ and w_i^-, respectively. In detail, WOLFFRAM (2000:351-352) defines his approach by $w_1^+ = w_1^- := x_1$ and, for $i > 1$,

$$w_i^+ \quad := \quad w_{i-1}^+ + D_i^+ \cdot (x_i - x_{i-1}) = \sum_{k=2}^{i} (x_k - x_{k-1}) D_k^+, \tag{3}$$

$$w_i^- \quad := \quad w_{i-1}^- + D_i^- \cdot (x_i - x_{i-1}) = \sum_{k=2}^{i} (x_k - x_{k-1}) D_k^-, \tag{4}$$

[1]The TQ approach has been adapted for application in various contexts. In a study of car use, for example, ROUWENDAL (1996) splits the fuel price variable x into two complementary price variables x^d and x^p to distinguish between diesel and petrol fuel types.

where $D_i^+ = 1$ for $x_i > x_{i-1}$ and 0 otherwise, while $D_i^- = 1 - D_i^+$.[2] From this definition, it becomes obvious that w^+ and w^- include cumulated differences of increasing and decreasing prices, respectively.

To demonstrate the superiority of his approach over the TQ decomposition, WOLFFRAM (1971) conceives a straightforward example presented in Table 1. For this purpose, WOLFFRAM (1971:358) assumes the following exact relationship between the predefined values of dependent variable y and those of the explanatory variable x, which is split up into x^+ and x^- according to the TQ decomposition:

$$y_i = a_i + 5x_i^+ + 3x_i^-. \tag{5}$$

In this equation, potential residual terms u_i are set to zero: $u_i = 0$, thereby attributing the varying differences between the predefined values y_i and the predicted values $\hat{y}_i := 5x_i^+ + 3x_i^-$ to variable a, whose components are also shown in Table 1.

As WOLFFRAM (1971:357) emphasizes, this contrasts with the classical Ordinary Least Squares (OLS) framework, in which variable a would adopt the role of a constant: $a = a_0$. It is not surprising, therefore, that when applying OLS methods, one obtains the following estimation equation for which both coefficient estimates, 6.25 and 6.99, differ greatly from the predefined coefficients in Equation 5:[3]

$$y_i = -40.23\ (11.03)\ + 6.25\ (0.74)\ x_i^+ + 6.99\ (0.88)\ x_i^- + \hat{u}_i, \tag{6}$$

with $R^2 = 0.912$, $\hat{u}_i \neq 0$ for all i, and standard errors reported in parentheses. In contrast, WOLFFRAM shows that the correct coefficients 5 and 3 are reproduced – apart from the sign of coefficient 3 – by using the proposed W technique and regressing y on w^+ and w^-:

$$y_i = 0 + 5w_i^+ - 3w_i^-, \tag{7}$$

where $\hat{u}_i = 0$ for all i and, hence, $R^2 = 1$. Obviously, this example was constructed in such a way that precisely this result will be obtained when using the W technique.

[2]Using the dummy variables D_i^+ and D_i^-, the TQ decomposition can be concisely described by $x_i^+ = D_i^+ x_i$ and $x_i^- = D_i^- x_i$ for $i > 1$ (MEYER, VON CRAMON-TAUBADEL, 2004:594).

[3]WOLFFRAM (1971:358) reported an estimate of -43.16 for the constant, which appears to be wrong.

Table 1: WOLFFRAM's Original Example and its Modification.

Original Values					W technique				TQ technique				Modified y
y	x	a	Δy	Δx	w^+	w^-	Δw^+	Δw^-	x^+	x^-	Δx^+	Δx^-	$\tilde{y}$
20	10	-30	–	–	10	10	–	–	10	0	–	–	20
35	13	-30	15	3	13	10	3	0	13	0	3	0	35
29	11	-4	-6	-2	13	12	0	2	0	11	-13	11	13
44	14	-26	15	3	16	12	3	0	14	0	14	-11	40
59	17	-26	15	3	19	12	3	0	17	0	3	0	55
44	12	8	-15	-5	19	17	0	5	0	12	-17	12	16
35	9	8	-9	-3	19	20	0	3	0	9	0	-3	7
70	16	-10	35	7	26	20	7	0	16	0	16	-9	50
90	20	-10	20	4	30	20	4	0	20	0	4	0	70
84	18	30	-6	-2	30	22	0	2	0	18	20	18	34

In what follows, we demonstrate that WOLFFRAM's critique with regard to the TQ decomposition is generally correct, although it is inappropriate to blame the TQ decomposition for a poor performance in this specific example. The reason is that the differences between the coefficient estimates reported in Equation (6) and the true coefficients of 5 and 3 is merely the result of the fact that the varying values a_i are approximated by a constant when Equation (5) is estimated by OLS. If one estimates Equation (5) by employing variable a as an additional regressor, thereby avoiding any omitted-variable bias, one can exactly reproduce the coefficients given in Equation (5).

