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Exchange Rate Volatility and other Determinants of Hysteresis in Exports – Empirical Evidence for the Euro Area

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This paper looks at potential reasons behind a weak reaction of Euro Area member countries' exports to small exchange rate movements. For this purpose it derives dynamic export hysteresis on a micro (firm) level and an aggregate level, if sunk adjustment costs matter for export market entry and exit decisions. Furthermore, we incorporate option-to-wait effects arising from exchange rate uncertainty and develop an algorithm which allows an estimation of the macro hysteresis loop. Our play regression model is then applied to empirical export equations (Euro Area member countries to the United States) and the sample period 1995 to 2014 (monthly and quarterly data). We do not confine ourselves to the aggregate macro level but also take a sectoral/branch perspective. Analysing one of the largest export destinations outside the Eurozone, the US, we find export hysteresis for many EA member countries. We also discuss the underlying dynamics more deeply.

Keywords: Euro Area, exchange rate movements, export demand, play-hysteresis, modelling techniques, switching regression, United States

JEL Classifications: C51, C63, E24, F41

1 Introduction

European politicians and business lobbyists have frequently been concerned with the external value of the European currency in earlier periods of Euro appreciation. In fact, concerns have been raised nearly every time when the euro appreciated. Interest groups agreed that the euro

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exchange rate had reached a “pain threshold“ for European companies. The latter implies that, beyond some boundaries (“pain thresholds”), stronger export reactions in case of an exchange rate are expected.

In this context, it is important to assess the extent to which the euro is too strong for a specific euro area member country. For this purpose, for instance Belke and Volz (2014) report estimates of the USD/EUR exchange rate pain thresholds and rank the euro area member countries accordingly. The USD/EUR threshold is estimated to be 1.54 for Germany, 1.29 for Spain, 1.28 for Finland, 1.23 for France, 1.19 for Italy, and a very low 1.04 for Greece. The point estimate for Germany turns out to be rather close to the pain threshold of USD/EUR 1.55 which has been calculated by Belke, Göcke and Günther (2013). What is more, the European Commission (2014) assesses Euro Area member states’ different degrees of vulnerability to changes in the exchange rate.

In this paper, however, we are also interested in calculating the lower real exchange rate (“competitiveness”) triggers which would lead to a spurt in Euro Area member countries’ exports. What motivates us is the fact that this perspective has become substantially more relevant in post-Lehman Europe because an improvement in the current account is of paramount importance to, among others, lower the foreign debt level and stimulate growth again.[1]

Potential reasons of a *weak reaction* of exports to small exchange rate movements are manifold: hedging of exchange rate uncertainty, low price elasticity of exports, pricing-to-market, and significant (sunk) market entry or/and exit costs.[2] Based on these arguments, a non-linear reaction of exports to exchange rate changes appears reasonable: small exchange rate changes only tend to have weak effects. However, stronger exchange rate changes which follow a monotonously one-directional trend at some point cause larger reactions of the export volume. The exchange rate which lets the firm change the volume of its export activity (i.e. the pain threshold) is product-dependent and should differ from company to company and from sector to sector (von Wartenberg, 2004). We emphasize that there is *heterogeneity of the exchange rate threshold across firms* on the micro level. Suppliers of niche products, such as in the field of specialized mechanical engineering or certain segments of the automobile business (hysteretic goods) can perhaps shrug off the increase in value of the euro with comparative ease, while firms with standard products (non-hysteretic goods) have a huge problem with a strong euro. What is more, dependent on *past* exchange rate movements, firms have earlier decided on their export activity status and have spent sunk costs on market entry investments when the exchange rate was favorable or, vice versa, may have retreated from the export markets if the exchange rate turned out unfavorable. Thus, past decisions are impacting

[1] For the following arguments see Belke, Göcke and Günther (2013).

[2] For further reasons of a weak reaction of Greek exports see Pelagidis (2014).

on the exporters' current reaction to exchange rate movements. This kind of path-dependence (not only) in foreign trade is associated with the term "hysteresis" (Baldwin, 1989, 1990, and Dixit, 1994).

We start from the basic insight that empirically addressing the phenomenon of non-linear reactions of exports is not straightforward. Since firms are (due to differences concerning e.g. their pricing-behaviour, their sunk cost structure etc.) heterogeneous with respect to their reaction on exchange rate changes, the necessary micro data may not be available. Even worse, aggregation of non-linear path-dependent microeconomic activity to a sectoral or macroeconomic analysis is not straightforward as well, since the path-dependent dynamic pattern may differ between the micro perspective of a firm and the aggregated macro perspective of an entire sector/economy consisting of *heterogeneous* firms (see the discussion in Göcke, 2002, and Belke, Göcke and Günther, 2013).

Our main objective is to contribute to a solution of these problems and to present and empirically apply an approach which captures the path-dependent non-linear dynamics on a macro level called *play-hysteresis*, since it shows an analogy to mechanical play. One of our main contributions is to integrate "play" into a standard regression framework. This has the advantage of a lower demand concerning the underlying data, since we can employ macro-data. Moreover, by developing a theory that is testable using more readily available macro data, the paper brings hysteresis closer to applicability, for instance, for policy makers looking for solutions of the still enduring crisis in some Euro Area member countries.

For these purposes, we employ models of hysteresis in trade derived from ferro-magnetism (for hysteresis in foreign trade see Kemp and Wan, 1974, Baldwin, 1989, Baldwin and Krugman, 1989 and Dixit, 1989, Kannebley, 2008, Roberts and Tybout, 1997).

The remainder of the paper proceeds as follows. Section 2 surveys export hysteresis on a micro (firm) level and an aggregated level if sunk adjustment costs matter for export market entry and exit decisions. Furthermore, the impacts of option-to-wait effects due to uncertainty on the aggregation procedure are illustrated. Section 3 presents an algorithm which allows an estimation of the aggregated/macro hysteresis loop taking into account the variable option value effects resulting from on changing volatility of exchange rates. In section 4, we apply the play regression model to Euro Area exports to the United States. We do not confine ourselves to the aggregate macro level but also take a sectoral/branch perspective. Section 5 finally concludes.

2 Hysteresis on The Micro Level and Aggregation to the Macro Level

2.1 'Band of Inaction' from a Microeconomic Perspective

Hysteresis in foreign trade is a result of sunk market-entry costs (Baldwin 1989, 1990). Potentially exporting firms must expend market-entry investments, e.g. for gathering information on the new market (costs for market research), setting up distribution and service networks, bearing the costs of establishing a brand name through advertising, and bringing the foreign product into conformity with domestic health regulations, or for hiring new workers to start the production of the exported goods, etc. These firm specific investments are (partially) irreversible and can ex-post be seen as sunk costs. Analogously a market entry can result in exit costs, e.g. if employees are receiving severance payments due to stopping the production and distribution of the exports. The introduction of sunk entry and exit costs results in a path-dependent (hysteresis) pattern of the firm's activity (see Figure 1).

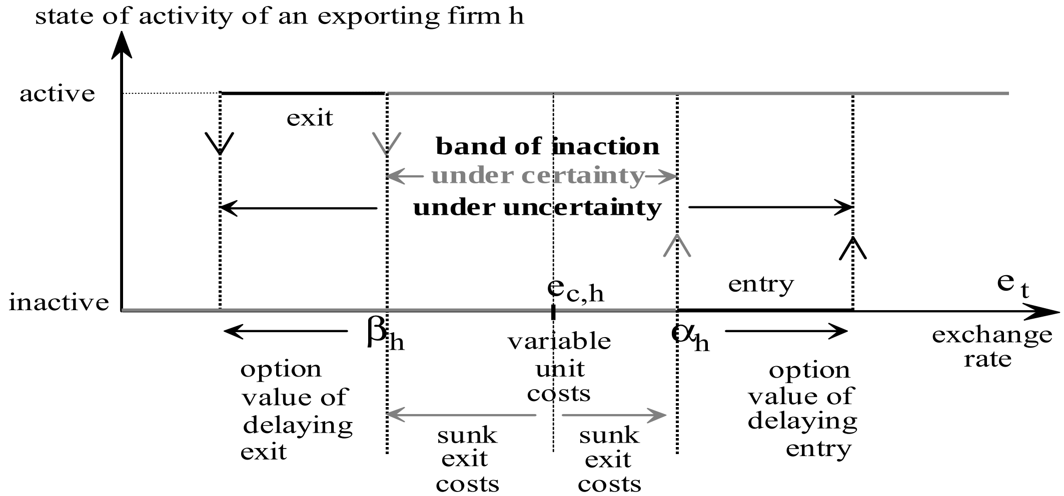
An exporting firm has to bear revenue changes in its home currency if the price on the export market does not change in proportion to the exchange rate. Assume a firm h that potentially produces and exports one unit. Without any market entry or exit costs, a specific exchange rate $e_{c,h}$ results in an exact compensation of the variable unit costs of the firm's export good. The exchange rate e is defined as the home currency price of foreign exchange. A devaluation (i.e. an increase of e) results in an entry into the foreign export market for $e > e_{c,h}$, and an revaluation triggers a market exit if $e < e_{c,h}$.

