

JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

SUNK COST HYSTERESIS AND
HYSTERESIS LOSSES

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*This thesis is dedicated to my husband and my parents.
For their endless love, support and encouragement.*

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Abstract

The transition from one economic equilibrium to another as a consequence of shocks is often associated with sunk adjustment costs. Firm-specific sunk market entry investments (or sunk market exit costs) in case of a reaction to price shocks are an example. These adjustment costs lead to a dynamic supply pattern similar to hysteresis. In analogy to “hysteresis losses” in ferromagnetism, we explicitly model dynamic adjustment losses in the course of market entry and exit cycles. We start from the micro level of a single firm and use explicit aggregation tools from hysteresis theory in mathematics and physics to calculate dynamic losses. We show that strong market fluctuations generate disproportionately large hysteresis losses for producers. This could offer a reason for the implementation of stabilizing measures and policies to prevent strong (price) variations or - alternatively - reduce the sunk entry and exit costs. However, the explicit inclusion of uncertainty (associated with an option value of waiting) is shown to reduce economic hysteresis losses.

Based on theoretical considerations of hysteresis losses, this manuscript also introduces a new measure (an indicator) to capture hysteresis losses empirically. As examples, the most important German export sectors to the U.S. and Italian wine exports to the U.S. are investigated. In both cases, the theoretical findings of over-proportionally large hysteresis losses compared to the changes in forcing variable could be approved.

Chapter 1

Introduction

Economics is “a delicate machine, the workings of which we do not really understand”, as Keynes wrote in the context of the great slump of 1930 (Keynes 1930, p. 126).

Nevertheless, economists busily observe the processes in economics and create theories trying to approximate the complexity of the reality. They lean on certain approaches to economics or even combine them to understand the economic processes that are dynamic from the time perspective. The structure of the economy itself as well as the economic relations between economic agents, and the nature of shocks shaking the economies and in some cases leading to structural changes incentivize economists to look for new ways in explaining these phenomena. Besides mainstream economics, there always exist heterodox approaches that try to strike a new path in the discipline. This manuscript presents a heterodox approach of hysteresis in economics that has been attracting growing attention in recent years as having the potential to explain consequences of the recession that followed the financial crisis in 2008.

Cross (Cross 1993, p. 71) catches our attention by claiming that “there is an irony that J. A. Ewing, who coined the term hysteresis, was Professor of Mechanism and Applied Mechanics at Cambridge University from 1890 until 1916 and overlapped at Kings’s College with the young John Maynard Keynes. There is, however, no record of an influence of Ewing on Keynes. Hysteresis could arguably have provided Keynes with a useful metaphor in his subsequent

“struggle to escape” from the non-hysteretic neoclassical doctrine”.

The events of recent years have made the world economy extremely uncertain. Owing to various crises (both political and economic), wars and terror, the world markets became unstable and world trade stagnated. It needs to be mentioned that the China bubble burst, currencies of many emerging countries (e.g. Russia) crashed, the global indebtedness strongly increased and thus the fear of rising interest rates on the part of the U.S. became grater, the oil price crashed and destabilized the income of commodity exporters. Moreover, a global energy transition was announced at the end of the climate conference in Paris, which is associated with high energy costs in the future (see Müller 2016). Finally, Brexit and Trump’s “America first” doctrine associated with isolationistic foreign policy stances complicate economic policy and make the business environment quite unpredictable. The higher global uncertainty directly influences decision-making processes of worldwide-operating (exporting) firms in the form of e.g. exchange rate fluctuations. As an example, the $\$/\text{€}$ -exchange rate has fluctuated between 0.89 and 1.66 since the introduction of the euro, resulting in high losses of exporters or even their market exit in the case of home currency appreciation. This kind of uncertainty incentivizes exporting firms to be more cautious and delay their decisions regarding the intensity of their business activity. In other words, firms tend to make use of the option to wait and see how the economic environment will develop in the near future.

The option of waiting is even more important and valuable if the activity of firms is associated with sunk adjustment costs. In many cases, firms must incur sunk costs to enter new markets. Since these entry investments are firm-specific, firms cannot recoup these costs if they exit. Analogously, a market exit results in exit costs if production is stopped. These sunk entry and exit costs result in a path-dependent behavior of firms, which is called “hysteresis”. Directly after a firm has entered a market, firm-specific entry investments in fact have to be treated as sunk costs, although this investment is not really lost, as long as the firm continues to be active on the market. However, in case of a later market exit, the sunk entry investment actually has to be written off and sunk exit costs must be paid. In a complete market entry and exit cycle, both sunk entry and exit costs finally have to be written off. Consequently, during the complete entry and exit

cycle of a firm, a dynamic loss is generated comprising the sum of sunk entry and exit costs that were paid. This is analogous to a phenomenon in physics called the “hysteresis loss”, where heat is produced by magnetization-demagnetization cycles. In contrast to the standard microeconomic market model, where welfare effects (producer and consumer surpluses, deadweight losses, etc.) are analyzed for static market equilibrium situations, this manuscript deals with both theoretical and empirical issues of dynamic losses directly caused by variations in the economic environment during the adjustment process towards equilibria, or by fluctuations around and switches between different equilibria. We model this along the lines of the hysteresis loss in magnetization. We will show that – as in the case of magnetism – these losses caused by a “loading-unloading” (i.e. market entry-exit) cycle are proportional to the area inside the so-called “hysteresis loop” (see Mayergoyz 2003, p. 50).

Shifting the focus from welfare effects in an equilibrium state - as is done e.g. in the case of deadweight losses - to welfare effects of fluctuations around equilibria given that adjustment costs are relevant is a promising topic.

This manuscript deals with the concept of hysteresis losses in a general price-output constellation and later applies it in the special case of international trade. As the term “hysteresis” (see e.g. Baldwin 1989) reveals, in our considerations we treat the economy as a dynamic entity that develops and grows in time in the context of history. Due to irreversible investments, the influence of history (or memory of the system) and option value effects, we observe path-dependent output (e.g. export) reactions leading to long-lasting effects of input (e.g. exchange rate) changes to the output level, which represents the typical recession scenario.

We have ascertained that large economic fluctuations generate disproportionately high dynamic adjustment costs, due to the over-proportionate effect of price changes on the size of the dynamic losses. Especially the strong economic fluctuations of recent years (in exchange rates, share and real estate prices, commodity and oil prices, etc.) should have led to a dissipation effect for many sunk investments (that ultimately had to be written off), which are likely to show similarities to the hysteresis losses described in this manuscript. From an economic policy perspective, this could offer an additional reason for the implementation of stabilizing measures and policies, first and foremost to prevent strong variations

on markets. Examples of such stabilizing (dynamic loss-avoiding) policies could be (stable) fixed exchange rates, financial market regulations or even two-price buffer stock schemes on commodity markets. However, an alternative policy to reduce the hysteresis losses would be to preserve flexible markets, i.e. to reduce the sunk costs that act like barriers for market entry and exit.

The relevance of our analysis can be illustrated for agricultural and commodity markets. As an example: agricultural markets exhibit a relatively high volatility due to their strong links with natural shocks, associated with high costs for the economy. A number of studies regarding the development of commodity prices and their volatility state that the price volatility in the last decade was higher than in the 1990s (e.g. see Huchet-Bourdon 2011; Von Braun 2012; Food and United Nations 2011; OECD/Food and United Nations 2014; Bank 2015). Existing literature regarding the welfare impacts of commodity price volatility mostly deals with static welfare losses in terms of consumer income changes and concentrates on the demand side (see e.g. Bellemare et al. 2013). By contrast, we analyze dynamic losses of producers (farmers) caused by sunk adjustment costs. The fact that the (food) price volatility in the past was high - and tends to remain so in the future - underlines the relevance of the sunk adjustment costs in the form of investments or disinvestments that producers have to face after every price shock. The markets with high sunk costs are those with the greatest barriers to entry and exit, while once the sunk costs are incurred, they cannot be recovered. Together with the presence of uncertainty, the existence of sunk costs significantly changes the “normal” economic behavior of producers, resulting in hysteresis. Since hysteresis effects are an empirically-proven phenomenon in economics, the consequences in terms of economic hysteresis losses resulting from fluctuations are a relevant question.

This manuscript comprises nine chapters. Chapter 2 provides some historical notes of the origin of hysteresis phenomenon in physics, illustrates the main properties of “strong” (macroeconomic) hysteresis and discusses the issue of hysteresis in different economic fields associated with different determinants. Chapter 3 explains the concept of sunk cost hysteresis starting with the microeconomic foundation and presenting the simplest microeconomic consideration of firm-level modeling of hysteresis, which is called non-ideal relay. It continues with the aggre-

gation using the procedure of Preisach 1935 and ends with the macroeconomic hysteresis loop. It is shown that being discrete at the micro level, the path-dependent switches of the supply curve at the macro level become continuous and the hysteresis loop takes the form of a lens. Additionally, the shape of the hysteresis curve and the risk neutrality assumption are discussed. Subsequently, chapters 4 and 5 build the core of this manuscript, whereby the dynamic hysteresis losses (with and without explicit modeling of uncertainty) are analyzed in a systematic way, starting from the microeconomic level of a single firm and explicitly modeling the aggregation to hysteresis effects on entire markets, using explicit tools from mathematical/physical hysteresis theory, which is novel in economics. Chapter 6 deals with the linearized hysteresis curve, called play hysteresis. It represents an approximation (simplification) of the Preisach model that enables an empirical analysis. The behavior of a system illustrated in the play-hysteresis model is mathematically captured by the play algorithm (Belke-Göcke algorithm), which is explained in detail in the following section. Based on the Belke-Göcke algorithm and the play hysteresis model, a new hysteresis losses indicator is conceived using explicit mathematical/geometrical tools, which is also novel in the economic hysteresis literature. This indicator enables an empirical discussion of the hysteresis losses issue executed in chapter 8. Chapter 7 builds on chapters 3 and 4 and adopts the general price-output-based concept to the special case of international trade using exchange rate as the input and export volume as the output variable. In this context, the effects of the exchange rate elasticity of export prices and the currency of costs on the exports are incorporated. Chapter 8 investigates hysteresis losses empirically using the hysteresis losses model of international trade (from chapter 7), the Belke-Göcke algorithm and the hysteresis losses indicator (from chapter 6). Products from different areas and different countries of origin are considered. As a first example, German exports to the U.S. in the most important industrial sectors are analyzed. Following this, Italian wine exports to the U.S. are investigated. In chapter 9, the findings of the manuscript are discussed and political implications are proposed.

Parts of this manuscript were developed in cooperative work with other researchers and presented in international conferences. The core of this manuscript represented by chapters 3, 4 and 5 is based on the following paper: Matthias

Göcke and Jolita Matulaityte¹ (2015), “Modeling Economic Hysteresis Losses Caused by Sunk Adjustment Costs”, MAGKS – Joint Discussion Paper Series in Economics by the Universities of Aachen, Gießen, Göttingen, Kassel, Marburg and Siegen, No. 36-2015. A modified version of this paper is accepted for publication in *Journal of Post Keynesian Economics* (forthcoming). This paper was also presented in the following international workshops and conferences: INFER Workshop on Heterodox Economics in Coimbra, Portugal; 17th INFER Annual Conference in Luton, UK and 4th Annual Lithuanian Conference on Economic Research in Kaunas, Lithuania.

Sections 6.4, 6.5 and 8.2 are based on the following paper: Jolita Adamonis and Laura M. Werner (forthcoming), “A New Measure to Quantify Hysteresis Losses: the Case of Italian Wine Exports to the US”, which is accepted for publication in *Macroeconomic Dynamics*. This paper was presented in the following international conferences: 18th INFER Annual Conference in Reus, Spain; 23rd Enometrics Conference in Colmar, France and 56. Gewisola Annual Conference in Bonn, Germany.

Section 8.1 is based on the paper: Jolita Adamonis (2017), “Hysteresis Losses in German Exports to the U.S.”. This paper was presented in the following international conferences: 21st EBES Conference in Budapest, Hungary and 19th INFER Annual Conference in Bordeaux, France. All the comments of the participants and anonymous referees helped us to improve the papers and thus this manuscript.

¹My maiden name.

Chapter 2

Hysteresis in economics

2.1 Brief literature overview of modeling the ferromagnetic hysteresis

Whereas the term “hysteresis” is not widely known and used in economics, it is well known and important in the scientific field of its origin, namely physics. The definition itself was coined at the end of the 19th century by the Scottish physicist James Alfred Ewing, who investigated magnetic materials. The term “hysteresis” stems from ancient Greek “hystérēsis” meaning “a coming short, a deficiency, a lagging behind” (Dictionary.com 2017). The same source defines “hysteresis” as “the phenomenon exhibited by a system in which the reaction of the system to changes is dependent upon its past reactions to change”. In other words, hysteretic systems have memories. However, there is much more behind the hysteresis phenomenon. In this and the following sections, we will provide some historical notes to the science of hysteresis and discuss the properties of hysteretic systems with some examples from physics. The underlying models in the following discussion are the scalar Preisach models of hysteresis (see Preisach 1935, Mayergoyz 1986).