Furthermore, one point that immediately emerges from WOLFFRAM's example is that in case of irreversibility, one may expect distinct intercepts a^+ and a^-, $a^+ \neq a^-$, as is shown in the following modification of WOLFFRAM's example:

$$\tilde{y}_i = -30D_i^+ - 20D_i^- + 5x_i^+ + 3x_i^-, \tag{8}$$

with $a^+ = -30D_i^+$ and $a^- = -20D_i^-$ and the modified values $\tilde{y}_i$ for the dependent variable being shown in Table 1. Equation (8) reflects the fact that in case of asymmetry, one would expect two entirely distinct functions, one for each of the two different regimes of either increasing or decreasing values of x.

If one falsely estimates Equation (8) by using a common intercept, the following OLS results are obtained:

$$\tilde{y}_i = -24.87\ (1.89) + 4.67\ (0.13)\ x_i^+ + 3.36\ (0.15)\ x_i^-. \tag{9}$$

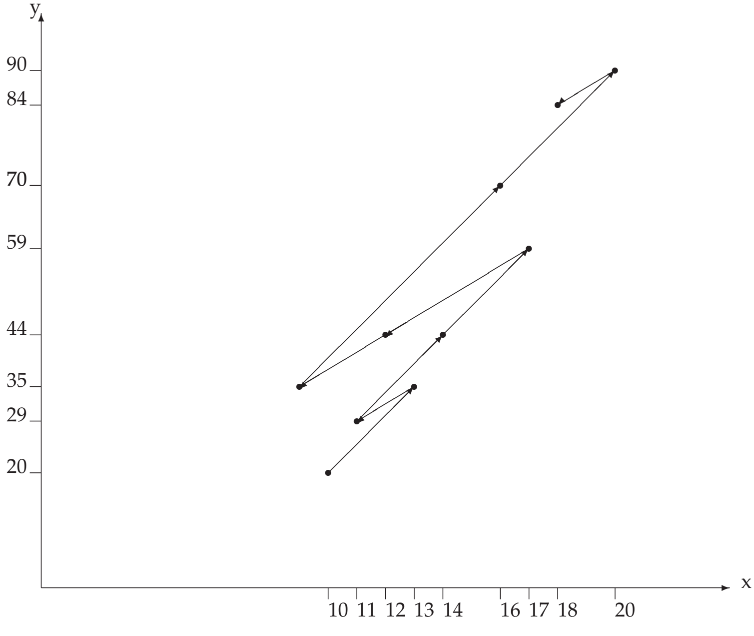
In statistical terms, the coefficient estimates of x_i^+ and x_i^- are significantly different from the true vales 5 and 3, respectively. Clearly, these estimation results, which seem to support WOLFFRAM's criticism with respect to the TQ decomposition, are due to omitted-variable bias. This bias could be readily avoided by including two dummy variables that capture the different intercepts, rather than employing a common constant, thereby perfectly reproducing Equation (8).

Figure 1 illustrates, however, that in the WOLFFRAM example, the application of the TQ decomposition would require more than two distinct intercepts a^+ and a^-. Rather, while three individual intercepts are necessary to describe those parts of the graph with a positive slope of +5 by a linear function, again three distinct intercepts are required for the downward-sloping parts of the graph. From this illustration, it therefore follows that, generally, the TQ decomposition is not a viable procedure to capture asymmetric relationships, as in case of entirely different intercepts no degrees of freedom are left over.