The reaction to exchange rate changes alters if sunk costs have to be considered. A market entry of a previously inactive firm only results if not only variable/unit costs but sunk entry costs are covered as well. Thus the exchange rate triggering an entry α_h exceeds the variable cost rate $e_{c,h}$. After a firm has entered the export market, the foreign currency may depreciate. But once in the market, it is still profitable for the firm to sell as long as the resulting losses are below sunk exit costs. Thus, the exit trigger β_h is below $e_{c,h}$. In a situation with sunk entry and exit costs the entry and the exit triggers differ which results in a 'band of inaction'.[3] Inside this band, the current exchange rate does not unambiguously determine the current state of the firm's activity.

Since entry and exit costs can be interpreted as an irreversible investment, in the case of uncertainty (i.e. if exchange rates are seen as stochastic) the real option approach has to be applied (Belke and Gros, 1998, 2001, Bentolila and Bertola, 1990, Dixit and Pindyck, 1994, Belke and Göcke, 1999, 2005). An inactive firm's decision on a present entry, includes the option to stay passive and to enter later. A stochastic exchange rate which at the moment is covering costs, may again decrease in the future. If the firm stays passive although the present situation tempts to enter the market, it can avoid future losses in case this favorable situation is only short. An entry cancels the option to enter later and to "wait-and-see" if the future exchange rate will turn out to be (un)favorable. Thus, in a stochastic situation, the sunk costs and, additionally, an option value of waiting have to be covered in order to trigger an entry.

[3] This micro hysteresis pattern is a so-called "non-ideal relay", see Krasnosel'skii and Pokrovskii (1989), p. 263.

Figure 1: Micro Hysteresis: Activity of a Firm h



Thus, uncertainty implies an upward shift of the entry trigger. Analogously, uncertainty creates an option value of waiting for a previously active firm deciding about a market entry, resulting in a reduction of the exit trigger. The opportunity of a “wait-and-see”-strategy shifts the exit-trigger to the left, and analogously the entry-trigger to the right: the ‘band of inaction’ is widened by uncertainty. This widening effect on the inaction-band is the stronger, the more volatile the exchange rate is expected by the firm.

2.2 Aggregation to the Macroeconomic Perspective and the Emergence of 'Play'

The pattern of hysteresis depends on the scope: the *micro*economic behaviour as presented above shows a discontinuous switching-pattern (being active or not on a foreign market). However, *macro*economic dynamics of *aggregate* exports of a sector/country show a different pattern if based on an aggregation over firms with heterogeneous cost structures. The aggregate macroeconomic loop is characterized by a smooth/continuous transition between different “branches” of the loop, occurring with changes in the direction of the exchange rate movement. We now outline an aggregation approach based on the Preisach approach introduced by Mayergoyz (1986) (generally used in mathematics and physics to model aggregation of hysteresis effects, for applications in economics see Amable et al., 1991, 1995, Cross, 1994, Göcke, 1994, Piscitelli et al., 1999, Mota and Vasconcelos, 2012).

Every potentially active firm h is characterized by a distinct α_h/β_h-entry/exit-set. In a diagram with entry/exit triggers on the axes (Figure 2), all α/β-points representing the heterogeneous firms can be found in the triangle area T above the 45°-line, since $\alpha_h \geq \beta_h$. Points located on the 45°-line represent non-hysteretic employers (i.e. firms with zero sunk costs, thus, $\alpha_h = \beta_h$).

Assume a simple initial situation with an exchange rate $e = 0$ and no firm being active. Now, a rising exchange rate leads to an entry of the firms with the lowest entry trigger α_h. Aggregate exports increase, as traced in Figure 2 (a), with a growing space of the hatched triangle S_t^+ representing the firms which have entered (and S_t^- representing the inactive firms). For a rising e the triangle S_t^+ grows via shifting the horizontal borderline upwards. The corresponding aggregate export reaction is depicted in Figure 5 by the path OA.

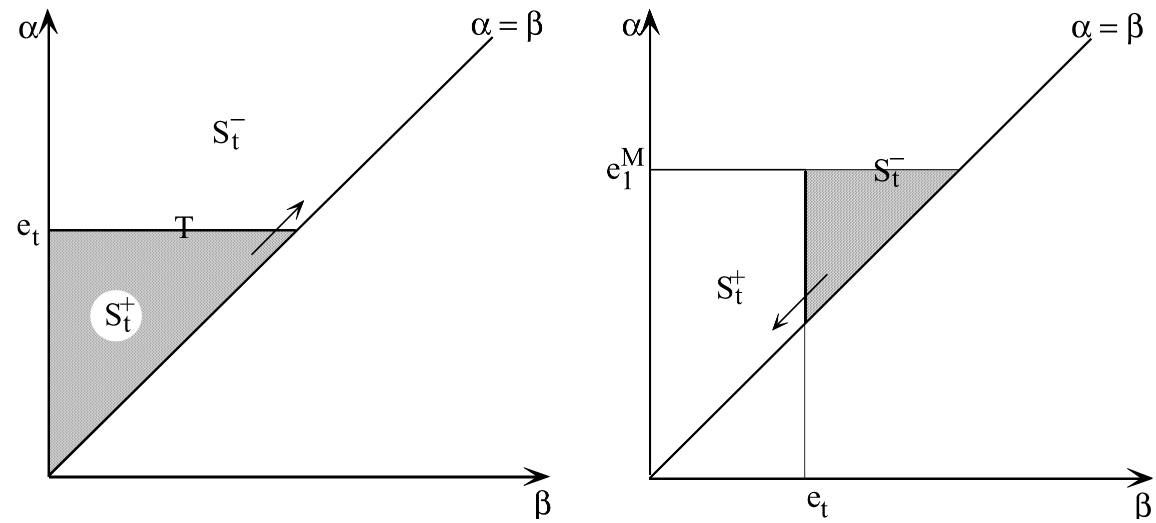
Figure 2 (b) shows the effects of a subsequent price decrease (after a local maximum e_1^M was reached). By passing their exit triggers β_h firms will leave the market, represented by a left vertical shift of the S_t^--S_t^+-borderline. The corresponding aggregate path in Figure 3 is BC.

After again changing the direction (at the local minimum e_1^m) as depicted in Figure 2 (c) only the right-horizontal part of the S_t^+-borderline is shifted upwards (as long as the old maximum e_1^M is not passed), resulting in an aggregate reaction CD in Figure 3. A subsequent exchange rate decrease (Figure 2 (d)) corresponds to DE in Figure 3. With several cycles a "staircase"-borderline of the S_t^+-area of active firms results, where the coordinates of the staircase are determined by past extrema of the movement of e. If later on the exchange rate passes "old" local extrema, the corresponding staircase-corner is erased from the "memory" of the macro system. Aggregation results in a changed type of hysteresis: a *continuous* branch-to-branch transition in the macro loop occurs with *every local extremum* of the path of the input variable, while at the microeconomic firm level passing of specific *triggers* causes *dis*continuous switches. The *distribution* of the firms in the $\alpha \geq \beta$-triangle determines the *curvature* of the branches of the macro loop. The more clustered the firms are in a specific area, the more "curved" are the branches.