The phenomenon of ferromagnetic hysteresis was found and first described by the physicists Weber 1852 and Maxwell 1881. The physicist Ewing 1881 pursued the idea of Maxwell and worked out a concept of ferromagnetic hysteresis supported by simple calculations (see Jiles and Atherton 1986, p. 49). The

physicists Weiss and Freudenreich 1916 developed a model of ferromagnetism that was revisited by another physicist, Preisach 1935, who presented a geometrical interpretation of the models (see Visintin 1994, p. 9). Preisach's models of ferromagnetism reveal the main properties of the hysteresis phenomenon and are favored and widely used among scientists of the other fields, including economists. This manuscript also applies the hysteresis phenomenon in economics using the scalar Preisach models.

The first functional approach of hysteresis was proposed years later by an engineer, Bouc 1971. Other important names in the context of formal modeling of hysteresis are Krasnosel'skii and Pokrovskii 1989, a mathematician and a physicist who conducted a systematic analysis of the mathematical properties of the hysteresis operators and thus developed formal instruments within the scope of the general systems theory (see Visintin 1994, p. 11). These instruments are used in economics to model hysteresis at the microeconomic level. Finally, the engineer Mayergoyz 1986 proposed mathematical models of hysteresis that are quite general and applicable to the description of hysteresis of different nature.

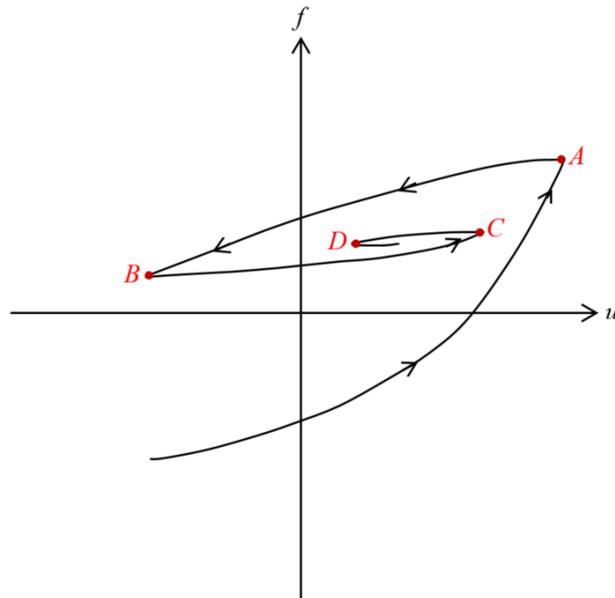
2.2 Hysteresis as a property of a system

One of the most important characteristics of hysteretic systems is memory. More specifically, hysteresis underlies the rate-independent memory, which is persistent and scale-invariant (see e.g. Visintin 1994, p. 13). The rate-independent memory effects lead to the so-called multibranch non-linearity of the system, which is illustrated in fig. 2.1.

According to Mayergoyz 1986, p. 603, multibranch non-linearity is a branch-to-branch transition (branching) that occurs after each input extremum. It constitutes the essence of hysteresis. Since we are interested in the "static" hysteresis non-linearities, only past extremum values of input determine the branches, whereas the speed of input variation between extremum values does not matter. The appropriate branch can only be chosen if the past input values and the associated output realizations are known.

Multibranch non-linearity is associated with three other characteristics of hysteretic systems: path dependency (looping), remanence and coercivity. Path

Figure 2.1: Multibranch non-linearity

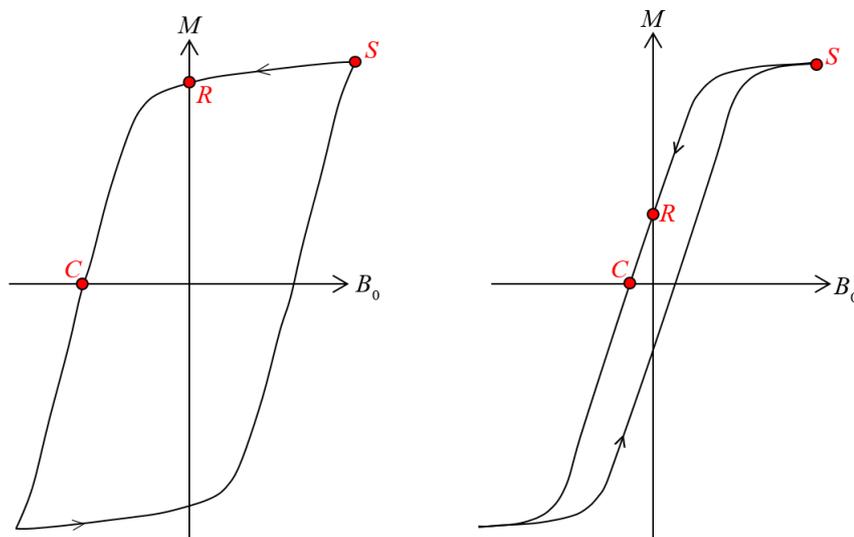


Source: Mayergoyz 1986, p. 604.

dependency implies that the current state of output (the appropriate branch) depends on the path that the input variable passes through, indicating certain past output realizations. Thus, there are several output values that are possible for one input level. Due to its persistent memory, the Post-Keynesian economist Davidson 1993, p. 320, compared the hysteresis concept to the “proverbial elephant that never forgets”. Fig. 2.2 illustrates two continuous hysteresis loops of different physical materials that result after a magnetization-demagnetization cycle and are associated with hysteresis regions (area inside the hysteresis loop) of different magnitudes. The narrower the hysteresis loop, the smaller its hysteresis region.

The hysteresis loops in fig. 2.2 illustrate the relationship of magnetization (M) to the external magnetic field (B_0), showing that the effects of an increasing magnetic field are different from those of a decreasing field (see Young et al. 2012, p. 945). When the external driving field magnetizes the material to saturation (point S in fig. 2.2), a removal of the external field does not remove the magnetization of the material; rather, a certain amount of magnetization remains (point R in fig. 2.2). This captures the remanence property, which is the stronger the

Figure 2.2: Continuous hysteresis loops of different physical materials



Sources: Myers 1997, p. 406, Young et al. 2012, p. 945.

larger a hysteresis region is. Remaining magnetization (remanence, marked with R) is very strong in the left-hand side and low in the right-hand side graph in fig. 2.2. In order to reduce the magnetization to zero, a certain external field in the opposite direction must be applied (point C in fig. 2.2). The measure of the reverse field needed to force the magnetization to zero after being saturated is called coercivity (see Myers 1997, p. 406). It is again the higher the larger hysteresis region is: coercivity (C) is large in the left-hand side and tiny in the right-hand side graph. The material illustrated in the right-hand side graph can be demagnetized from saturation to zero by a small external driving field. This characteristic is desirable for transformer and motor cores to minimize the energy dissipation that corresponds to the area of the hysteresis region inside the loop. The energy is dissipated as a result of the heat development in the material during the demagnetization process. In contrast to the right-hand side graph, the material captured in the left-hand side graph has a large hysteresis region associated with high energy dissipation during the magnetizing-demagnetizing cycle. This makes it inappropriate for electrical applications but perfect for other purposes - e.g. magnetic recording - due to its ability to retain a large fraction of the magnetization after removing the magnetizing force. High remanence is desirable

for permanent magnets and memory devices (see Young et al. 2012, p. 945).

Other important characteristics of hysteresis that are related to the aggregation process (in terms of ferromagnetics this is associated with aggregation of single iron crystals to the whole piece of iron) are discussed and illustrated in section 6.1.

The application of hysteresis in economics underlies the same reasoning as in physics. In economics, we analyze markets rather than physical materials and investigate the output behavior instead of magnetization. The specification of both output and the forcing input depends on the concrete market of interest. For example, if we consider international trade between two countries, we analyze the export behavior regarding the changes of the bilateral exchange rate. If we consider the job market, the output of interest is (un)employment and the forcing variable is the wage rate. In order to draw concrete policy implications, the relationship between input and output must be rigorously examined. In case of hysteretic systems, we observe persistent effects of temporary shocks on output (e.g. permanently high unemployment after a financial crisis due to high sunk hiring and firing costs) that require certain coercive forces to bring the output back to the initial situation (e.g. unemployment rate before crisis). In many cases, the standard political measures do not help much and alternative instruments are required to fight the cause of permanent output changes (e.g. special training programs for the unemployed persons).

An overview of different sources of hysteresis in economics is provided in the following section 2.3.

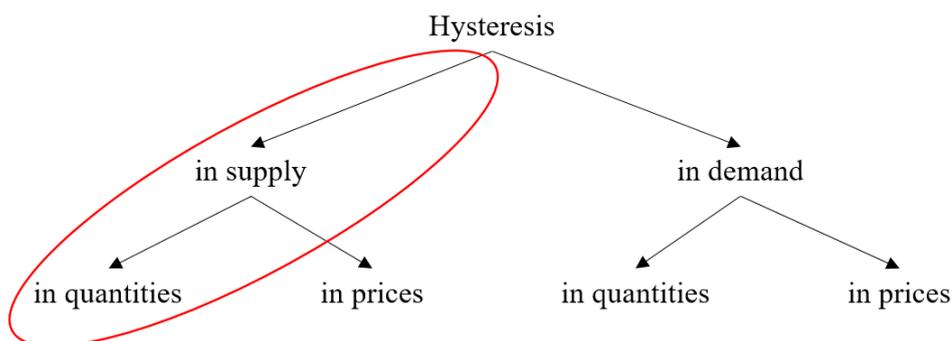
2.3 Hysteresis in different economic fields and related literature

Stemming from physics, hysteresis also appears in economics, chemistry, biology, experimental psychology and other fields (see Visintin 1994, p. 1). Useful survey articles about hysteresis in economic systems include Amable et al. 1992, Cross 1993, Cross et al. 2009 and Göcke 2002. The main economic applications of the hysteresis concept are in labor economics and international trade. They will be

briefly discussed in this section.

Fig. 2.3 provides an overview of potential hysteresis effects on a market that are associated with different determinants/sources of this phenomenon. Thus, hysteresis can occur on both market sides, namely supply or/and demand. In addition, hysteretic behavior associated with delayed and permanent effects can be exhibited by either quantities or prices.

Figure 2.3: Overview of hysteresis on different market sides



As a first example, we discuss hysteresis on the supply side of the market occurring in quantities (marked with the red circle in fig. 2.3). This type of hysteresis is typically applied in international trade. Hysteresis and threshold effects in international trade were first considered by Kemp and Wan 1974, followed by Baldwin 1989, Baldwin and Lyons 1989, Baldwin 1990, Baldwin and Krugman 1989 and Dixit 1992. They all recognized that modeling the economic activity of exporting firms - especially on markets with high barriers to entry and exit - is more appropriate in many cases using the dynamic hysteresis framework, which takes the firm's economic past into account to determine the right current equilibrium.

To enter new markets, firms often have to incur sunk costs, e.g. for gathering information on the new market and market research, setting up distribution and service networks, advertising or establishing a brand name or hiring new workers and building firm-specific human capital, etc. Since these entry investments are firm and market specific, the firms cannot recoup these costs if they exit. Such firms will only enter the market if both unit variable and sunk entry costs are covered by the revenues/prices, meaning that the individual price entry threshold

of a certain firm is higher than its unit variable costs. Analogously, a market exit results in exit costs - e.g. for severance payments for fired employees - if the production is stopped. Consequently, a certain firm will not exit the market even if its unit variable costs cannot be covered by its unit revenues. The exit only takes place if the loss from continuing producing exceeds the sunk exit costs. Therefore, the exit threshold price is lower than the entry trigger and lower than the unit variable costs. Accordingly, the sunk entry and exit costs together with uncertainty regarding the future price development result in a path-dependent behavior of firms, which is called “sunk cost hysteresis” (see Amable et al. 1991, Baldwin 1989, Baldwin 1990, Baldwin and Krugman 1989, Dixit and Pindyck 1994). It constitutes that a temporary exogenous shock in a forcing variable - e.g. an increase in costs or appreciation of one’s own currency against the trade partner’s currency - can lead to permanent effects on the firm’s production (export) intensity. The sum of the sunk costs induced by a firm that entered and subsequently exited the market represents the hysteresis losses, which are comparable with energy dissipation in the form of heat as a result of a loading-unloading process in physical materials (see section 2.2). At the macroeconomic level, hysteresis losses are proportional to the hysteresis region inside the loop (see fig. 2.2), whose extent depends on the functional form of the hysteresis curve. This specific type of hysteresis that occurs on the supply side of the market is what we focus on in this manuscript. We model hysteresis losses and build the hysteresis losses indicator based on the idea of the sunk adjustment costs. The concept of sunk costs representing the microeconomic foundation of hysteresis is discussed in detail in section 3.1. Microeconomic hysteresis losses are modeled in section 4.1.