Furthermore, from this illustration a natural definition of asymmetry in terms of first differences $\Delta x_i := x_i - x_{i-1}$ and $\Delta y_i := y_i - y_{i-1}$ suggests itself: While for those parts of the graph with a positive slope the first differences of y and x are related by a factor $\beta^+ = 5$: $\Delta y_i = \beta^+ \Delta x_i$, the downward-sloping parts of the graph are linked by a factor $\beta^- = 3$: $\Delta y_i = \beta^- \Delta x_i$. These proportions also become apparent from Table 1 and the respective columns related to the first differences of x and y. Combining both the upward- and downward-sloping parts provides for a straightforward and highly intuitive definition of asymmetry: There is an asymmetric relationship between two variables x and y if the null hypothesis $H_0 : \beta^+ = \beta^-$ can be rejected for the following equation of first differences:

$$\Delta y_i = \beta^+ \Delta x_i D_i^+ + \beta^- \Delta x_i D_i^-. \tag{10}$$

Figure 1: Illustration of WOLFFRAM's Example



In case of symmetry, that is, in case that H_0 is true and, hence, $\beta := \beta^+ = \beta^-$, the relationship between y and x is also called reversible and simplifies to:

$$\Delta y_i = \beta \Delta x_i \underbrace{(D_i^+ + D_i^-)}_{=1} = \beta \Delta x_i. \tag{11}$$

By recursive iteration, the following equation for y_i in levels can be derived from reversible relationship (11):

$$\begin{aligned} y_i &= y_{i-1} + \beta \cdot (x_i - x_{i-1}) \qquad (\text{if } i > 2) \\ &= y_{i-2} + \beta \cdot (x_{i-1} - x_{i-2}) + \beta \cdot (x_i - x_{i-1}) \qquad (\text{if } i > 3) \\ &= y_{i-2} - \beta \cdot x_{i-2} + \beta \cdot x_i = ... \\ &= y_1 - \beta \cdot x_1 + \beta \cdot x_i. \end{aligned}$$

In short, from reversible relationship (11) it follows that $y_i = \beta \cdot x_i$ for all $i \geq 1$.

In a similar vein, a representation for y_i can be gained from asymmetry definition

(10) for $i > 1$:

$$\begin{aligned} y_i &= y_{i-1} + \beta^+ \cdot (x_i - x_{i-1}) D_i^+ + \beta^- \cdot (x_i - x_{i-1}) D_i^- \\ &= \ldots \\ &= y_1 + \beta^+ \underbrace{\sum_{k=2}^{i} (x_k - x_{k-1}) D_k^+}_{= w_i^+ - w_1^+} + \beta^- \underbrace{\sum_{k=2}^{i} (x_k - x_{k-1}) D_k^-}_{= w_i^- - w_1^-} \\ &= y_1 - \beta^+ w_1^+ - \beta^- w_1^- + \beta^+ w_i^+ + \beta^- w_i^-. \end{aligned}$$

Hence, adopting asymmetry definition (10) implies that y_i can be decomposed according to the W technique proposed by WOLFFRAM (see also his example given by Equation (7)):

$$y_i = \beta^+ w_i^+ + \beta^- w_i^-. \tag{12}$$

In short, both definitions (10) and (12) of asymmetry are equivalent in theory. Using OLS methods, this equivalence can also be easily confirmed for WOLFFRAM's empirical example presented in Table 1, for which one gets the following estimates: $\widehat{\beta}^+ = 5$ and $\widehat{\beta}^- = -3$ for definition (10) and $\widehat{\beta}^- = 3$ for definition (12), respectively, while standard errors are vanishing for both coefficients.

HOUK (1977:570) proposes an alternative approach that "is consistent with the WOLFFRAM technique but is operationally clearer". In fact, from a theoretical point of view, his approach is even equivalent to WOLFFRAM's technique given by Equation (12), as will be shown now. From WOLFFRAM's asymmetry specification (12) and, specifically, $y_1 = \beta^+ w_1^+ + \beta^- w_1^-$, it follows that

$$y_i - y_1 = \beta^+ (w_i^+ - w_1^+) + \beta^- (w_i^- - w_1^-) \qquad \text{for } i > 1. \tag{13}$$

By defining a new dependent variable $y_i^* := y_i - y_1$, Equation (13) reads:

$$y_i^* = \beta^+ (\sum_{k=2}^{i} (x_k - x_{k-1}) D_k^+) + \beta^- (\sum_{k=2}^{i} (x_k - x_{k-1}) D_k^-) \qquad (i > 1), \tag{14}$$

where, in contrast to WOLFFRAM's specification (12), the right-hand side is purged from any initial values.[4] (In fact, instead of (14), HOUK (1977:570) suggests a specifi-