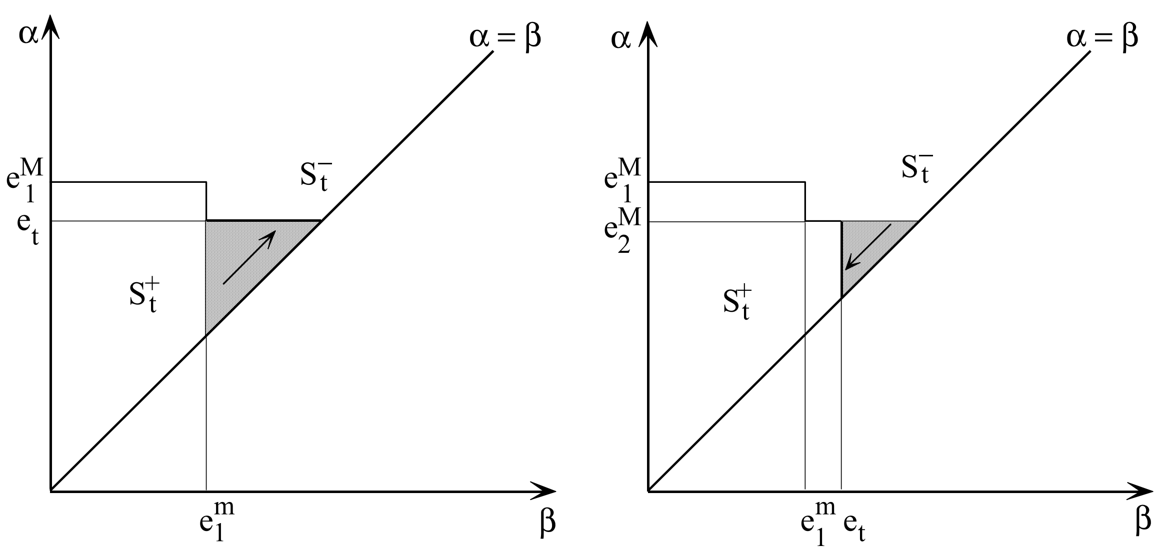
Illustrating the effects of uncertainty on aggregate exports, we assume – as a starting point – a situation without any stochastic effects. The preceding time path of the exchange rate has (under certainty) created an area of active firms S^+ (see Figure 4 (a)). The introduction of uncertainty affects all firms bearing *sunk costs* in the same way (Belke and Göcke, 1999, p. 275, Belke and Göcke, 2005): increasing entry (α_h) and decreasing exit (β_h) triggers are shifting the (α_h,β_h) points of all hysteretic firms in an outward direction, dependent on the extent of uncertainty (S^+ is shifted to the north-west to $S^{+'}$ in Figure 4 (b)). However, the introduction of uncertainty does not have an impact on the location of the non-hysteretic firms (without any sunk costs, remaining on the α=β-line). As a result of the re-location of the hysteretic firms, a "depopulated" zone parallel to the α=β-line emerges.

Figure 2: The Preisach Aggregation Procedure: Active Firms under a Volatile Exchange Rate

(a) ascending exchange rate (b) descending exchange rate



(c) again increasing exchange rate (d) again decreasing exchange rate



Source: Following Amable et al. (1991), Figure 3 and 4.

Figure 3: Aggregate Macroeconomic Hysteresis Loop.

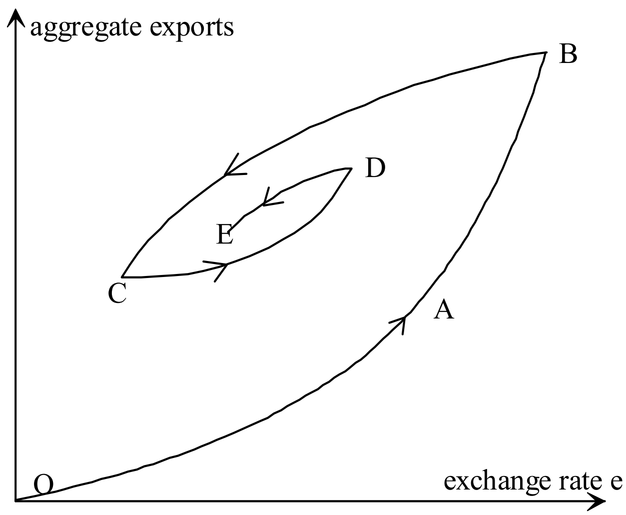
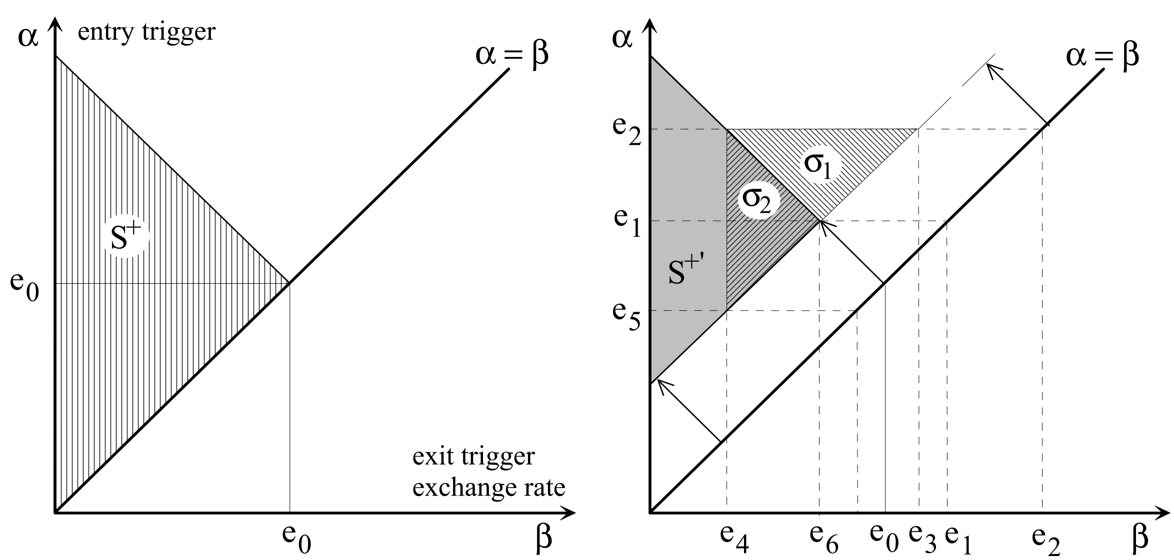


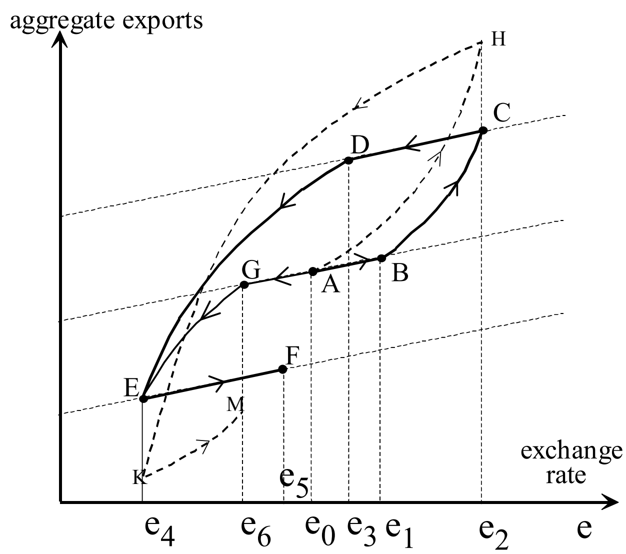
Figure 4: Activity of (Heterogeneous) Firms Dependent on the Exchange Rate

(a) in an initial situation without uncertainty (b) after introduction of uncertainty



Source: following Belke and Göcke (2001a, 2005)

Figure 5: Macro Hysteresis Loop Under Uncertainty Including 'Play'



Source: following Belke and Göcke (2001a, 2005)

This "depopulation" effect has consequences for the type of reaction pattern on the aggregate level. Starting from an initial realization e_0, an increase in the exchange rate up to e_1 leads to a *weak* reaction of exports (i.e., in 'play' analogous to backlash in mechanics) because there will be no firm with sunk costs which will enter. This corresponds to a movement from A to B in Figure 5. After passing the play area, an increase, e.g. to the local maximum e_2, causes a *strong* reaction (called 'spurt') which results from an entry of those firms represented by area σ_1 in Figure 4 (b), which is resulting in the path B to C in Figure 5. If afterwards the exchange rate decreases towards e_3, at first a *weak* ('play') reaction (CD) results, until e_3 is passed leading to a spurt reaction if e is falling further on. An exchange rate sequence $e_0 \rightarrow e_1 \rightarrow e_2 \rightarrow e_3 \rightarrow e_4 \rightarrow e_5$ results in a macroeconomic hysteresis loop characterized by a trajectory ABCDEF. In comparison, the corresponding hysteresis loop under certainty can be depicted by the dotted path AHKM.

Summarizing, uncertainty horizontally expands the macro hysteresis loop. This is based on a weak sensitivity of exports with respect to exchange rate changes inside some 'play' areas that occur with each reversal of the input (exchange rate) direction. In order to have permanent effects, exchange rate movements first have to pass a play/inaction area. This shows some similarities to the necessity of passing triggers on the micro level. However, in contrast to the micro-band-of-inaction, the play-area is shifted by past exchange rate movements, if these were spurts.