One of the first attempts to capture hysteresis effects in international trade empirically using dummy variables can be found in Baldwin and Krugman 1989 and Baldwin 1990. A review of different methods used to describe economic path-dependence and structural shifts/breaks can be found in Belke et al. 2014. From the authors’ perspective, the most important empirical models in this context are based on “strong” hysteresis (see Amable et al. 1991). As noted by Belke et al. 2014, there are two of them: a direct application of the Preisach 1935 aggregation method (the aggregation issue is discussed in sections 3.2 and 6.1),

which is introduced by Piscitelli et al. 2000; and the play algorithm, which is based on the linear play-hysteresis model and introduced by Belke and Göcke 2001. The latter is discussed in section 6.3 and used in the empirical part of this manuscript. These two approaches are similar in that both of them calculate an artificial forcing/input variable from an original input variable (e.g. exchange rate), which is ultimately included into a regression framework. Useful empirical contributions proving the existence of hysteresis in international trade include Amable et al. 1995, Baldwin 1990, Belke et al. 2013, Belke and Volz 2015, Campa 2004, Dixit 1989, De Prince and Kannebley Jr. 2013 and Kannebley Jr. 2008.

Amable et al. 1992 and Amable et al. 1993 discussed the issue of hysteresis to shed more light in the hysteresis literature due to numerous incorrect interpretations of the hysteresis phenomenon.

Supply hysteresis may also be caused by other factors, e.g. learning-by-doing, which is associated with the permanent reduction of production costs. In the absence of the sunk adjustment costs, a firm will enter the market as soon as the production costs are covered by the revenues. Due to learning-by-doing effects that occur after the firm's entry, it will not exit the market at the same price level at which it entered the market. Depending on the extent to which the production costs have been reduced, the firm delays its exit to the new point associated with lower production costs. In the presence of the sunk entry and exit costs, the hysteresis effect becomes stronger due to learning-by-doing, since a firm delays its market exit by a greater extent. The zone of delaying entry and exit decisions (difference between price entry and exit triggers) becomes larger and the new exit trigger is adjusted to the lower production costs.

Hysteresis may also occur in prices on the supply side of a market, since hysteresis has an effect on quantities and thus on the simultaneous equilibrium in the quantity-price dimensions. In this case, a temporary exogenous shock leads to permanent effects on the price level. For example, Fedoseeva and Werner 2015 found hysteresis in prices of German beer exports to different destination countries caused by exchange rate fluctuations. One of the potential causes for this type of hysteresis is learning-by-doing, due to which permanently lower prices can be realized as a result of lower production costs.

Hysteresis may also occur on the demand (in both quantities and prices) side,

being caused by e.g. demand carry-over effects that result due to imperfectly-informed consumers. These effects are associated with experience after consuming goods that the consumer did not previously try. As a result, the consumer will be willing to pay more for such an experience good (Baldwin 1990, p. 130).¹ In case of substitutes, the consumer may then permanently change his consuming behavior in favor of the newly-experienced good, especially if the prices of these goods are similar. Permanent effects on consumer behavior can also be caused by certain price developments of substitutes and complementary goods.

The oldest and most popular economic application of hysteresis can be found in labor economics. As stated in Blanchard and Summers 1986a, p.1, the mainstream theory of that time suggested that the “equilibrium unemployment is determined by labor market institutions, moves slowly and is unaffected by actual unemployment”. However, this theory often failed to explain the equilibrium unemployment level of the later 20th century, especially in times of permanently high unemployment. This incentivized economists to develop alternative theories to derive appropriate policy implications. Phelps 1972, Sachs 1986, Blanchard and Summers 1986a and Blanchard and Summers 1986b were first to consider hysteresis effects in unemployment. All of them proposed an approach incorporating the idea that the equilibrium unemployment rate is path-dependent, and depends on the path that the actual unemployment passes through in the context of history with the focus on the relationship between unemployment and wage setting. On the one hand, the membership theories distinguish between insiders and outsiders and state that wage setting in a firm is influenced by its employees rather than the unemployed workers. On the other hand, duration theories distinguish between the short- and long-term unemployment of workers, whereby the long-term unemployed have little influence on wage setting due to e.g. lower productivity as a result of losing their job skills while unemployed. In combination these theories are able to explain high persistent unemployment (see Blanchard and Summers 1986b, p. 2). The intuition of unemployment hysteresis is that: hiring workers and acquiring the firm-specific human capital is associated with high costs that are sunk, since the firm cannot recoup them if it lowers pro-

¹In a static price-quantity-diagram, this is associated with an upward shift of the demand curve.

duction intensity or shuts down. The demand of the production factor labor not only depends on labor productivity but also on its costs, i.e. wage. The higher the wage, the lower the labor demand. Now let us assume an economic downturn, e.g. a recession accompanied by a decreasing demand for goods and services. As a result, firms have to reduce their production intensity, fire their workers and pay them severance payments, which in turn are sunk costs. Similar to sunk cost hysteresis applied to international trade, two threshold wages as forcing factors of microeconomic labor demand result: a lower wage for hiring and a higher wage for firing the employees. Moreover, the employed workers have wage bargaining power and might force the firm to increase their wage as the recession is over. In case the labor productivity remains the same, the production costs for this firm increase due to higher wages and the firm's ability to employ new workers is reduced. Furthermore, as time goes by the unemployed workers lose their job skills, become unproductive and potentially depressed. This lowers their chances of being employed. As a result, the difference between hiring and firing wages becomes larger, which in aggregation leads to permanently higher unemployment owing to an economic downturn. Path-dependent behavior of the (un)employment reveals that political measures solely aiming to promote demand are insufficient to lower the unemployment rate. Special programs for unemployed workers are needed to motivate and help them to get their job skills back or acquire new ones.² Further useful contributions discussing hysteresis in (un)employment include Ayala et al. 2012, Belke and Göcke 1999, Belke and Göcke 2001, Belke and Göcke 2005, Cross et al. 2005, Cross and Allan 1988, Lindbeck and Snower 1986, Mota and Vasconcelos 2012 and Mota et al. 2012.

Hysteresis is usually modeled considering just one market side, either supply or demand. An interesting contribution to hysteresis literature is Göcke and Werner 2015. Here, the hysteresis phenomenon is modeled in a market model with both market sides assuming that hysteresis is exhibited on one of the market

²An example of such programs is a project in Lithuania called "Supporting the employment of the long-term unemployed", which started in August 2014 and ends in December 2017. The project is financed by the European Union Structural Funds and Lithuanian government. The program aims to help the unemployed to acquire and/or improve their job skills and integrate them in the job market (see LLE 2017). A number of persons have made use of this program and are now fully integrated in the job market despite their relatively old age.

sides and caused by an external demand or supply shock (graphically captured as a shift of the particular non-hysteretic curve). In their model, the input variable - which is price - becomes endogenous. As a result, both quantity and price hysteresis can be modeled.

To sum up, there are many determinants of hysteresis, including sunk costs, uncertainty, learning-by-doing, demand carry-over effects, secular unemployment associated with losing skills for workers and many more.³ For modeling hysteresis losses, it is very important to differentiate between the sources of hysteresis in the particular market. In this manuscript, we model the losses caused and generated by sunk cost hysteresis and thus measure the hysteresis losses in monetary units. The hysteresis losses associated with e.g. unemployment hysteresis have another dimension and modeling such losses requires some modifications of our model, which is worth discussing yet lies beyond the scope of this manuscript.

³Other potential causes for weak export reactions - e.g, hedging of exchange rate uncertainty, exporters profile and price elasticity of exports - are briefly discussed in Belke et al. 2013.

Chapter 3

Sunk costs and the concept of hysteresis

This chapter is based on the following papers: Göcke and Matulaityte 2015, and Adamonis and Göcke forthcoming.

3.1 Sunk costs and hysteresis at the firm level

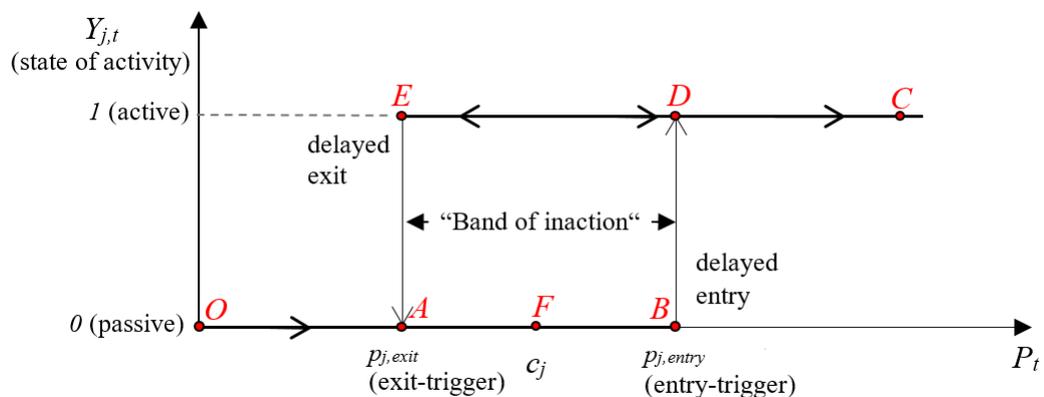
3.1.1 Hysteresis band and the non-ideal relay

First, the simplest form of hysteresis - called “non-ideal relay” (Krasnosel’skii and Pokrovskii 1989, p. 263) - is considered. In general cases as well as the special case of international trade, this hysteresis phenomenon occurs due to sunk entry and exit costs (see Baldwin 1989; Baldwin 1990), which induce a “band of inaction” related to changes in the economic environment. A firm observes the development of a forcing variable (e.g. the price level, or - in the special case of international trade - the exchange rate) and does not change its economic behavior – i.e. its state of market (in)activity – until the price (or exchange rate) changes significantly and passes certain trigger values specific to each (heterogeneous) firm. In other words, a firm delays its entry and exit due to sunk entry and exit costs. Moreover, once the economic behavior of firm j has changed (due to large past price changes), it will not completely return to the initial state, even if the forcing variable (price or exchange rate) returns to

its initial level (see Göcke 2002, p. 168). This kind of after-effect is called the remanence property (see Göcke 2002, p. 171). It plays an important role in our subsequent analysis of the dynamic losses associated with sunk adjustment costs.

Fig. 3.1 illustrates the decision process of a one-product firm j , which can be described as a “non-ideal relay”. The following explanation of microeconomic hysteresis follows Belke and Göcke 1999. The ordinate in fig. 3.1 captures the state of activity of firm j or its supply in current period t . The abscissa reflects the net price received by firms on the market for one unit of the good sold. Depending on the size of sunk costs, the threshold value for an exit is on the left-hand side and the threshold value for an entry is on the right-hand side of the variable/unit costs (marked as point F in fig. 3.1). There are also two potential equilibria between the exit/entry thresholds. The currently valid equilibrium can only be determined if the state of activity of a previous period is known. Between the two triggers, there is a “band of inaction”, since only a move outside this band - passing one of the triggers - will result in a switch in the state of activity. Thus, if the market price varies within the hysteresis band, firm j remains in its state, which can be either active or passive.

Figure 3.1: Non-ideal relay under certainty



Source: Own representation based on Belke and Göcke 2001.

Thus, the economic behavior of a price taker in period t depends not only on the price development, but also the previous state of its activity. There are two states of activity that a firm may have had in the previous period ($t-1$), namely passive or active. A passive firm does not produce any goods, so its production

level is zero ($y_{j,t-1} = 0$). An active firm produces one unit of goods ($y_{j,t-1} = 1$). If a firm was passive, it can choose to remain passive or enter the market in a current period and become active. The firm remains passive as the market price varies in the interval between zero and the entry trigger. Thus, the supply curve of a previously passive firm j corresponds to the line OAB in fig. 3.1. However, if the price rises further so that the entry-trigger value is passed, the firm enters the market (paying sunk entry costs) and is active. After the entry, the supply of firm j corresponds to the line EDC (see fig. 3.1) and remains at the same level as long as the price varies between the exit trigger and infinity. In this case, the firm does not change its behavior and continues producing. However, as later on the price falls below the exit trigger, the firm shuts down (pays exit costs), becoming passive again. The cycle $ABDEA$ represents a complete hysteresis loop, which can also be described as a switch between different (path-dependent) supply curves of the firm. In the next section, this adjustment pattern is modeled explicitly for a simple case of a one-period optimization of a single firm.