[4]The same goal could be achieved by setting $w_1^+ = w_1^- = 0$, rather than $w_1^+ = w_1^- = x_1$, as is suggested by WOLFFRAM (1971:358).

cation including a deterministic trend αt. This trend is dropped here for the sake of simplicity, but included in the empirical example presented in the next section.) Again, using OLS methods, the equivalence of both HOUK's and WOLFFRAM's definitions can be confirmed for WOLFFRAM's empirical example, for which the estimates for the slope coefficients β^+ and β^- turn out to be the same, respectively.

Finally, HOUK (1977:570) additionally suggests a specification that includes only first differences of the increasing and decreasing phases of x without summing these up, as in Equation (14):

$$\Delta y_i = \alpha + \beta^+ \Delta x_i D_i^+ + \beta^- \Delta x_i D_i^-. \tag{15}$$

Apart from constant α, with this specification, HOUK, in fact, proposes testing asymmetry according to asymmetry definition (10).

In sum, while numerous approaches have been suggested in the economic literature to capture asymmetry, this section has demonstrated that, theoretically and for contrived examples, such as WOLFFRAM's, in which stochastic disturbances are absent, both WOLFFRAM's and HOUK's approaches are equivalent to the asymmetry definition (10), which is based on first differences. However, for empirical examples originating from the real world, such as that presented in the subsequent section, we now demonstrate that WOLFFRAM's and HOUK's approaches and the definition based on first differences may yield contrary answers to the question of asymmetry.

3 Empirical Illustration

To illustrate this point, we present an empirical application that regresses per-capita coffee consumption in the U. S. on the price of robusta coffee beans. Coffee is a commodity that lends itself to investigation in the context of price asymmetries, as commodity price cycles lead to frequent and large price fluctuations. The assembled data set is measured on a yearly basis spanning 1960 through 2011 and is compiled from two sources: the data on prices, which are expressed in real terms using the base year

2005, is taken from the Global Economic Monitor (GEM) Commodities web site of the WORLD BANK (2013). The data on per-capita coffee consumption is drawn from the USDA Food Availability System.

For keeping the example simple and as close as possible to the theoretical discussion of the previous section, we abstain from using more sophisticated methods, such as co-integration and error-correction models, although DICKEY-FULLER tests indicate that we cannot reject the null hypothesis that both the price and the per-capita consumption variables are integrated of order one, I(1). Referencing Equations 1-4, we transform the price series x using the TQ- and W decompositions, which serve as explanatory variables to explain per-capita consumption y. Furthermore, we add the variable *year* to account for secular trends in per-capita consumption. The empirical results obtained from the TQ- and W decompositions are compared in Table 2 to those received from the estimation of asymmetry definition (10), as well as those from HOUK's approach, for which the key explanatory variables are defined as follows: $h_i^+ := \sum_{k=2}^{i} (x_k - x_{k-1}) D_k^+ = w_i^+ - w_1^+$ and $h_i^- := \sum_{k=2}^{i} (x_k - x_{k-1}) D_k^- = w_i^- - w_1^-$.

Several outcomes bear highlighting: First, apart from the constants, the empirical results of WOLFFRAM's and HOUK's specifications are identical. This is due to the fact that both the dependent variables y_i and y_i^* and the key explanatory variables h_i^+, h_i^- and w_i^+, w_i^- differ merely by constants. In other words, WOLFFRAM's and HOUK's approaches are not only theoretically equivalent, as has been shown in the previous section, but are also identical from an empirical point of view.

Second, while all key explanatory variables show the expected signs, yet are not always statistically significant, F tests clearly reject the null hypothesis of symmetry only for the WOLFFRAM (= HOUK) approach, but neither for the TQ specification nor for the approach based on first differences. This divergence raises the question as to which approach should be preferred when conclusions are drawn with respect to asymmetry, with the TQ decomposition of TWEETEN and QUANCE (1969) being known to be an inferior option.