3. A Linear Approximation of the Aggregate Play-Dynamics

3.1 Linearized Play-Dynamics with Constant and Variable Play Width

To simplify the empirical analysis of macroeconomic play, Belke and Göcke (2001a, 2001b) developed a linear approximation of the play dynamics, still based on play areas and a continuous transition between play and spurt dynamics, however, only based on two different slopes between linear sections of the dynamics. In order to give an impression of the simplified linearized play-dynamics we first illustrate a simple situation with a *constant* width γ of the play area (see Figure 6): Start with point A (e_0) located on the downward leading (left) spurt line. If e changes the direction and increases, the trajectory enters the play area and results in a weak play reaction (B) until the entire play area is passed (e_2, at C). A further increase to e_3 induces a strong reaction of y along the (right) upward leading spurt line (D). If followed by an exchange rate decrease, this (up to e_4) creates a new play-line DE, which is shifted upwards and to the right compared to the "old" play-line AC. A further exchange rate decrease (to e_5, point F) then is captured by the left spurt-down-line. Again, the play area is shifted by a past spurt movement, now downwards and to the left (to line FG).[4] Summarizing, persistent effects emerge, if movements go beyond a play area and lead to reactions on a spurt-line, resulting in a shift of the play area. In contrast, there are no permanent effects from small variations taking place only inside the play-area.

Related to the option-of-waiting effects, the play area is widened in a situation with increasing uncertainty. Thus changes in the play width must be implemented into the linearized play model which is illustrated in Figure 7.

After some upward movement on the (right) spurt up line we start from point H (e_6). Dependent on the current width of the play, the opposite (left) spurt line is horizontally shifted, while the location of the right spurt line is fixed as long as an upwards movement is continued. Generally, the spurt line on which the most recent movement has taken place serves as an anchor (here the "spurt up line") while the opposite spurt line (in our example the left "spurt down line") is shifted horizontally via play variations. If, e.g. an initially high degree of uncertainty leads to a large play width γ_0, this leads to a left spurt located at spurt down_0 line. A decrease from $e_7 \rightarrow e_8$ in the γ_0-situation results in a weak play reaction (points $H \rightarrow J$). However, if later on in a situation described by point J uncertainty is reduced, this

[4] In the example of Figure 6 we assume a positive impact of e (home currency price of foreign exchange) on y (exports). Therefore, the left spurt line points downwards and the right spurt line shows upwards. In case of a negative reactions/relations, the direction of the spurt lines is reversed.

Figure 6: Linear Spurt Areas and Constant Play

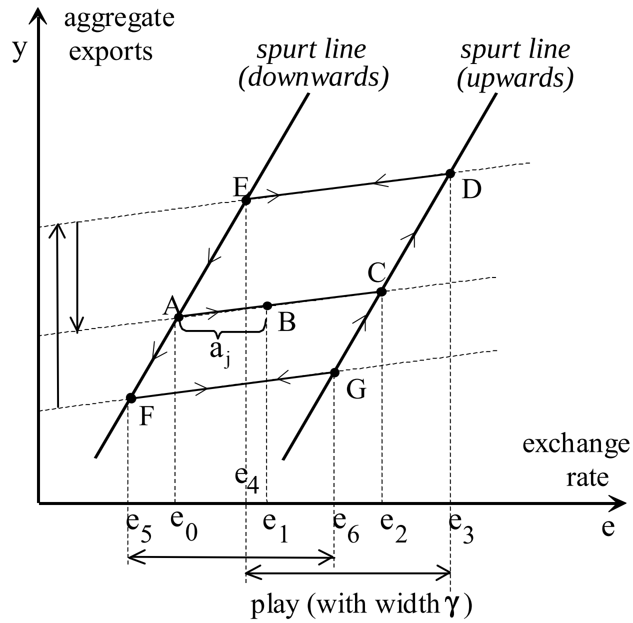
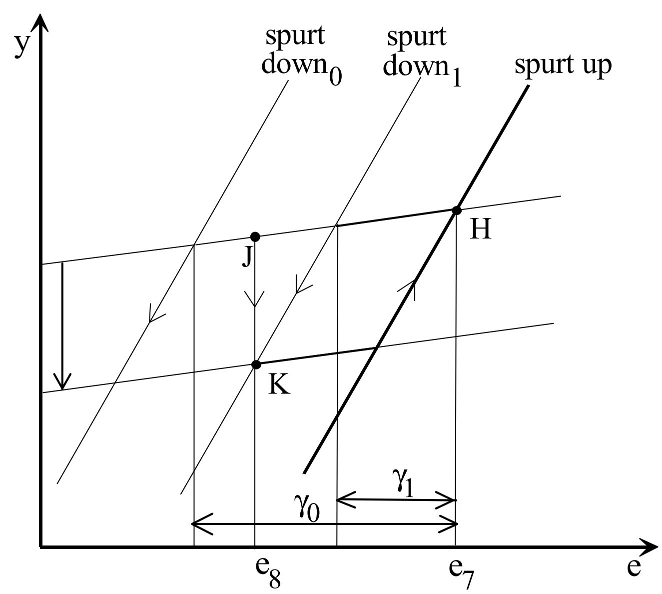


Figure 7: Linear Spurt Areas and Variable Play



causes a reduction of the play width $\gamma_0 \rightarrow \gamma_1$. Thus, a horizontal shift of the left (spurt down$_0$) to (spurt down$_1$) occurs. Due to the reduction of the play width the system ends up in point K, and at the same time the play area is shifted downwards. Summarizing, movements on the spurt line resulting from changes in the forcing variable e as well as variations of the width of the play area result in vertical shifts of the relevant play line, i.e. in persistent hysteresis effects.

3.2 An Algorithm Capturing Linear Play

Based on summing up the independent variable movements on the spurt-line as well as effects of changes in the play width the Belke / Göcke (2001a)-algorithm calculates an artificial shift variable. This "*spurt variable*" s_t sums up all spurt movements which had led to shifts of the play area. Actually, the spurt variable s_t is just the series of the original forcing variable e_t where all small changes inside the play areas are filtered out. Since this filtering is based on the play width, the resulting spurt variable s_t depends on the size of γ_t. As a result a standard linear equation of the following type can be estimated (e.g. by OLS):

$$y_t = \text{constant} + \alpha \cdot e_t + \beta \cdot s_t(\gamma_t) + \text{function(further variables)} \qquad (1)$$

This filtering procedure is explained in the following: A change in the forcing variable e (Δe) takes place either inside the play area γ leading to a weak reaction or on a spurt line resulting in a strong reaction of y (Δy). The movement of e inside the play area is denoted as Δa (and cumulated as a) and the movement on a spurt line as Δs. If Δe starts on a spurt line and enters the play area, this change is denoted as Δe_j^S. In Figure 6 this corresponds to the movement $A \rightarrow B \rightarrow C$. In the past, the variation of e has led to j changes between the left and the right spurt line. The change Δe_j^S may enter the play area by an extent of Δa_j or even pass the entire play γ and enter the opposite spurt line by Δs_j. If we start from a spurt line, the change Δa_j equals the cumulated movement inside the play area a_j (movement $A \rightarrow B$ in Figure 6). The assignment of exchange rate movements to play and spurt reactions is:

$$\Delta e_j^S = a_j + \Delta s_j \quad \text{with:} \quad \Delta s_j = \begin{cases} \text{sign}(\Delta e_j^S) \cdot (|\Delta e_j^S| - \gamma) & \text{if} \quad (|\Delta e_j^S| - \gamma) > 0 \\ 0 \quad \text{else} \end{cases} \qquad (2)$$

The effect (Δy) induced by Δe_j^S is composed of the weak play reaction ($A \rightarrow B \rightarrow C$) and – by occasion – additionally of a strong spurt reaction ($C \rightarrow D$). The parameter α denotes the weak play reaction and $(\alpha + \beta)$ the strong spurt reaction:

$$\Delta y_j^s = \alpha \cdot a_j + (\alpha + \beta) \cdot \Delta s_j \quad \text{with: } |\alpha| < |\alpha + \beta| \tag{3}$$

The location of play areas is shifted vertically by moves on the spurt lines. Accordingly, the cumulated vertical shift V_{j-1} of the play line resulting from all previous movements on both spurt lines ($i = 0...j-1$) are:

$$V_{j-1} = \beta \cdot \left[\sum_{i=0}^{j-1} \Delta s_i \right] = \beta \cdot s_{j-1} \text{ with: } s_{j-1} \equiv \sum_{i=0}^{j-1} \Delta s_i. \tag{4}$$