3.1.2 Sunk costs in a discrete one-period model

A one-period model - with the firm's time horizon reduced to the current period - is the simplest microeconomic perspective on the hysteresis phenomenon. It is used to formalize and illustrate a firm's economic behavior taking the changes of a forcing variable into account. The forcing variable in this model is the price. The drivers of e.g. food price changes are different supply and demand side shocks, speculation in commodity prices, exchange rate changes or even tariff and non-tariff barriers. A firm is able to produce and sell just one product (i.e. it is a single-product firm) and the sales volume always equals one unit (single-unit). A real firm producing several units can be seen as fictitiously disaggregated into single units. Each of them is characterized by a non-ideal relay if sunk costs are relevant to changing the activity state of the respective unit. Entering and exiting the market is associated with the sunk entry (k_j) and exit (l_j) costs. This induces a difference between the entry and exit threshold prices (p_{entry} and p_{exit} , respectively). Depending on both the previous and current state of activity, the following unit cost function of firm j is assumed for the current period t (the

subsequent explanations in this subchapter follow Göcke 2002, p. 170 et sqq.):

$$K_{j,t} = \begin{cases} c_j, & \text{if } y_{j,t} = y_{j,t-1} = 1, \\ c_j + k_j, & \text{if } y_{j,t} = 1, y_{j,t-1} = 0, \\ l_j, & \text{if } y_{j,t} = 0, y_{j,t-1} = 1, \\ 0, & \text{if } y_{j,t} = y_{j,t-1} = 0, \text{ with } c_j, k_j, l_j > 0 \end{cases} \quad (3.1)$$

c_j represents the unit variable costs of firm j , $y_{j,t}$ is the production and sales volume of firm j within the current period and $y_{j,t-1}$ is a measure for the sales in the previous time period. In the case of activity of firm j , the output is normalized to 1. k_j quantifies the sunk entry costs that must be paid for an increase in sales by this additional unit of production. l_j denotes sunk exit costs that must be paid if sales are reduced by this unit. Consequently, the following output function of firm j can be written depending on the previous level of production and the current price level (p_t):

$$y_{j,t} = \begin{cases} 1, & \text{if } y_{j,t-1} = 1, p_t \geq c_j - l_j \\ 1, & \text{if } y_{j,t-1} = 0, p_t \geq c_j + k_j \\ 0, & \text{if } y_{j,t-1} = 1, p_t \leq c_j - l_j \\ 0, & \text{if } y_{j,t-1} = 0, p_t \leq c_j + k_j \end{cases} \quad (3.2)$$

If firm j did not sell in the previous period and remains inactive in the current period, there are no costs (fourth line in eq. (3.1)). As eq. (3.2) states, in this case firm j does not sell as long as the price does not exceed the threshold for an entry (p_{entry}), which is the sum of the variable and sunk entry costs (fourth line in eq. (3.2)). However, if firm j encounters a price change stimulating an entry into the market in period t (second line in eq. (3.2)), it has to pay sunk entry costs and the variable costs (as described by the second line of eq. (3.1)). After the entry, it will not exit immediately if the price falls below the entry-trigger value. Firm j keeps selling unless the price falls below its exit threshold value (p_{exit}), which is the difference between variable and sunk exit costs. Firm j pays variable costs c_j if it remains active in period t . If the price level decreases below the exit threshold, the third line of eq. (3.2) becomes valid and firm j leaves the market, paying only the sunk exit costs (third line in eq. (3.1)).

Thus, firm j has two threshold prices. Market entry results for $p > p_{j,entry} =$

$c_j + k_j$, and the firm exits the market, if $p < p_{j,exit} = c_j - l_j$. Every heterogeneous firm with its specific cost structure can be characterized by a combination of its individual thresholds (prices) inducing market entry and/or exit. The distance between the entry and exit threshold values equals the sum of the sunk entry and exit costs ($k_j + l_j$). This zone is called the “band of inaction” and it is wider the higher the sunk costs. The firm’s profit maximization problem is solved by minimizing its costs and contemporaneously optimizing the production intensity, taking the previous volume of production into account.

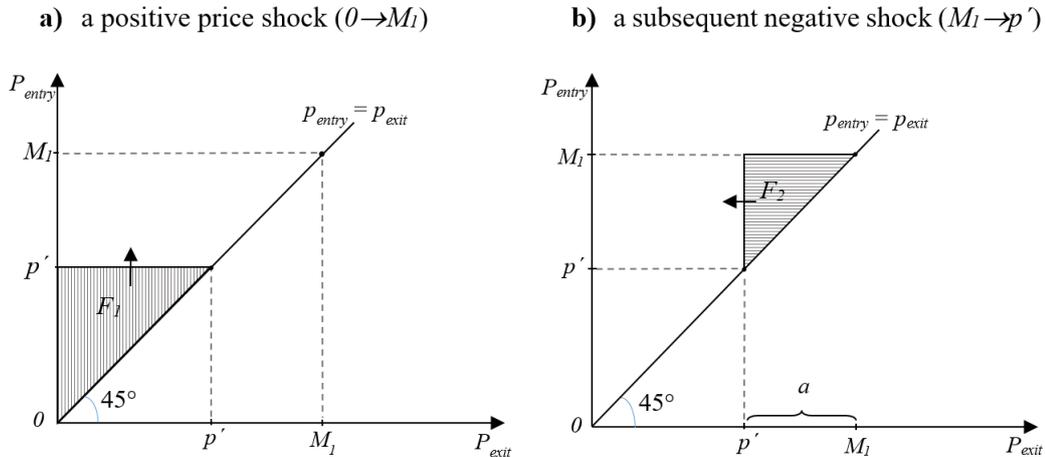
The non-ideal relay model illustrated in fig. 3.1 allows for an analysis of only one element of an aggregate economic system, which comprises a multitude of heterogeneous units sold on the entire aggregate market. Below, we will present an adequate aggregation procedure to derive the path-dependent behavior (and adjustment/hysteresis losses) of an entire market.

3.2 Aggregated hysteresis loop for heterogeneous firms under certainty

As stated above, every firm j has a specific cost structure that implicates heterogeneity in entry and exit thresholds (this means that every firm has an individual non-ideal relay operator ($\hat{\gamma}_{j,p_{entry}p_{exit}}$)). In the mathematical Preisach-Mayergoyz-Krasnosel’skii aggregation procedure (see Preisach 1935; Cross 1993, pp.85; Mayergoyz 2003, pp. 1; Mayergoyz 2006, pp.293), the non-ideal relay is the elementary hysteresis operator (Mayergoyz 1986, p.604). It illustrates a micro element of an aggregate macro system. Based on the Preisach-Mayergoyz-Krasnosel’skii procedure, we aggregate the supply of heterogeneous firms or sum up firms entering and/or exiting the market following a certain price change. The following explanations of the aggregation procedure are based on Amable et al. 1991.

Fig. 3.2 contains two entry-exit-trigger diagrams, each with the exit threshold price variable on the abscissa and the entry price trigger on the ordinate. Each heterogeneous unit/firm is represented by an individual $(p_{entry}; p_{exit})$ -point in such a diagram. The 45°-line represents firms without any sunk adjustment costs, for which the entry trigger equals the exit threshold value (“non-hysteretic” firms,

Figure 3.2: Cumulated output changes induced by a positive and a subsequent negative price shocks



Source: Own representation based on Amable et al. 1991.

with $p_{entry} = p_{exit}$). The area above the 45° -line captures all of the firms with sunk adjustment costs („hysteretic“ firms) since for these firms the entry-trigger price is higher than the exit trigger. The area below the 45° -line represents impossible combinations of the entry and exit threshold values, since $p_{exit} > p_{entry}$. The behavior of every hysteretic firm is assumed to be a non-ideal relay, as illustrated in fig. 3.1. Given that the output of every active firm is one, the aggregate output volume corresponds to the number of active firms on the market. Real firms producing more than one unit can be considered as artificially disaggregated into single-unit firms, each represented by a point in the diagram. We assume that all of the firms have the same time horizon and cannot re-enter or re-exit the market. As a simplification, a continuous *uniform distribution*¹ of firms in the upper triangle area of the (P_{entry}/P_{exit}) diagram is assumed, whereby each geometrical area in the diagram is proportional to the number of represented firms.

The left-hand diagram of fig. 3.2 illustrates the cumulated output change induced by a positive price shock and the right-hand graph shows the effect of a subsequent negative shock. In case of a positive price change, starting at 0 and

¹The distribution of firms in the (P_{entry}/P_{exit}) diagram determines the curvature of the aggregated hysteresis loop.

going up to a maximum M_1 ($0 \rightarrow p' \rightarrow M_1$), the triangle area F_1 is generated, representing the cumulated output increase or the number of firms that have entered the market due to the favorable change of the forcing variable. The numeric value of the triangle area F_1 is:

$$F_1 = \rho \cdot \frac{1}{2} \cdot (p' - 0)^2 = \rho \cdot \frac{1}{2} \cdot (p')^2 \quad (3.3)$$

with ρ as a density parameter of the firm distribution inside the area above the ($p_{entry} = p_{exit}$)-line and p' as a price change if the price increase starts at 0. M_1 is the maximum price where the initial price increase has turned around. The right-hand diagram of fig. 3.2 captures the effect of a later price reduction, which follows the price increase to M_1 . Thus, the triangle area F_2 represents the cumulated output reduction or the multitude of firms that have exited the market after the subsequent price fall from M_1 to p' (with an absolute price change equal to a):

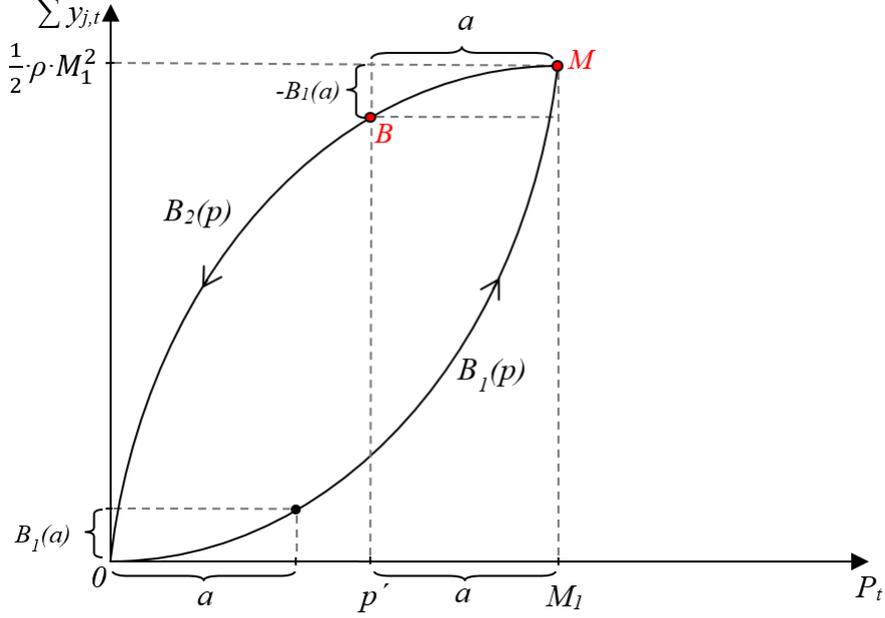
$$F_2 = \rho \cdot \frac{1}{2} \cdot (M_1 - p')^2 = \rho \cdot \frac{1}{2} \cdot (a)^2 \quad (3.4)$$

Fig. 3.3 illustrates the aggregate output or the sum of active firms depending on price changes ($0 \rightarrow p' \rightarrow M_1$ and $M_1 \rightarrow p' \rightarrow 0$).² This constitutes a complete aggregate/macro hysteresis loop. The aggregate hysteresis loop has the form of a lens and comprises an upward- ($B_1(p')$) and a downward-leading ($B_2(p')$) branch. Each part of the macro hysteresis loop in fig. 3.3 corresponds to an area in the (P_{entry}/P_{exit}) diagram in fig. 3.2. The upward branch captures the quantitative effects of a positive price change, whereby every point on this line can be calculated by means of eq. (3.3). The downward branch captures the impact of the subsequent negative price change. Each point on this curve can be quantified via eq. (3.4). Given the uniform distribution of firms, this effect is again equivalent to a triangle area (as in the case of the initial increase), and the following relation results:

$$F_2 = B_2(M_1) - B_2(p') = B_1(a) \quad (3.5)$$

²For a detailed aggregation procedure, see Amable et al. 1991; Göcke 2002.

Figure 3.3: Macroeconomic hysteresis loop resulting from price changes $M_1 \rightarrow 0 \rightarrow M_1$ or $0 \rightarrow M_1 \rightarrow 0$



Source: Own representation based on Amable et al. 1991.