We argue that, for at least three reasons, the asymmetry definition based on first differences should be preferred. First, while it is equivalent to WOLFFRAM's decomposition in a deterministic context, but is generally different in empirical examples with a limited number of observations,[5] the basic principle of asymmetry is reflected in a highly transparent manner only by definition (10).

Table 2: Empirical Comparison of Asymmetry Approaches.

	TWEETEN, QUANCE		WOLFFRAM		HOUK		First Differences	
	y		y		y^*		Δy	
	Coeffs.	Errors	Coeffs.	Errors	Coeffs.	Errors	Coeffs.	Errors
x^+	** -0.0052	(0.0013)	–	–	–	–	–	–
x^-	** -0.0072	(0.0018)	–	–	–	–	–	–
w^+	–	–	**-0.0072	(0.0010)	–	–	–	–
w^-	–	–	0.0013	(0.0011)	–	–	–	–
h^+	–	–	–	–	**-0.0072	(0.0010)	–	–
h^-	–	–	–	–	0.0013	(0.0011)	–	–
ΔxD^+	–	–	–	–	–	–	**-0.0042	(0.0012)
ΔxD^-	–	–	–	–	–	–	-0.0015	(0.0013)
year	** -0.1566	(0.0137)	0.0477	(0.0319)	0.0477	(0.0319)	0.0076	(0.0054)
const.	**324.31	(27.42)	-76.94	(62.29)	-94.87	(62.57)	-15.12	(10.64)
Adj. R^2	0.743		0.854		0.854		0.227	
Correlation	$(x^+, x^-) : -0.64$		$(w^+, w^-) : 0.97$		$(h^+, h^-) : 0.97$		$(\Delta xD^+, \Delta xD^-) : 0.18$	
F tests	$F(1,48) = 2.76$		$F(1,48) =$ **41.20		$F(1,48) =$ **41.20		$F(1,47) = 1.89$	

Number of observations: 52

Second, beyond this theoretical argument, due to its formulation in first differences, definition (10) is also adequate in cases when the variables involved are I(1), as in our coffee example. Upon employing DICKEY-FULLER tests, we can reject the null hypotheses that ΔxD^+, ΔxD^-, and Δy are I(1). In contrast, the W technique may be prone to spurious correlation, as our empirical example illustrates: DICKEY-FULLER

[5]Using a simulation and a modification of WOLFFRAM's example that includes normally distributed error terms, we find indistinguishable coefficient estimates for both approaches for 10,000 observations, but substantially divergent estimates for only 100 observations. In this case, we also receive contradictory results for the issue of asymmetry.

tests indicate that (1) we cannot reject the null hypotheses that both variables, w^+ and w^-, are I(1) and (2) there is no co-integration relationship between y, w^+ and w^-. Third, the W technique is highly prone to multi-collinearity. In the coffee example, for instance, the correlation coefficient between w^+ and w^- amounts to about 0.97, whereas the correlation between ΔxD^+ and ΔxD^- is substantially lower at 0.18.[6]

4 Summary and Conclusion

This paper has demonstrated that WOLFFRAM's (1971) method for dealing with asymmetry, which has established itself as a standard within the field of agricultural economics and other economic disciplines, is principally consistent with an alternative definition of asymmetry that is based on first differences and highlighted here. While both approaches yield the same results for the stylized example given by WOLFFRAM (1971), using an empirical example originating from the real world in which the data generation process is characterized by a stochastic component and the number of observations is typically limited, we have illustrated that both definitions may yield contrary answers to the question of asymmetry.

This divergence raises the question as to which approach should be preferred when conclusions are drawn with respect to asymmetry. On the basis of our theoretical discussion, we argue that in such situations the definition of asymmetry based on first differences should be preferred for several reasons, not least because it is more easy to grasp than WOLFFRAM's W technique to capture asymmetry. In fact, the W technique incorporates the history of the price trajectory by splitting up the price variable x into two complementary variables w^+ and w^- that reflect either cumulated price increases or decreases, respectively. This technique comes at some cost of intuition: Because the W technique implies that the *level* of dependent variable y is supposed to be explained by cumulated *changes* of an explanatory variable x, it is not immediately clear how to interpret the coefficients. Beyond this, as our empirical example has illustrated, the

[6]For WOLFFRAM's example, the correlation coefficient between w^+ and w^- amounts to about 0.88.

W technique may be more prone to spurious correlation, as well as multi-collinearity problems.

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