The current realization of the dependent variable is based on the shift V resulting from past spurts plus the current reaction Δy_j^s:

$$y_j = C^* + V_{j-1} + \Delta y_j^s = C^* + \beta \cdot \sum_{i=0}^{j-1} \Delta s_i + \alpha \cdot a_j + (\alpha + \beta) \cdot \Delta s_j$$

$$\Rightarrow \quad y_j = C^* + \beta \cdot \sum_{i=0}^{j} \Delta s_i + \alpha \cdot \Delta e_j^s \tag{5}$$

$$\Rightarrow \quad y_j = C^* - \alpha \cdot \sum_{i=0}^{j-1} \Delta e_i + \beta \cdot \sum_{i=0}^{j} \Delta s_i + \alpha \cdot \left(\sum_{i=0}^{j-1} \Delta e_i + \Delta e_j^s \right)$$

$$\text{with: } C \equiv C^* - \alpha \cdot \sum_{i=0}^{j-1} \Delta e_i$$

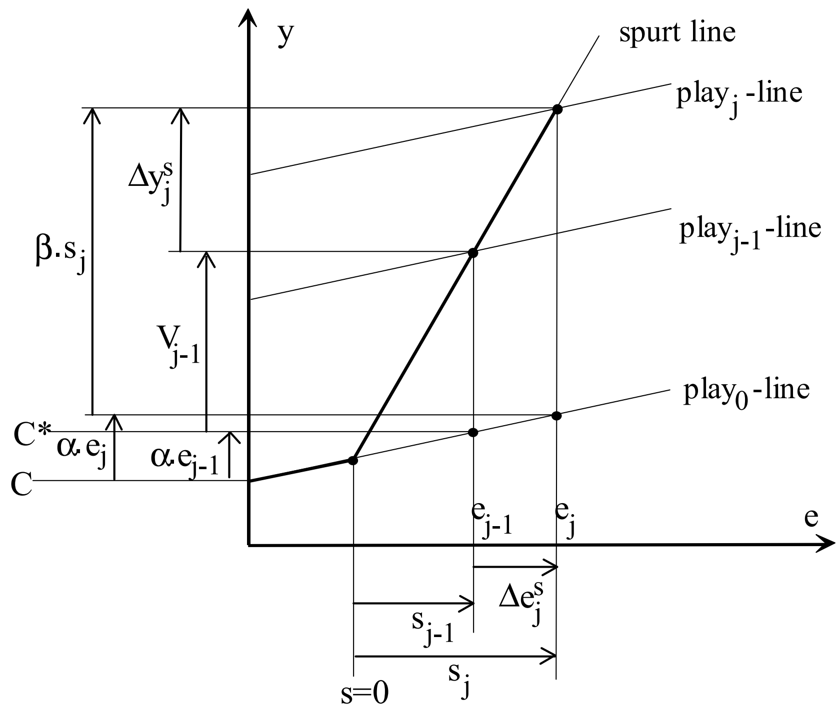
A simple linear equation results from the procedure:

$$\Rightarrow \quad y_j = C + \alpha \cdot e_j + \beta \cdot s_j \tag{6}$$

Figure 8 gives a graphical representation of the transformations of eqs. (5) and (6).

The non-linear play hysteresis is captured by adding a spurt variable s_j summarizing all preceding spurt movements to a linear equation. This spurt variable can be interpreted as the filtered input variable e, where movements inside the play area are filtered out. Instead of accumulating over an index j (describing the past changeovers between the spurt lines) an accumulation over a time index t can be applied without any loss of information. Moreover, additional non-hysteretic regressors (e.g. z_t) can be added, so that a generalized model results:

Figure 8: Shift of The Play Area Induced by Past Spurts and the Current Reaction Δy_j^s



$$y_t = C^* + \beta \cdot \sum_{k=0}^{t} \Delta s_t + \alpha \cdot \Delta e_t + \lambda \cdot z_t \quad \Rightarrow y_t = C + \alpha \cdot e_t + \beta \cdot s_t + \lambda \cdot z_t \qquad (7)$$

For a detailed presentation of the filtering algorithm (and for a translation into an EViews batch program) in the case of a variable play width, we refer to Belke and Göcke (2001a). The Eviews implementation of the play algorithm allows to control the play width by another variable. In order to capture the positive impacts of uncertainty on the play width we model p in a simple linear way as a function of an uncertainty proxy variable u_t.

$$p_t = \gamma + \delta \cdot u_t \;\text{ with: }\; \gamma, \delta \geq 0 \;\text{ and }\; u_t \geq 0 \;\Rightarrow\; p_t \geq 0 \qquad (8)$$

As a proxy variable u_t, we typically use the variance of the exchange rate series in preceding 12 month (based on monthly data).

3.3 Characteristics of the regression model

In order to estimate the linearized model simple OLS regression can be applied. This is done by a grid search over different sizes of the play width resulting from different levels of the parameters γ and δ. The play width, which leads to a spurt variable resulting in the highest R-squared is used to determine the estimated play width.

The play hysteresis loop is based on joined adjacent sections. In a play regression the positions of the ‘knots’ between spurt and play sections are a-priori unknown, and depend on the parameters γ and δ. However, these parameters have to be estimated in order to identify the positions of the knots and to determine the spurt variable s. If in switching regression models the knots are a-priori unknown, the properties of the regression results are problematic, even if the typical regression model assumptions (like normally distributed i.i.d error terms, etc.) are valid.[5] However, in the case of a switching regression with joined adjacent sections – as it is the case of the play loop – the OLS-estimators are consistent and asymptotically normally distributed. Unfortunately, the finite sample properties remain problematic: the parameter estimates are not even approximately normally distributed for small samples, and for finite samples local maxima in the likelihood function may occur.[6]

In practice, a specific problem with the local maxima in the likelihood function becomes valid, since the R2-plot of the grid search actually often shows local maxima for different sizes of the play width, so that the estimation procedure in some cases gives no definite result. Furthermore, if the equilibrium is not only affected by persistent hysteretic (remanence) effects, but also by structural breaks stemming from other sources, theses structural breaks are in some cases “found” by the play regression as an artefact. This is the case if the filtering process for very large sizes of the play width results in a spurt variable which only once changes its value at the moment where the largest variation took place. This “degenerated” spurt variable in fact is very similar to a dummy variable changing its (0,1)-level at this point of time. Thus, in time series, where important structural breaks took place at the same time the largest variations in the input variable (in our case the exchange rate) had happened, the highest R2-levels in the grid search procedure may be result just for this “degenerated” case. In our export equations (estimated in the next chapter), this happened in several cases, and the play-regression finds as an artefact a structural break via a dummy-type generated exchange rate spurt variable. Typically this happens for two points in time, the Euro launch in 1999/2000 and the financial crisis in 2008.

We tried to address this by explicitly integrating structural breaks as additional explaining variables in the regression. However, in some cases a reduced significance of the spurt variable, i.e. of endogenous hysteresis effects originally stemming from the exchange rate movement, were the consequence. Concluding, our procedure has some difficulties in

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[5] See Hujer (1986), pp. 231 ff., and Poirier (1976), pp. 108 ff.

[6] See Poirier (1976), pp. 117 ff., Hudson (1966) and Hinkley (1969) for an overview of the properties of ML- (OLS-) estimators for a situation with unknown but continuous switches between adjacent sections. See Poirier (1976), p. 129, Hinkley (1969, 1971) for the small sample properties of these estimates.

differentiating structural breaks from other sources against structural breaks stemming from (play) hysteresis dynamics. However, even from a theoretical point of view this differentiation is difficult, since significant structural breaks in the export equations occurring at specific moments of high economic variations and uncertainty may in fact be originally due to hysteresis effects in general, however not directly tracing back to exchange rate fluctuations, but stemming from other hysteretic economic relations, indirectly spilling over to the exports.

In the following we apply the play regression model developed above to estimations of Euro area exports directed to the United States, both country- and sector-wise. This is for exemplification reasons (having long time series available) but also because the dollar-euro exchange rate is one of the world's mostly watched bilateral exchange rates.

4 An application of the play regression model to Euro Area exports to the United States

In accordance, with gravity equation considerations we work with the following data (quarterly, 1997-2014, or monthly, 1995-2014):

- **Real exchange rates** are taken from the Research Service of the United States Department of Agriculture and converted to quarters and months using average observations.
- **Exports to the US** are taken from the Eurostat database and are expressed in real values by using the GDP deflator (OECD).
- **Real GDP** is taken from the respective national Central Bank's sources in Thomson Reuters (in case of monthly data we used industrial production data from the same source)
- **Exporting countries:** Austria, Belgium, Germany, Spain, Finland, France, Greece, Ireland, Italy, Netherlands and Portugal.

and use the following abbreviations:

for specific events

EL - Euro Launch,

FC - Financial Crisis

for SITC classifications

MA - Machinery,

OP - Optical Equipment,

ENG - Engineering,

BEV- Beverages.