The upward branch captures the aggregate output change by increasing prices and equals the area F_1 from fig. 3.2. Thus, the maximum of this upward branch (point M) resulting from the price increase from 0 to M_1 equals:

$$B_1(M_1) = \rho \cdot \frac{1}{2} \cdot (M_1 - 0)^2 = \rho \cdot \frac{1}{2} \cdot M_1^2 \quad (3.6)$$

If the price level subsequently falls from M_1 to p' , the number of exit firms or aggregate supply reduction equals the area F_2 in fig. 3.2. The aggregate output changes resulting from a negative price shock are captured by the part of the downward branch, going down from point M to B (in fig. 3.3). At point B , the following level of production results:

$$B_2(p') = B_1(M_1) - B_1(M_1 - p') = \rho \cdot \frac{1}{2} \cdot M_1^2 - \rho \cdot \frac{1}{2} \cdot a^2 \quad (3.7)$$

In sum, if the price rises from 0 to M_1 , the aggregated output change is illustrated by the upward branch going from 0 to $B_1(M_1)$. The aggregate output reduction due to the subsequent price fall from M_1 to p' is captured by the part

of the downward-leading branch falling from $B_1(M_1)$ to $B_2(p')$.

3.3 The shape of the macroeconomic hysteresis loop

The aggregation procedure illustrated in section 3.2 is based on a uniform distribution of firms in the Preisach triangle in the (P_{entry}/P_{exit}) diagram. The constant density of firms in this triangle is reflected by ρ . The uniform distribution of firms leads to the hysteresis loop, whose branches are quadratic functions, since the loops are derived from the areas of triangles. If we further assume a symmetric course of the hysteresis loop and use z as an additional distribution density parameter that allows capturing different densities in the Preisach triangle, the upward-leading branch $B_1(p)$ in a general case can be formalized as follows (see eq. (3.6)):

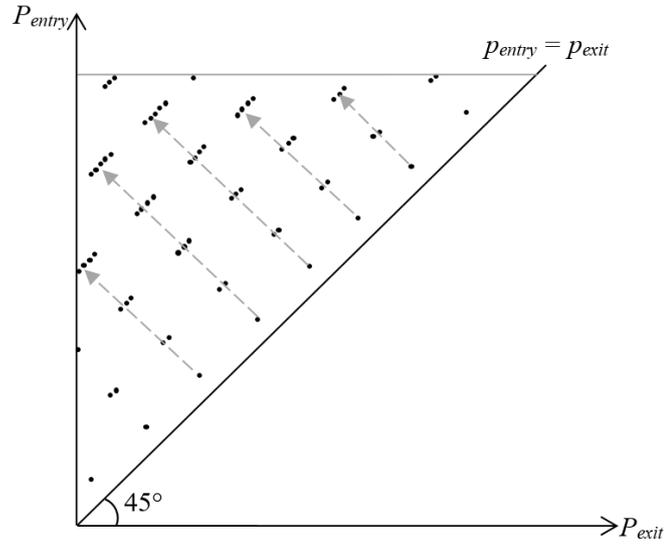
$$B_1(p) = \rho \cdot \frac{1}{2} \cdot p^{2+z} \quad (3.8)$$

In case of a uniform distribution, $z = 0$. For example, if the density of firms becomes different in certain parts of the Preisach triangle due to changes in uncertainty, risk awareness or the extent of the sunk adjustment costs³, z takes either a negative or positive value depending on the extent and direction of changes in density. In the following, two different cases will be illustrated: an increasing and a decreasing density of firms that differently form the hysteresis loop. In contrast to section 5.3, a case of a complete “depopulation” of firms in the Preisach triangle leading to a shift of the hysteresis branches is not analyzed in this section to focus only on the shape of the loop. However, a combination of both - different distribution densities and the “depopulated” part in the Preisach triangle is conceivable and - in case of a decreasing density moving from the 45°-line towards the ordinate - more realistic.

As a first scenario, increasing (higher) price entry and decreasing exit trigger values are considered, resulting in a rising density of firms going orthogonal from

³For a detailed description of the uncertainty effects on firms' location in the (P_{entry}/P_{exit}) diagram, see section 5.3 and the effects of adjustment cost changes are illustrated in section 9.

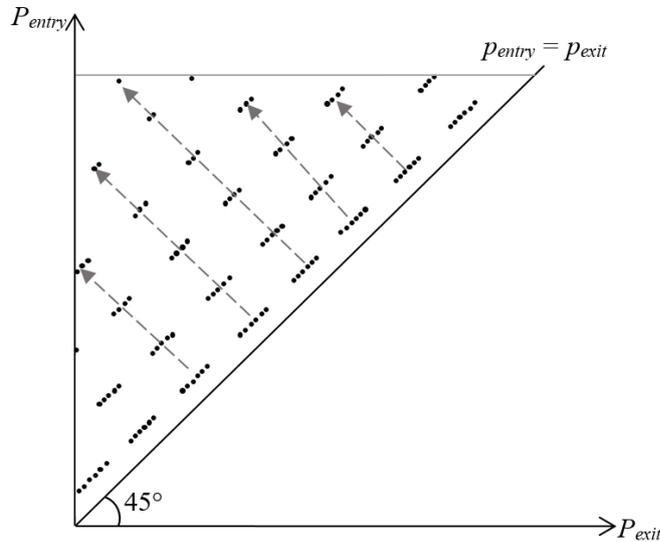
Figure 3.4: Increasing density of firms in the Preisach triangle



the 45°-line towards the ordinate in the (P_{entry}/P_{exit}) diagram. Such effects can be caused by e.g. an increase in uncertainty, risk aversion or risen sunk adjustment costs. If the density of firms in the Preisach triangle rises rather than being constant (as assumed in section 3.2), z takes a positive value ($z > 0$) (see illustration in fig. 3.4). For example, in a case that z equals 1, the hysteresis loop becomes a cubic function (see eq. (3.8)). Higher values of z induce higher power of the loop-functions leading to a more humped shape of the branches.

The second scenario can be caused by e.g. reduction of market entry and exit barriers, reduced price volatility or risk-seeking among economic agents, leading to lower market entry and exit triggers and thus a decreasing density of firms going orthogonal from the 45°-line towards the ordinate. z can take any value from the interval $(-1; 0)$ inducing a power of loop-branches from the interval $(1; 2)$. The decreasing density of firms in the Preisach triangle is illustrated in fig. 3.5. In the case that with the orthogonal distance from the 45°-line, the density of firms declines by factor 0.5, the distribution density parameter z equals -0.5 and induces less humped shape of the hysteresis branches.

Figure 3.5: Decreasing density of firms in the Preisach triangle



3.4 Risk neutrality assumption

The modeling of hysteresis losses in benchmark models in chapters 4 and 5 is based on the risk neutrality assumption, meaning that the preferences of economic agents are not affected by uncertainty. The use of this assumption simplifies the model, but still allows us to identify the main links between certain market parameters.

Chapter 5 deals with hysteresis losses under uncertainty and shows that solely due to the stochastic nature of market prices the “band of inaction” of each firm becomes wider in comparison to the model without risk (see fig. 3.1). This points to the fact that firms make more cautious decisions, even if we maintain the risk neutrality assumption. However, such a behavior of risk-neutral firms is quite comprehensible since each of them has an option to wait and observe the development of price levels, which is also valuable. In section 5.1, the effects of uncertainty on the microeconomic “band of inaction” are discussed in further detail. The main message of this section is that in case of uncertainty not only the unit variable as well as sunk entry costs but also the option value of waiting (opportunity costs of the entry decision) must be covered to give firms stimulus to enter the market. Analogous to this, a firm has an incentive to leave the market

if the market price is at such a low level that the loss from activity is higher than the sum of sunk exit costs and the option value of waiting (opportunity costs of the exit decision). Section 5.1 covers the calculation of the expected present value of the option to wait for both - active and passive firms. The probability of a single positive (or negative) price change in the next period is assumed to be 0.5.

Thus, the cautious behavior of firms results from a quite simple profit calculation taking both implicit and explicit costs into account. In other words, taking option value into account (being cautious in decision making) is a consequence of a risk-neutral maximization of an expected value with the presence of an option.

Chapter 4

Hysteresis losses under certainty

This chapter is based on the following papers: Göcke and Matulaityte 2015, and Adamonis and Göcke forthcoming.

4.1 Hysteresis losses in a discrete one-period microeconomic model

The non-ideal relay model (see fig. 3.1) is now applied to determine the loss caused by price dynamics that changes the activity state of a firm. This loss arises due to the sunk costs that a firm has to bear if it changes its production volume. The entry investment (from a previous period) cannot be used further in case of an exit and has to be written off. Additionally, sunk exit costs have to be paid. Thus, the hysteresis loss induced by a complete entry-exit cycle becomes effective with the market exit. Therefore, starting from a low price level, we need following price changes to complete a full loading-unloading cycle: a significant price increase inducing the firm's entry into the market and a subsequent drastic price fall passing the exit threshold. I.e. a closed hysteresis loop, such as $ABDEA$ in fig. 3.1 is required for a hysteresis loss to occur.

The assumption of a single-product and single-unit firm still holds. Therefore, after every change of activity of firm j , an output change of one unit is observed ($|\Delta y_j| = 1$). The area enclosed by the hysteresis loop $ABDEA$ can be quantified as follows:

$$[c_j + k_j - (c_j - l_j)] \cdot |\Delta y_j| = k_j + l_j \quad (4.1)$$

According to eq. (4.1), the area within the hysteresis loop in the non-ideal relay model equals the sum of the sunk entry and exit investments. Thus, the geometric area enclosed by the hysteresis loop - i.e. the area between the triggers in the non-ideal relay - represents the dynamic loss of a complete entry-exit cycle in a one-period model under certainty.

4.2 Hysteresis losses in a discrete multi-period microeconomic model

Following Belke and Göcke 1999, the threshold values that stimulate an expansion or reduction in production are now calculated based on a multi-period optimization. The non-ideal relay model presented in the previous sections is used again. The present value ($V_{j,t}$) from the activity of firm j in the current period and expected for the infinite future is now a sum of two components – the profit in period t ($R_{j,t}$) and the present value of annuity due to future revenues - whereby the latter is discounted by the factor $\delta = \frac{1}{1+i}$ with an interest rate i (Belke and Göcke 1999, pp. 265):

$$V_{j,t} = R_{j,t} + \frac{1}{1+i} \cdot V_{j,t+1} \quad (4.2)$$

The operating profit in the current period ($R_{j,t}$) can be calculated as the difference between revenue and operating costs (see eq. (4.3)). The latter depends on the sales volume of firm j , which can either be higher (lower) than in previous period ($t - 1$) and include the sunk entry (exit) costs in addition to the unit variable costs, or it can be unchanged compared to the past production and contain no sunk adjustment costs. Given that firm j can either produce one unit or be inactive, the following current profit results in:

$$R_{j,t} = \begin{cases} p_t - c_j - k_j, & \text{if } y_{j,t} = 1 > y_{j,t-1} = 0 \\ p_t - c_j, & \text{if } y_{j,t} = y_{j,t-1} = 1 \\ -l_j, & \text{if } y_{j,t} = 0 < y_{j,t-1} = 1 \end{cases} \quad (4.3)$$

We assume that firm j expects the same price as in the current period for the entire infinite future, whereby the time indices for price and operating costs can be omitted. Thus, the present value of future profits can be calculated as follows:

$$\delta \cdot V_{j,t+1} = \begin{cases} \frac{\delta \cdot (p - c_j)}{1 - \delta}, & \text{if } y_{j,t-1} < y_{j,t} = y_{j,t+1}, \text{ with } \delta = \frac{1}{1+i} \\ 0, & \text{if } y_{j,t} < y_{j,t-1} \end{cases} \quad (4.4)$$

Eq. (4.4) captures two scenarios: [1] entry in t , followed by a positive (expected) present value of future profits, which is the discounted value of operating profit as an annuity; or [2] exit in t followed by zero future profits. Therefore, in case of an entry in t , the benefit of firm j is the sum of the operating profit and the present value of future profits in $t + 1$ (see first line in eq. (4.5)). The operating profit of a firm entering the market is defined in the first line of eq. (4.3). If a previously-active firm j remains active in t and $t + 1$, it does not have to pay sunk adjustment costs in any period and the annual profit of firm j is defined in the second line of eq. (4.3). If firm j exits the market in t , it has neither an operating nor any future profits. However, it experiences sunk exit costs (see the last line in eq. (4.3)).

$$V_{j,t} = R_{j,t} + \delta \cdot V_{j,t+1} = \begin{cases} \frac{p - c_j - (1 - \delta)k_j}{1 - \delta}, & \text{if } y_{j,t-1} < y_{j,t} = y_{j,t+1} \\ \frac{p - c_j}{1 - \delta}, & \text{if } y_{j,t-1} = y_{j,t} = y_{j,t+1} \\ -l_j, & \text{if } y_{j,t-1} > y_{j,t} \end{cases} \quad (4.5)$$

Firm j enters the market or expands in production at time t (first case of eq. (4.5)) if the present value from activity ($V_{j,t}$) by entry in t is positive:

$$\frac{p - c_j - (1 - \delta)k_j}{1 - \delta} > 0 \Rightarrow p_{\text{entry}} = c_j + (1 - \delta)k_j \quad (4.6)$$

Thus, on the one hand, for a previously-inactive firm a price above p_{entry} (see

eq. (4.6)) stimulates an expansion in production at time t . On the other hand, firm j leaves the market if its loss from continuing production exceeds the loss from shutting down. Therefore, the exit threshold is calculated by:

$$\frac{p-c_j}{1-\delta} < -l_j \Rightarrow p_{exit} = c_j - (1-\delta)l_j \quad (4.7)$$

If the price falls below p_{exit} (see eq. (4.7)), firm j reduces its production. If we look back at fig. 3.1 and substitute the trigger values from the one-period model by the trigger values defined in eqs. (4.6) and (4.7), a modified hysteresis band results. In the one-period model, it was shown that the hysteresis loss equals the geometric area inside the non-ideal relay loop between the triggers. This area can be computed as follows:

$$(1-\delta)(k_j + l_j) \cdot |\Delta y_j| = (1-\delta)(k_j + l_j) \quad (4.8)$$

This expression can be interpreted as the *interest costs* on the sunk entry investment and exit disinvestment. Compared to the sum of sunk costs ($k_j + l_j$) as the actual dynamic loss if an entire entry and exit cycle is run through, the area inside the non-ideal relay loop now is not equivalent but only *proportional* to the hysteresis loss: the geometric area inside the loop has to be divided by $(1-\delta) \approx i$, or multiplied by $1/(1-\delta) \approx 1/i$. The multiplier typically has a value higher than 1. Thus, due to multi-period optimization, the hysteresis loss is typically larger than the area inside the hysteresis loop.

4.3 Aggregation of hysteresis losses with heterogeneous firms in entry-exit cycles

The aim of this section - as one of the most important contributions of this study - is to cumulate the hysteresis losses ($l_j + k_j$) of all exiting firms $j = 1, 2, \dots, N$ during a price cycle $0 \rightarrow (p > p_{entry}) \rightarrow (p < p_{exit})$. For reasons of simplicity, the interpretation of the aggregation procedure is based on the one-period model

introduced in section 3.1. The assumptions made in section 3.1 still hold.¹As stated above, the sunk entry and exit costs are presumed to be written off after the market exit has come about. Thus, only the effect of a subsequent negative shock following a previous positive shock is relevant for calculating hysteresis losses based on the cumulating procedure. The dynamic loss in economics can be modeled in a similar way as the hysteresis loss in magnetization (Mayergoyz 2003, pp. 50). The basis for this is the feasibility of a geometric interpretation of the sunk entry and exit costs as depicted in fig. 4.1. The latter has a structure similar to fig. 3.2: the ordinate captures the entry trigger and the abscissa the exit trigger. The 45°-line represents the “non-hysteretic” firms, while „hysteretic“ firms are all located in the triangle above the 45°-line. Point *A* illustrates the non-ideal relay of a particular hysteretic firm *j* with the sunk entry and exit costs (k_j and l_j respectively), the variable costs c_j and the resulting entry and exit price triggers $p_{j,entry}$ and $p_{j,exit}$. *A* (hypothetical) non-hysteretic firm with entry/exit trigger c_j is represented by point *B* if it has the same variable costs as the hysteretic firm *j* but no sunk costs. The existence of the sunk entry costs (k_j) leads to the shift of a firm’s vertical position upwards by an extent of k_j and results in a higher entry-trigger value ($p_{j,entry} > c_j$). This is illustrated by an upward arrow starting at point *B*. Due to the sunk exit costs (l_j) the horizontal position of a sunk exit cost firm is shifted to the left by an extent of l_j . This is illustrated by the solid arrow starting at point *B* and pointing to the left. This shifts the hysteretic firm’s point *A* to a lower exit price trigger ($p_{j,exit} < c_j$).

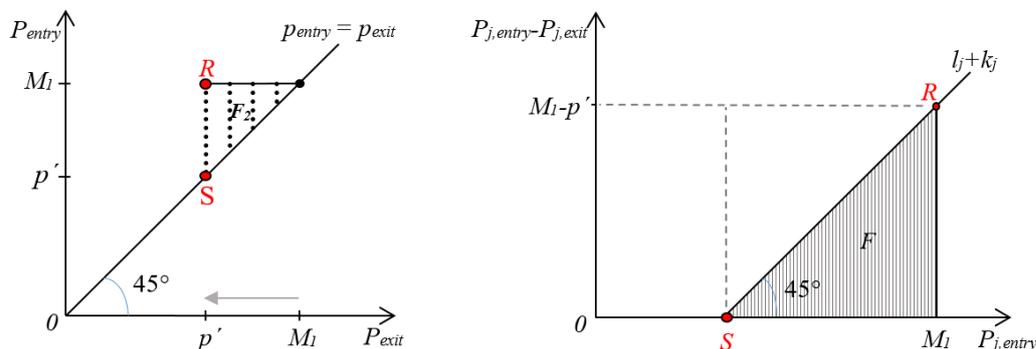
Thus, the inclusion of sunk (dis)investments allocates firm *j* from point *B* to *A*. The higher the sum of the sunk costs, the further from the 45°-line a firm is located and the larger the difference in its economic behavior in comparison to the “non-hysteretic” firms located on the 45°-line. Consequently, both the vertical and the horizontal distance between point *A* and the 45°-line equals the sum of sunk entry and exit investments. This distance can also be calculated as the difference between the entry and exit triggers of the firm *j*. It is the hysteresis loss of this firm, if a price cycle leads to an entry and later an exit of this firm:

¹One-product and one-unit firms with the same time horizon and no possibility to re-enter or re-exit the market are assumed.

$$F = \rho \cdot \int_{p'}^{M_1} (M_1 - p) dp = \rho \cdot \frac{1}{2} \cdot (M_1 - p')^2 \quad (4.10)$$

Thus, in order to sum up the hysteresis loss of all heterogeneous firms on a certain vertical line in the (P_{entry}/P_{exit}) diagram, a “vertical integration” over p_{entry} must be executed.

Figure 4.2: Cumulation of hysteresis losses in P_{entry}/P_{exit} diagram after a price reduction $M_1 \rightarrow p'$



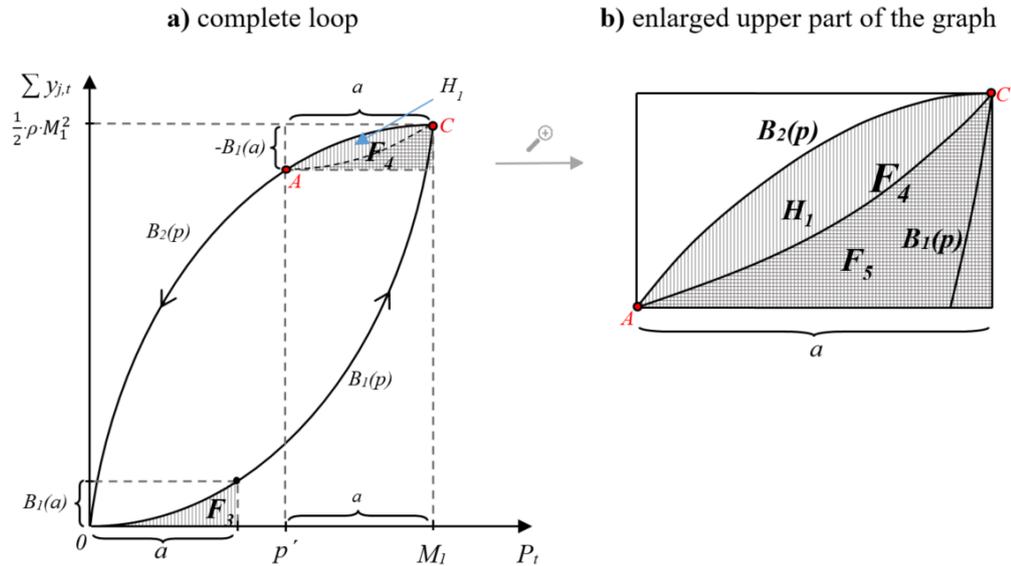
The cumulated hysteresis loss H of all firms located on any vertical line in the left-hand graph in fig. 4.2 can be calculated using the same expression as in eq. (4.10) for different levels of p . In this example, all of the relevant p -values are in the interval $[p'; M_1]$ (see fig. 4.2). Therefore, in order to calculate the hysteresis loss of all firms in the area F_2 (see the left-hand graph in fig. 4.2), a subsequent “horizontal integration” (over p_{exit}) of all vertical lines in (P_{entry}/P_{exit}) diagram over different prices (p) in the aforementioned interval has to be executed:

$$H = \int_{p'}^{M_1} \rho \cdot \frac{1}{2} \cdot (M_1 - p)^2 dp = \frac{\rho}{6} (M_1 - p')^3 \quad (4.11)$$

Now we return to the hysteresis loop derived in section 3.2 and illustrated by fig. 3.3 to graphically interpret the hysteresis loss calculated in eq. (4.11). Fig. 4.3 depicts the aggregated output depending on price variations. The illustrated loop is the closed loop generated by the price changes $0 \rightarrow M_1 \rightarrow p' \rightarrow 0$. The right-hand graph is simply an optically-enlarged upper part of the hysteresis loop on the left-hand side. If the system passes through the complete hysteresis loop,

the hysteresis loss H is graphically represented by the geometrical area enclosed by the loop (see Mayergoyz 2003, p. 50) as illustrated in fig. 4.3a.

Figure 4.3: Hysteresis loss as an area enclosed by the maximum (extreme) loop



Source: Own representation based on Amable et al. 1991 and Mayergoyz 2003.

However, if the loop is not closed given that the forcing variable does not completely change back to the initial level 0 but only decreases to the level p' as illustrated in fig. 4.2, the hysteresis loss can be graphically interpreted by fictitiously assuming an artificially-closed “inside” loop. This can be done if a subsequent fictitious prices increase from p' back to the maximum M_1 is assumed. As a result of this fictitious price cycle $M_1 \rightarrow p' \rightarrow M_1$, a small (inside) loop is generated enclosing the area H_1 , which represents the hysteresis loss induced by the price change $0 \rightarrow M_1 \rightarrow p'$. According to eq. (3.5), the parity of the areas F_3 and F_5 can be claimed, where F_3 and F_5 are the squared areas and F_4 is the whole dashed area in fig. 4.3b. Consequently, the lens-shaped hysteresis loss (H_1) can be computed as the difference between F_4 and F_3 . The area F_4 is an integral of the downward-leading branch $B_2(p)$ in the interval $[p'; M_1]$ minus the area of the rectangle $Ap'M_1C$. The downward branch $B_2(p)$ corresponds to the area F_2 specified in eq. (3.4).

$$F_4 = \left[\int_{p'}^{M_1} B_2(p) dp \right] - B_2(p') \cdot (M_1 - p') = \frac{\rho}{3} \cdot (M_1 - p')^3 \quad (4.12)$$

The area F_3 can be quantified as an integral of an upward branch $B_1(p)$ in the interval $[0; a]$. The upward branch $B_1(p)$ corresponds to the area F_1 specified in eq. (3.3).

$$F_3 = \int_0^a B_1(p) dp = \int_0^{M_1-p'} \left(\rho \cdot \frac{1}{2} \cdot p^2 \right) dp = \frac{\rho}{6} \cdot (M_1 - p')^3 \quad (4.13)$$

Therefore, the area H_1 in fig. 4.3 is quantified as follows:

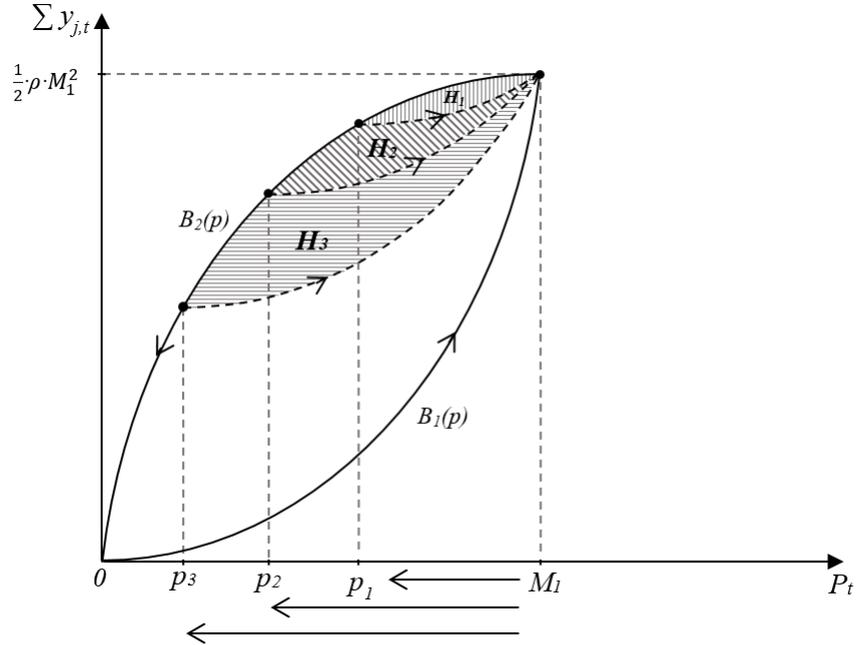
$$H_1 = F_4 - F_3 = \frac{\rho}{3} \cdot (M_1 - p')^3 - \frac{\rho}{6} \cdot (M_1 - p')^3 = \frac{\rho}{6} \cdot (M_1 - p')^3 \quad (4.14)$$

The equality between eq. (4.11) and eq. (4.14) confirms the correctness of the hysteresis loss interpretation as an area inside the hysteresis loop. Fig. 4.4 provides an example with three price changes of different extents: $M_1 \rightarrow p_1$, $M_1 \rightarrow p_2$ and $M_1 \rightarrow p_3$.