The more heterogeneous the goods and the higher the fixed costs in the specific branch are, the more we expect hysteretic effects to prevail.

Estimation

According to section 3, we conduct our estimations of eq. (8) via OLS (see Belke and Göcke, 2001a). The underlying algorithms have been developed in accordance with sections 2 and 3 and are available on request.

Empirical results

In the following, we display some selected results to highlight the general empirical pattern (Tables 1 to 3). We take Ireland as our illustrative example because it is a textbook case open economy which fits our hysteresis approach quite well. Moreover, Belke, Oeking and Setzer (2015) accordingly show that a lagged response ("play") of Irish exports to a wide variety of shocks may be due to the large number of multinational corporations in Ireland, which are presumably less tied to the domestic situation and should therefore react less to domestic demand shocks than firms with a strong domestic focus. The remaining results are tabulated in Tables 4 (quarterly data) and 5 (monthly data). Table 1 starts with the estimation output for the case of *constant play* width for Ireland's exports to the US resulting from a one-dimensional grid search over different sizes of the play width.

Figure 10 shows the Irish real exchange rate in comparison with the resulting spurt variable (i.e. the „filtered e" mentioned further above). It becomes clear that the spurt variable, as expected from hysteresis theory, filters the original variable by only reacting to strong and enduring changes in the variable.

We now turn towards an exemplary estimation for a variable play case. Table 2 below displays the estimation output (Ireland) resulting from a two-dimensional grid search with variable play (p = 0.01 + 74 * var). Figure 11 adds a graphical comparison of the Irish real exchange rate and the resulting spurt variable. As in the case of constant play, the regression equation including the spurt variable clearly outperforms the original specification as measured, for instance, by the empirical realisation of the R-squared.

Table 3 demonstrates that the same is valid for a variety of sectoral/branch specifications as for instance for the Irish exports of engineering goods.

The overall results across countries and sectors are summarised in Table 4 (quarterly data and Table 5 (monthly data, n.a. = not available for the total time span), again differentiating between constant and variable play (play with variance). Bold face indicates a significant fit indicating play-hysteresis to prevail immediately without further robustness check.

In general, we expected hysteresis effects to appear and play areas to be the larger for a given sector, the more *heterogeneous* the respective products/firms are (for instance, chemical products and road vehicles, sectors investigated for hysteresis effects in Belke, Göcke and Günther, 2013, however, much less so fuels etc.) and the *bigger entry and exit costs* are.

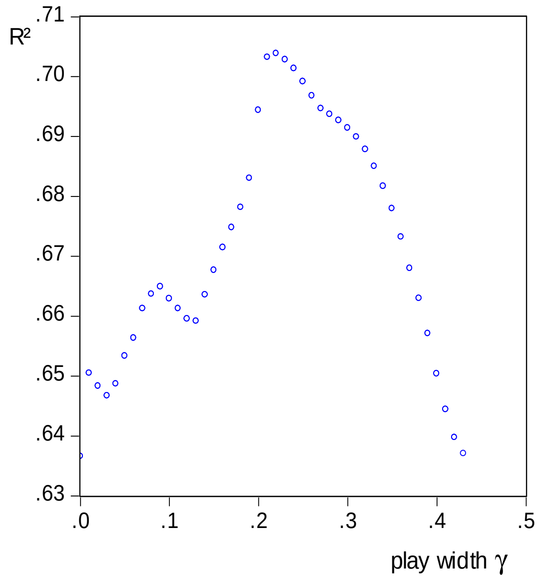
Table 1: Estimation Output (Ireland) Resulting from a One-Dimensional Grid Search with Constant Play Over γ ($p = \gamma = 0.22$)

Dependent Variable: Exports from Ireland to the US 1997 (Q1) – 2014 (Q3)		
	(1)	(2)
C	-59051783*** (20218929)	13141228 (26505041)
W	38635245*** (6471721.)	9394275. (9716241.)
Spurt		51397372*** (13585086)
USGDP(-1)	3992.782** (1843.837)	-1634.682 (2242.032)
TREND	175829.1 (126876.4)	632442.0*** (167007.5)
R-squared	0.636549	0.703838
Adjusted R-squared	0.602475	0.670931
S.E. of regression	5464765.	4972019.
Sum squared resid	1.91E+15	1.56E+15
Log likelihood	-1198.542	-1191.274
F-statistic	18.68162	21.38879
Prob(F-statistic)	0.000000	0.000000
Mean dependent var	40208034	40208034
S.D. dependent var	8667413.	8667413.
Akaike info criterion	33.95893	33.78236
Schwarz criterion	34.18201	34.03731
Hannan-Quinn criter.	34.04764	33.88374
Durbin-Watson stat	0.706665	0.826208
Observations	71	71

Note: *p<0.1; **p<0.05; ***p<0.01. Quarterly data.

It clearly turns out that the spurt variable more than substitutes the original real exchange rate variable, as measured by the R-squared, and that its coefficient has the expected sign. For illustration purposes we add the empirical realisation of our grid search procedure which reveals $p = \gamma = 0.22$ as that constant play maximizing the R-squared of the estimation equation.

Figure 9: R-squared Grid Search for Different Sizes of Play Width (Ireland, constant play)



However, average productivity should play a less important role in determining the degree of hysteresis in exports (Bernard and Jensen, 2004, Greenaway and Kneller, 2003, Hiep and Ohta 2007, pp. 23f.). The established theoretical studies in the field of trade hysteresis thus emphasize the importance of the *combination* of firm/goods heterogeneity and sunk costs in determining the behaviour of firms in doing business abroad (Bernard and Jensen, 2004, and Roberts and Tybout, 1997). This expected pattern is clearly corroborated by our empirical results.

Let us now finally go beyond our illustrating Irish case and comment on the results for aggregate and sectoral exports for the other Euro Area member countries under investigation here.

For instance, for Germany with its sophisticated and less price-sensitive heterogeneous export product line (cars and chemical products whose exports typically necessitate huge amounts of sunk costs) export hysteresis is easily established empirically.

This is well known and a stylized fact from a couple of other studies (Belke, Göcke and Günther, 2013).

On the contrary, it was more difficult to find export hysteresis effects for Greece (no significant play-hysteresis entries in Tables 4 and 5) whose largest export shares are within

Figure 10: Real Exchange Rate and the Resulting Spurt Variable (γ=0.22)

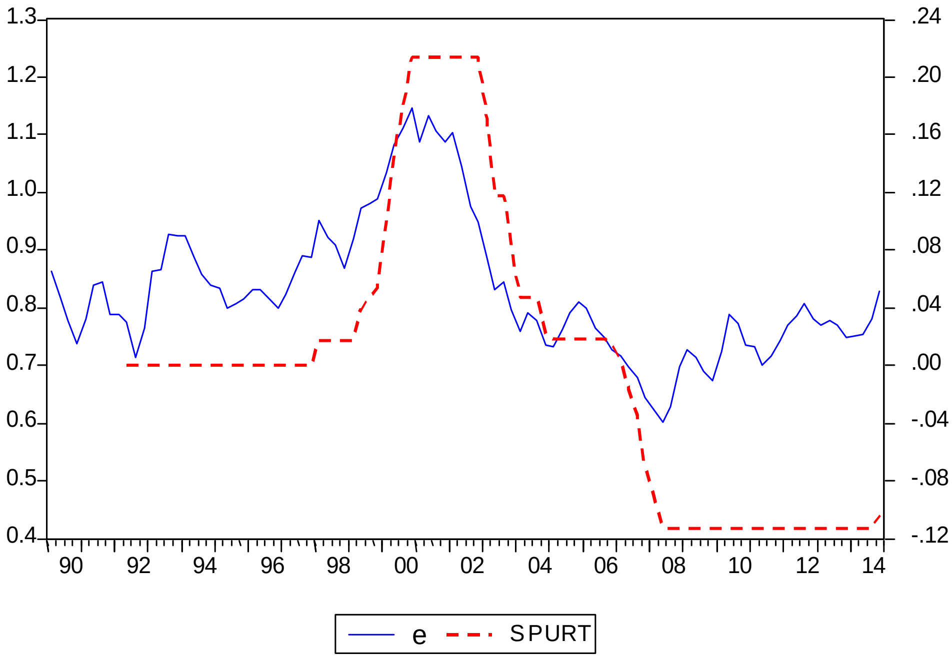


Figure 11: Real Exchange Rate and the Resulting Spurt Variable (Ireland)
*(γ= 0.01 + 74 * var)*