As stated above, in order to determine the hysteresis loss graphically, we have to imagine an artificially closed inner loop. This can be achieved by adding the fictitious loop that leads back to the initial maximum M_1 . By doing so, fictitious inner loops (lenses) are generated for every potential price reduction. Thus, H_1 is the lens capturing the hysteresis loss in case of a price reduction to p_1 , H_2 represents the lens with a hysteresis loss after a price change to p_2 and H_3 is the hysteresis loss resulting from a price reduction to p_3 . If the price fell completely back to 0, the whole area inside the outer maximum loop would describe the hysteresis loss of this complete ($0 \rightarrow M_1 \rightarrow 0$) cycle of the price level.

As is obvious from eq. (4.14) and the illustration of the hysteresis loss lenses in fig. 4.4, the size of this loss - as a cubic function of the price variation ($M_1 - p'$) - increases by degree 3 if we assume a uniform distribution (ρ) of firms in the (P_{entry}/P_{exit}) diagram. For instance, doubling [or tripling] the size of a price cycle ($p' \rightarrow M_1 \rightarrow p'$) results in an increase of the generated hysteresis loss by a factor 8 [or 27]. Thus, large economic fluctuations generate disproportionately high dynamic adjustment costs.

Figure 4.4: Hysteresis losses generated by different price changes under certainty



Source: Own representation based on Amable et al. 1991 and Mayergoyz 2003.

4.4 Macroeconomic hysteresis losses and the shape of the hysteresis loop

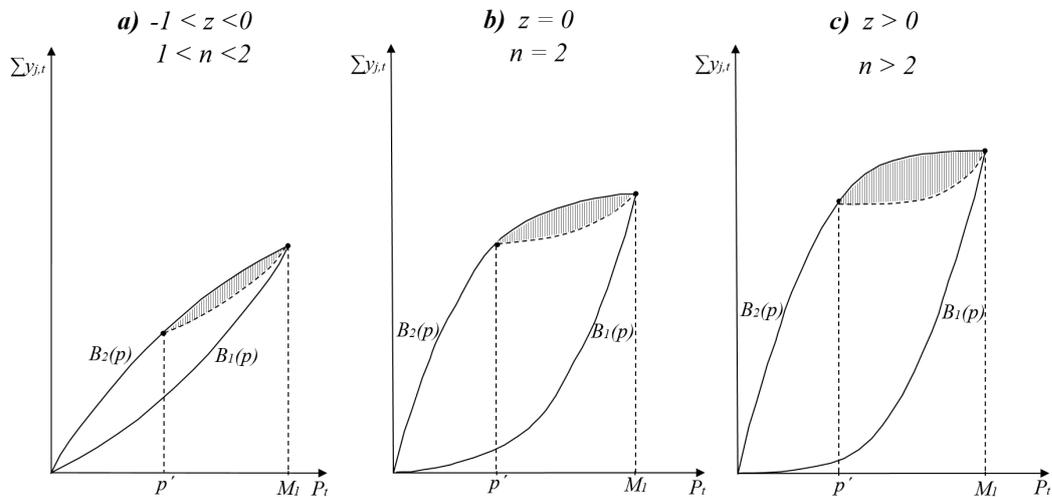
If we combine what has been worked out in sections 3.3 and 4.3 (see eqs. (3.8) and (4.14)), we are able to discuss the extent of hysteresis losses taking distribution density of firms in the Preisach triangle into account.

Fig. 4.5 illustrates three cases with different density of firms in the Preisach triangle: a decreasing density with $-1 < z < 0$, a uniform distribution with $z = 0$ and an increasing density with $z > 0$.

In fig. 4.5b, we see a hysteresis loop resulting from the assumption of a uniform distribution in the Preisach triangle ($z = 0$) as in the benchmark model in sections 3.2 and 4.3. Here, the hysteresis branches are quadratic and the resulting dynamic losses are cubic functions of the price variation ($M_1 - p'$) (see eq. (4.14)).

A decreasing density of firms in a Preisach triangle is illustrated in fig. 3.5 in

Figure 4.5: Hysteresis losses depending on different distribution of firms in the Preisach triangle



Note: z captures an additional distribution density parameter that allows capturing different densities in the Preisach triangle; n reflects the exponent of the hysteresis branches $B_1(p)$ and $B_2(p)$.

section 3.3. The negative value of z leads to an exponent of branches that can take any value from the interval $(1; 2)$ which is lower than in our benchmark case with uniform distribution and $z = 0$. The lower exponent is associated with a less humped shape of the branches. As a consequence, hysteresis branches with lower exponent enclose smaller areas (hysteresis regions) and generate lower hysteresis losses after negative price changes, since hysteresis losses are proportional or in a very special case with one-period optimization under certainty even equal the area inside the hysteresis loop (analogous to magnetism in physics) (see Mayergoyz 2003, p. 50). The case of decreasing density of firms is illustrated in fig. 4.5a.

Fig. 4.5c illustrates hysteresis losses in case of an increasing density of firms in the Preisach triangle with distribution density parameter $z > 0$ (see fig. 3.4). In this particular case, the exponent of hysteresis branches is higher than 2 and encloses larger areas than in case of a uniform distribution due to the more humped shape of the branches, leading to very high hysteresis losses.

This section makes clear that influencing the shape of the hysteresis loop - or more precisely, the distribution density of firms in the Preisach triangle - enables

us to control the extent of hysteresis losses. At the micro level this indicates the influence on the width of the “band of inaction” of each (potentially) active firm. Such economic policy is discussed in detail in chapter 9.

Chapter 5

Hysteresis losses under uncertainty

This chapter is based on the following papers: Göcke and Matulaityte 2015, and Adamonis and Göcke forthcoming.

5.1 Effects of uncertainty on the width of hysteresis band in a one-period microeconomic model

In the previous sections, it was assumed that the firms ignore the uncertain stochastic nature of the future price level when they decide about market entry or exit. However, if the price is stochastic, a real option approach applies. For example, an inactive firm deciding on a present entry has to consider the alternative option of a later entry. A current price level that covers costs may decrease in the future, and by remaining passive the firm can avoid future losses for this potential future situation. Moreover, a current entry eliminates the option to enter later and “wait-and-see” whether the future price will prove favorable. As a result, in addition to the sunk costs, an option value of waiting has to be covered to trigger an entry. Thus, uncertainty implies an upward shift of the entry-trigger price. The opportunity of a market entry is analogous to an American call option,

which can be defined as a right to buy a stock at a present strike price (see Dixit 1992). In our model, the sunk entry investments represent the “strike price” of the market entry. Intrinsically, the option has a value of waiting, called a “holding premium” (Dixit 1992, p. 116). Entering the market eliminates this option and causes the loss of the “holding premium” representing the opportunity costs of the entry decision. This only offers an incentive to enter the market if this loss is covered by future profits. Analogously, a disinvestment (market exit) is comparable with an American put option (Belke and Göcke 1999, p. 263). Therefore, the existence of uncertainty requires a correction in modeling the hysteresis losses that takes these option effects into account. Dixit 1989 models entry and exit decisions in a stochastic situation assuming a Brownian motion of a price level, which is a standard assumption in the option pricing theory. Even more simple, we assume that in the next period a single change in the price level will happen, which can either be positive $(+\varepsilon)$ or negative $(-\varepsilon)$ with the same probability of 0.5. Rest of this chapter follows Belke and Göcke 2005. The firm only anticipates the effects of stochastic variations on the next entry (or exit) decision. A later re-exit (or re-entry) due to ongoing stochastic fluctuations is not considered for reasons of simplicity. The option value for an individual firm j depends on its previous state of activity. Thus, we have to analyze the behavior of both a previously-active and -passive firm. In the first case, a previously-active firm j has to decide between an immediate exit in t and staying active in t with an option to exit in the future ($t+1$) if the price change is unfavorable ($[-\varepsilon]$ - realization). Using the same notation as in previous sections, the following expected present value of a “wait-and-see” (value of a put option) strategy results:

$$E_t(V_{j,t}^{wait} | y_{j,t-1} = 1) = (p - c_j) - \left(\frac{1}{2} \cdot \delta \cdot l_j\right) + \left(\frac{1}{2} \cdot \delta \cdot \frac{p + \varepsilon - c_j}{1 - \delta}\right) \quad (5.1)$$

The first expression in parentheses is the current profit from remaining active, the second captures the probability-weighted and discounted sunk exit costs in case of a $[-\varepsilon]$ - realization (leading to an exit in $t+1$) and the last one represents a probability-weighted present value of the annuity resulting from a future continuation of activity in case of a $[\varepsilon]$ - realization. A firm is indifferent between

an immediate exit and waiting if the expected present value equals the payment resulting from the exit costs ($-l_j$). Solving this equation results in the following exit trigger:

$$p_{j,exit}^u = c_j - (1 - \delta) \cdot l_j - \frac{\delta \cdot \varepsilon}{2 - \delta} \quad (5.2)$$

By combining eqs. (4.7) and (5.2), the relationship between the exit trigger values under certainty and under uncertainty become obvious:¹

$$p_{j,exit}^u = p_{j,exit}^c - \frac{\varepsilon}{1 + 2i} \quad (5.3)$$

If we now consider a previously-passive firm j that has to decide between an immediate entry in t and remaining passive in t with an option to enter in the future if the price change is favorable ($[+\varepsilon]$ - realization), the following expected present value of a “wait-and-see” strategy results:

$$E_t(V_{j,t}^{wait} | y_{j,t-1} = 0) = -\left(\frac{1}{2} \cdot \delta \cdot k_j\right) + \left(\frac{1}{2} \cdot \delta \cdot \frac{p + \varepsilon - c_j}{1 - \delta}\right) \quad (5.4)$$

The first expression in parentheses captures the probability-weighted and discounted sunk entry costs in case of the $[+\varepsilon]$ - realization (leading to an entry in $t + 1$), while the second one represents the probability-weighted and discounted annuity value resulting from an entry in $t + 1$.

The expected value of an immediate entry in t is:

$$E_t(V_{j,t}^{entry}) = -k_j + \frac{p - c_j}{1 - \delta} \quad (5.5)$$

The firm is indifferent between remaining passive and entering the market if both expected present values are equal [$E_t(V_{j,t}^{wait}) = E_t(V_{j,t}^{entry})$], resulting in the following entry-trigger value:

$$p_{j,entry}^u = c_j + (1 - \delta) \cdot k_j + \frac{\delta \cdot \varepsilon}{2 - \delta} \quad (5.6)$$

Combining eqs. (4.6) and (5.6), the following relationship between the entry-trigger values under certainty and uncertainty results:

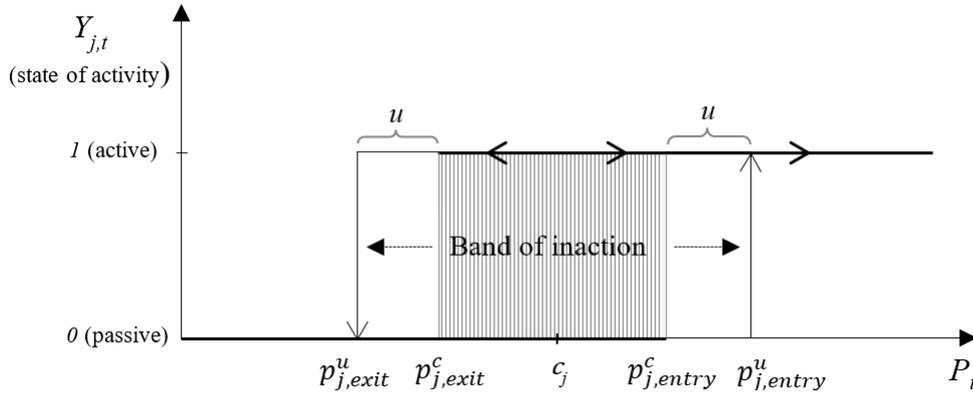
¹The discount factor δ equals $\frac{1}{(1+i)}$.

$$p_{j,entry}^u = p_{j,entry}^c + \frac{\varepsilon}{1 + 2i} \tag{5.7}$$

5.2 Hysteresis losses in a discrete multi-period model

As the simple model has shown (see eqs. (5.3) and (5.7)), the presence of uncertainty and the associated option value effects shift the entry trigger upwards/to the right and the exit trigger downwards/to the left (see fig. 5.1). This widens the “band of inaction”. Fig. 5.1 (which is an extension of fig. 3.1) illustrates two complete hysteresis loops: one under certainty (with threshold values $p_{j,entry}^c$ and $p_{j,exit}^c$) and one under uncertainty (with $p_{j,entry}^u$ and $p_{j,exit}^u$).