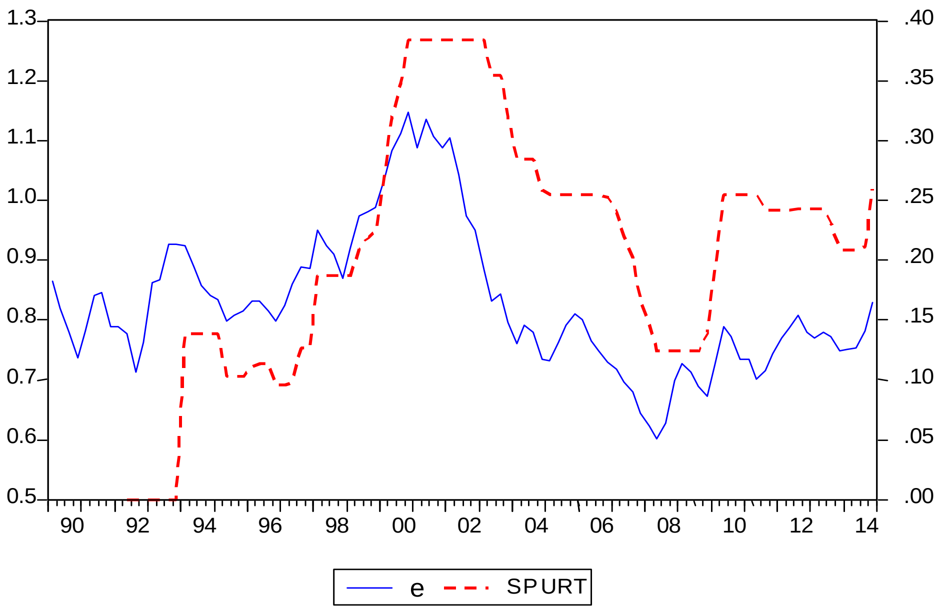


Table 2: Estimation Output (Ireland) Resulting from a One-Dimensional Grid Search with Variable Play (p = 0.01 + 74 * var)

Dependent Variable: Exports from Ireland to the US 1997 (Q1) – 2014 (Q3)

	(1)	(2)
C	-59051783***	13340087
	(20218929)	(20663722)
W	38635245***	2356206.
	(6471721.)	(8182584.)
Spurt		61669980***
		(10642819)
USGDP(-1)	3992.782**	-1265.709
	(1843.837)	(1753.998)
TREND	175829.1	410011.3***
	(126876.4)	(110910.0)
R-squared	0.636549	0.762909
Adjusted R-squared	0.602475	0.736565
S.E. of regression	5464765.	4448627.
Sum squared resid	1.91E+15	1.25E+15
Log likelihood	-1198.542	-1183.376
F-statistic	18.68162	28.96007
Prob(F-statistic)	0.000000	0.000000
Mean dependent var	40208034	40208034
S.D. dependent var	8667413.	8667413.
Akaike info criterion	33.95893	33.55990
Schwarz criterion	34.18201	33.81485
Hannan-Quinn criter.	34.04764	33.66128
Durbin-Watson stat	0.706665	1.014423
Observations	71	71

Note: *p<0.1; **p<0.05; ***p<0.01. Quarterly data.

Table 3: Estimation Output (Ireland, Engineering) Resulting from a One-Dimensional Grid Search with Variable Play (p = 0.12 + 169 * var)

Dependent Variable: Exports of Engineering Goods from Ireland to the US
1995 (M01) – 2014 (M12)

	(1)	(2)
C	-48992415***	14907105
	(18083299)	(16195908)
W	1.82E+08***	93007247***
	(16204565)	(15940123)
SPURT		1.92E+08***
		(18695811)
TREND	-175783.0***	-266840.6***
	(30514.45)	(26745.03)
R-squared	0.594462	0.723920
Adjusted R-squared	0.571134	0.706741
S.E. of regression	27533624	22768170
Sum squared resid	1.71E+17	1.17E+17
Log likelihood	-4444.753	-4398.610
F-statistic	25.48339	42.14146
Prob(F-statistic)	0.000000	0.000000
Mean dependent var	70001436	70001436
S.D. dependent var	42043878	42043878
Akaike info criterion	37.15628	36.78009
Schwarz criterion	37.35931	36.99763
Hannan-Quinn criter.	37.23809	36.86774
Durbin-Watson stat	0.529416	0.766850
Observations	240	240

Note: *p<0.1; **p<0.05; ***p<0.01. Monthly data.

Figure 12: Real Exchange Rate and the Resulting Spurt Variable (Ireland, Engineering)
*(γ = 0.12 + 169 * var)*

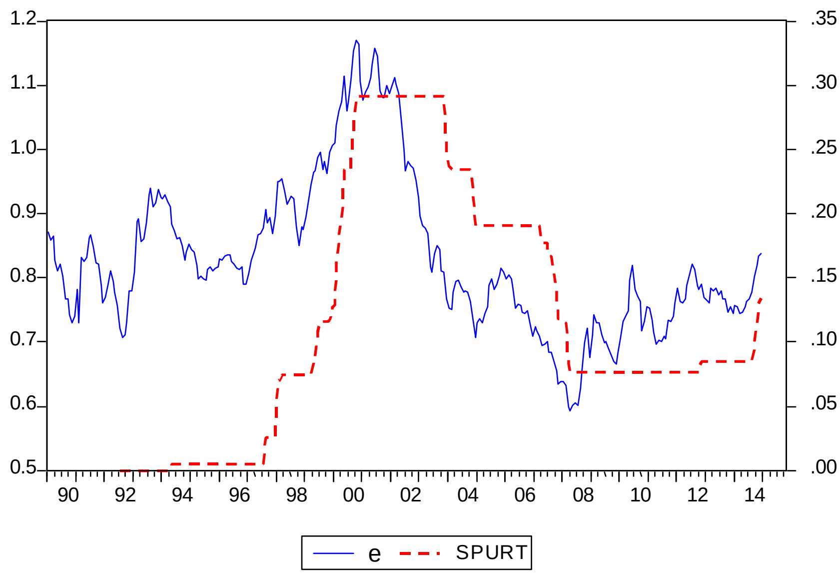


Table 4: Regression Results of Aggregated Exports (quarterly data)

Exporting country	Constant play	Play with variance
Austria	Structural break EL, FC	Structural break FC
Belgium	**0.35**	Structural break EL
Germany	Spurt not significant	**Play = 0 + 57 * var**
Spain	Structural break EL	Structural break EL, 2013
Finnland	0.04	Play = 0.02 + 18.7 * var
France	0.25	Structural break EL
Greece	0.42	Structural break FC
Ireland	**0.22**	**Play = 0.01 + 74 * var**
Italy	Structural break EL	**Play = 0 + 62 * var**
Netherlands	0.07	Structural break FC
Portugal	Structural break EL, FC	Structural break FC

the homogeneous export good categories oil and shipping. With certain limitations, this is also valid for some other current or previous Euro Area programme countries such as Portugal (also no significant play-hysteresis entries in Tables 4 and 5), except Ireland.

Belke, Oeking and Setzer (2015) identify a substitutive relationship between domestic and foreign sales for Spain (no significant entry at the aggregate level in Table 4) and Portugal (no significant entry in Tables 4 and 5), implying that both countries tend to export because home markets have broken down. This effect may have dominated the specific effect investigated in this paper, at least across the most recent part of the sample period. The non-significance of the play-hysteresis effect on the aggregated export level for France may be related to the lower general openness of the French economy (Belke, Oeking and Setzer, 2015).

As far as goods categories are concerned, there is – as expected - more evidence of export hysteresis for machinery, optical equipment and engineering than for more homogenous goods such as beverages, oil etc. The former are more widespread in the export profile of Northern Euro Area member countries. Seen on the whole, thus, play-hysteresis appears to be more relevant for Northern than for Southern European countries on the aggregate level. However, this does not exclude that play-hysteresis still matters also for single product groups in the South.

To summarize, one of our objectives has been to identify/quantify a “band of inaction” for Euro Area member countries’ exports, under exchange rate uncertainty. Analysing one of the largest export destinations outside the Eurozone, the US, to which 12% of total Euro Area exports were directed in 2012, we find hysteretic effects in many cases of Euro Area member countries’ exports. However, not every increase or decrease of the exchange rate will, automatically, lead to positive or negative reactions of the volume of exports. But a large appreciation of the euro means passing the play-area (i.e. a kind of 'pain-threshold') and results in a strong reaction of exports, and vice versa. But we also come up with something what we call structural break artefact (see, in detail, section 3), i.e. a breakdown of the play area to a one period structural break dummy, in a couple of cases. This finding refers to the Euro launch (EL) as well as to the financial crisis (FC) in Tables 4 and 5. It will be the natural starting point of our future research.

To give an intuition how the play regression converges to a kind of dummy variable indicating structural breaks in some cases – which makes it difficult to differentiate “genuine” play dynamics from underlying structural breaks, the example of the play-regression results for Spain are explicitly stated for the constant play regression. The plot of the R^2-grid-search over different sizes of the play width in the case of Spain is shown in Figure 13.

Table 5: Regression Results of Aggregated and Sectoral Exports (monthly data)

Exporting country	**Constant play**	**Play with variance**	**Play with variance Sectoral data**
Austria	Structural break EL, FC	Structural break FC	n.a.
Belgium	Structural break EL, FC	Structural break EL	n.a.
Germany	Structural break EL, FC	Structural break FC	**Play_CARS = 0.34 + 31 * var**
Spain	Structural break EL	Structural break FC	**Play_MA = 0 + 92 * var**
Finnland	0.1	**Play = 0.05 + 39 * var**	**Play_OP = 0.09 + 51 * var**
France	Structural break FC	Structural break FC	**Play_CA = 0.05 + 90 * var**
Greece	0.48	Play = 0.4 + 58 * var	Play_BEV = 0.01 + 60 * var
Ireland	**0.24**	**Play = 0.13 + 152 * var**	**Play_ENG = 0.12 + 169 * var**
Italy	Structural break EL, FC	Structural break FC	**Play_ENG = 0.05 + 74 * var**
Netherlands	Structural break EL, FC	Structural break FC	**Play_CA = 0 + 95 * var**
Portugal	Structural break EL, FC	Structural break FC	Structural break EL, FC

With a play width of γ=0.27 a local maximum in the grid-search-plot of R^2=0.727898 occurs (compared to R^2=0.706610 for a regression without any spurt effects, which is represented for a zero play at the left of the plot). However, for very large sizes of the play width the resulting R-squares are even larger, with an absolute maximum of R^2=0.744679 at the right limit with a play width of γ=0.55. Therefore, the LS regression states this as the R^2 maximizing estimation. The resulting plot of the spurt variable (which is actually a dummy variable and may capture the effects of the Euro launch in 2000) is illustrated in Figure 14.

Figure 13: Grid Search Results for Different Play-Widths (Spain, constant play):

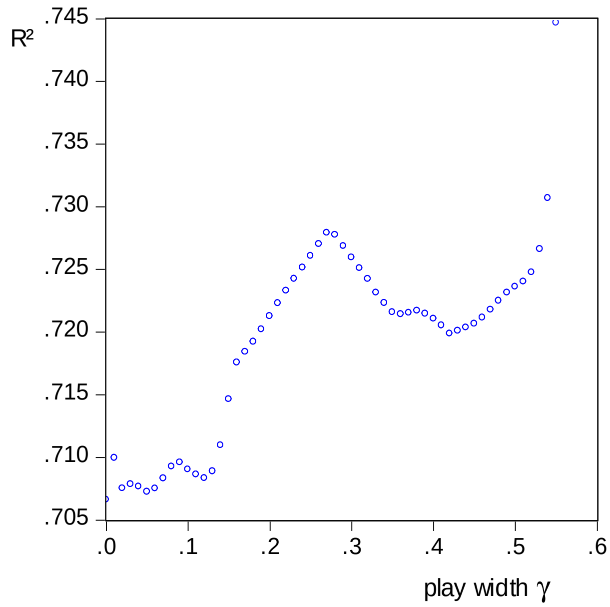
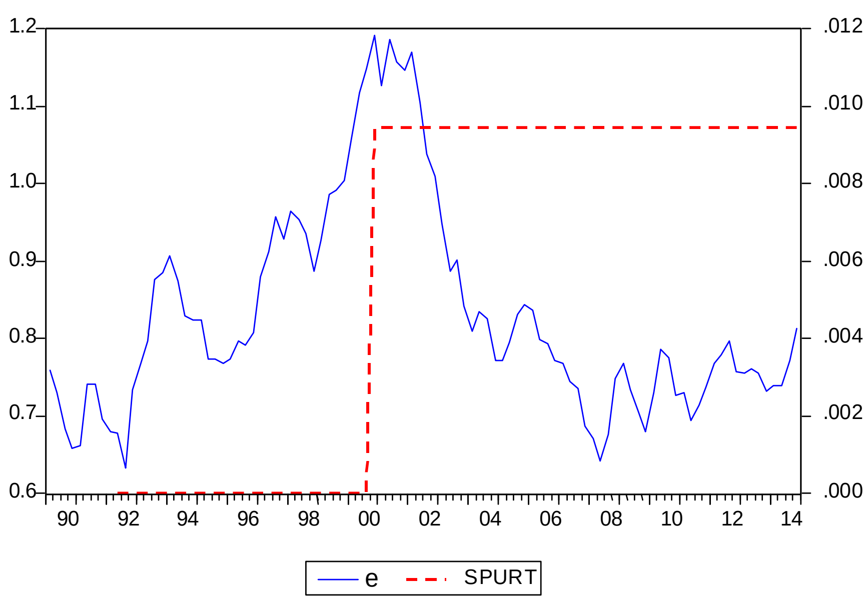


Figure 14: Exchange Rate and The Resulting Spurt Variable for γ=0.55 Converging to a Dummy (indicating The Euro-Launch) in the Case of Spain



If structural breaks are present, this is from a theoretical as well as an empirical/estimation perspective interrelated with the play dynamics. Furthermore, for small samples local maxima in the likelihood function are a property of the estimation for small samples. Thus just taking the local maximum (γ=0.27) as a "real" play effect and additionally integrating a dummy for the EL may not be the straightforward solution. At the moment, we have to leave this differentiation problem between these two types of persisting effects (play vs. structural breaks) for future research.

5 Conclusions

In this paper, we have derived export hysteresis on a micro (firm) level and an aggregate level if sunk adjustment costs matter for export market entry and exit decisions. Furthermore, the impacts of option-to-wait effects due to uncertainty on the aggregation procedure have been illustrated. Finally, we presented the so-called play-algorithm which allows an estimation of the aggregate/macro hysteresis loop taking into account the variable option value effects resulting from changing volatility of exchange rates.

In the applied part of the paper, we employed the play regression model to estimate dynamic empirical export equations (Euro Area member countries to the United States) – both on the macro and the sectoral/branch level. Analysing one of the largest export destinations outside the Eurozone, the US, we found hysteretic effects in many cases of Euro Area member countries' exports. However, not every increase or decrease of the exchange rate will, automatically, lead to positive or negative reactions of the volume of exports. But a large appreciation of the euro means passing the play-area (i.e. a kind of 'pain-threshold') and results in a strong reaction of exports, and vice versa. Correspondingly, our main objective has been fulfilled, namely to identify/quantify a "band of inaction" for Euro Area member countries' exports under exchange rate uncertainty.

A further stimulating result was that we also came up with something what we call structural break artefact, i.e. a breakdown of the play area to a one period structural break dummy. In our future research we will thus experiment with a break dummy as a proxy of the euro launch or the start of the financial crisis as an additional regressor. We feel legitimised to do so because there is observational equivalence between a break caused by hysteresis and a break induced by the financial crisis plus dynamic interactions. Furthermore we will implement a break dummy in order to modulate the width of the play area. However, the new dynamic interactions which may emerge in this context are not explored yet.

We can think of many useful directions of deriving policy conclusions from our estimation exercise. For instance, one could take a stance in the current debate about a too strong or too weak external value of the euro in the wake of unconventional monetary policies employed by the world's most important central banks such as the Fed and the ECB. Should the ECB go for FOREX market interventions if "pain thresholds" are surpassed? Remember in this context that questions like "What are the EA countries profiting most from it?" are at the core of the recent debate on QE's effects on the external value of the Euro.

How far should the Troika go in terms of internal devaluation and increasing international competitiveness to stimulate Greek exports? So future hysteresis based research could contribute to the important question what the export triggers for countries such as Greece are. And what is the impact of exporters' financial constraints or political uncertainty on the "band of inaction" in exports.

Finally, the analysis could be usefully extended to other destination countries beyond the US, could focus on relative exports and include other exchange rates as well.

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