Figure 5.1: Non-ideal relay and hysteresis losses under (un)certainty



Source: Own representation based on Belke and Göcke 2005.

Under certainty, the area inside the loop is proportional to the hysteresis loss. In case of uncertainty, we derive a different result. If we define the stochastic part of each trigger value as $u \equiv \frac{\varepsilon}{1+2i}$, (see eqs. (5.3) and (5.7)), the area enclosed by the uncertainty loop F^U (which is the whole area between p_{exit}^u and p_{entry}^u in fig. 5.1 equals:

$$F^U = (1 - \delta) \cdot (k_j + l_j) + 2u = (1 - \delta) \cdot H + 2u \tag{5.8}$$

Thus, the inclusion of stochastic effects increases the area inside the non-ideal

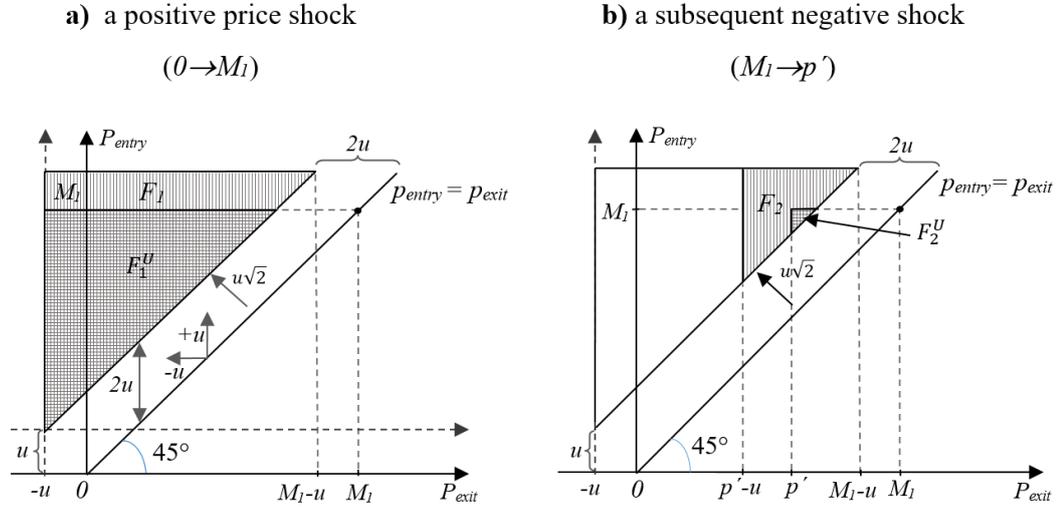
relay loop relative to the sum of the sunk costs H . Since a “wait-and-see” strategy in a stochastic environment sometimes prevents sunk entry and exit costs from actually being written off, option value effects reduce dynamic hysteresis losses H in relation to the area inside the hysteresis loop. The area inside the loop is no longer proportional to the hysteresis loss. In this regard, our model differs from the original (non-stochastic) case of hysteresis losses in ferromagnetism.

5.3 Aggregated hysteresis loop of heterogeneous firms under uncertainty

In this section, the effects of uncertainty on the aggregation of heterogeneous firms (see fig. 5.1) are shown following Belke and Göcke 2005. In order to illustrate this problem, again we will use (P_{entry}/P_{exit}) diagrams capturing all hysteretic firms in an area above the 45° -line (see fig. 5.2). For reasons of simplicity, in order to illustrate the principal effects of uncertainty on the aggregation procedure, we explicitly analyze only a simplified situation: we assume that all firms are affected by sunk costs, whereby there are no firms on the 45° -line. Moreover, all firms are assumed to be affected by uncertainty in the same way, resulting in the same widening effect on the band of inaction for all firms. Fig. 5.2 is an extension of fig. 3.2 and illustrates the aggregate effects of an inclusion of the option value effects (as calculated by the simple stochastic model above). Widening the “band of inaction” of each firm by $2u$ (see fig. 5.1) due to uncertainty means that the coordinate system of the entry-exit diagram with all hysteretic firms has to be shifted to the left by u and upwards by u to account for the “outward” shifts in both triggers. This results in a horizontal shift of the 45° -line by $2u$ or an orthogonal shift by $u\sqrt{2}$. The resulting area between the 45° -line and the shifted triangle area is now “depopulated” (i.e. there are no hysteretic firms that would enter or exit the market if the market price varies within this area).

If we compare figs. 3.2 and 5.2, it becomes obvious that under uncertainty both positive and negative output changes of the same extent as under certainty require a larger price change, or - vice versa - for a given price change the output reaction is weaker. For example, under certainty, the maximal output gain F_1 (see

Figure 5.2: Cumulated output changes induced by price changes under uncertainty



Source: Own representation based on Belke and Göcke 2005.

fig. 3.2a)) results if the price rises from 0 to M_1 . However, if the stochastic nature of prices is taken into account, a price increase from $p = 0$ to $p = M_1$ results in an output change under uncertainty F_1^U which is comparable to the reaction under certainty for a price increase only up to $p = (M_1 - u)$ (see squared triangle in fig. 5.2a). The reaction of a subsequent negative price shock under uncertainty is also weakened by option effects. For example, for a subsequent price decrease from M_1 to p' the output reduction is described by the small squared triangle area F_2^U instead of F_2 , as in the case of certainty (see fig. 3.2b)). For a small price decrease (smaller than the option value effect u), there would even be no negative reaction of the output. The aggregate reaction shows similarities to “play” (or “backlash”) phenomena (as known from mechanics or engineering).

The output gain under uncertainty after a price increase from 0 to M_1 (see fig. 5.2a)), described by triangle F_1^U , and adjusted by the density parameter ρ is:

$$F_1^U = \rho \cdot \frac{1}{2} \cdot (M_1 - u)^2 \quad (5.9)$$

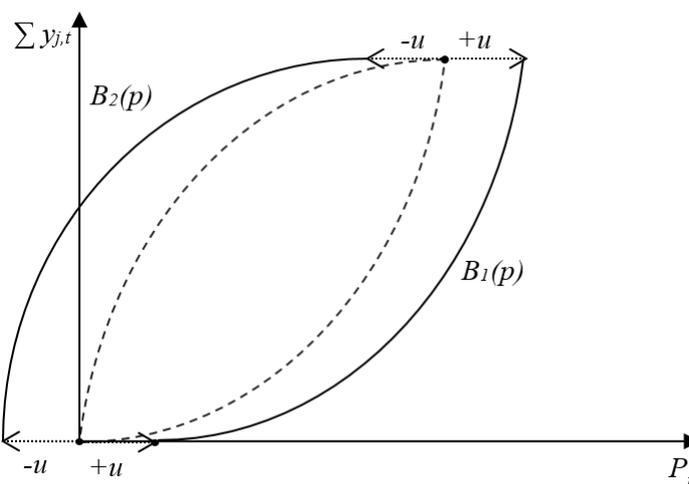
If the market price subsequently falls from the local maximum to p' , the output loss under uncertainty equals the density-adjusted triangle area F_2^U (see

fig. 5.2b)):

$$F_2^U = \rho \cdot \frac{1}{2} \cdot (M_1 - 2u - p')^2 \quad (5.10)$$

Fig. 5.3 schematically illustrates the effects of uncertainty on the aggregated behavior of firms (hysteresis loop) for all prices in the interval $[0; M_1]$. The aggregation procedure is analogous to that described in section 3.2. As a result of the inclusion of uncertainty, the downward-leading branch ($B_2(p)$) shifts to the left and the upward-leading branch ($B_1(p)$) shifts to the right, each by the absolute extent of u . The dotted lines illustrate the hysteresis loop in the case of certainty and the solid lines represent the hysteresis loop under uncertainty if option effects are considered.

Figure 5.3: Macro hysteresis loop including option value effects



Source: Own representation based on Belke and Göcke 2005.

5.4 Aggregated hysteresis losses of heterogeneous firms

As fig. 5.4 in combination with fig. 5.2 illustrates, a price increase from 0 to M_1 now changes the aggregate output by $y = \rho \cdot \frac{1}{2} (M_1 - u)^2$, which is remarkably

smaller than in the case of no option value effects. Fig. 5.4 provides some examples of hysteresis losses associated with a subsequent price decrease of different extents: $M_1 \rightarrow p_0$, $M_1 \rightarrow p_1$ and $M_1 \rightarrow p_2$. If the price falls only slightly from maximum M_1 (by less than the option value effect of uncertainty u) to p_0 , there are no hysteretic firms in this “play” area that exit the market. Firms only start to leave the market if the market price falls below p_0 (i.e. by more than u). The resulting hysteresis losses under uncertainty can be calculated analogous to hysteresis losses under certainty (see section 4.3). Assuming a price fall from M_1 to the level p' (corresponding to p' in fig. 3.3, 4.2 and 4.3) the following function capturing the hysteresis losses results:

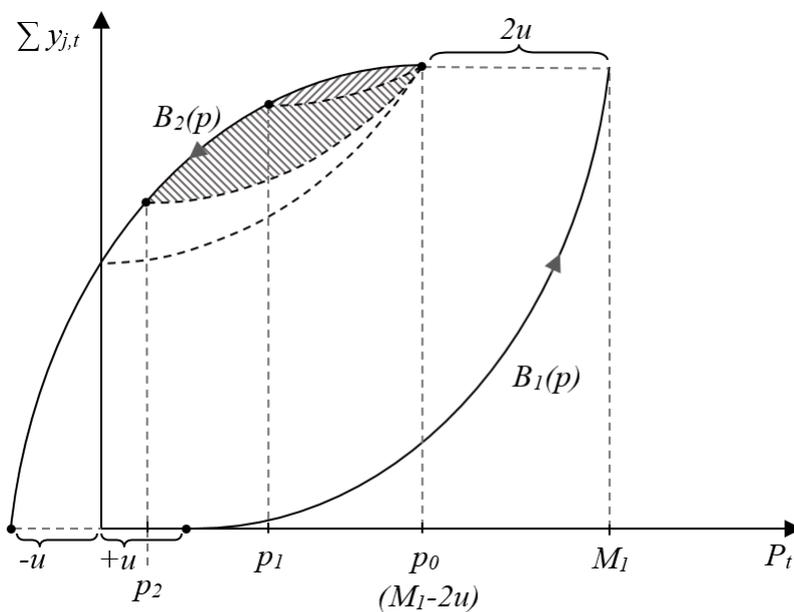
$$H = \begin{cases} \frac{\rho}{6} \cdot (M_1 - 2u - p')^3, & \text{if } (M_1 - 2u - p') > 0 \\ 0, & \text{if } \textit{else} \end{cases} \quad (5.11)$$

As the second case of eq. (5.11) captures and fig. 5.4 illustrates, (analogous to “backlash” in mechanics) “play” areas for price changes of an extent of $2u$ arise due to option value effects. In such areas, no hysteresis losses occur, since due to a wait-and-see strategy no firm will actually leave the market. However, if a positive price shock is followed by a price reduction larger than $2u$ (in fig. 5.4 for a market price lower than p_0), hysteresis losses are generated and can be graphically illustrated and interpreted analogous to fig. 4.4. However, in the case of substantial uncertainty effects, the resulting hysteresis loss areas are considerably reduced, due to the trimming by the “play” area (by $2u$).

Even, if the market price for their products is negative (which is theoretically conceivable), some firms will remain active in the market because the firms consider an expected potential positive price change, hoping not to experience hysteresis losses.

In sum, an inclusion of uncertainty effects results in a “play” area in which no hysteresis losses (and actually no quantitative output reactions) are generated due to waiting. The size of this inaction area is positively correlated with the degree of uncertainty (in our extremely simple model, the size of play $2u$ is even in a linear way related to the size ε of the stochastic shock). In other words, when the stochastic nature of prices is taken into account, firms become more cautious and delay their entry and exit decisions. On the one hand, declining

Figure 5.4: Hysteresis losses generated by different price changes under uncertainty



Source: Own representation based on Belke and Göcke 2005 and Mayergoyz 2003.

prices generate smaller hysteresis losses since the exit triggers are lower under uncertainty, but on the other hand, a certain output gain requires a higher price increase, which makes economic reactions under uncertainty more “sticky” at the micro and the aggregate level.

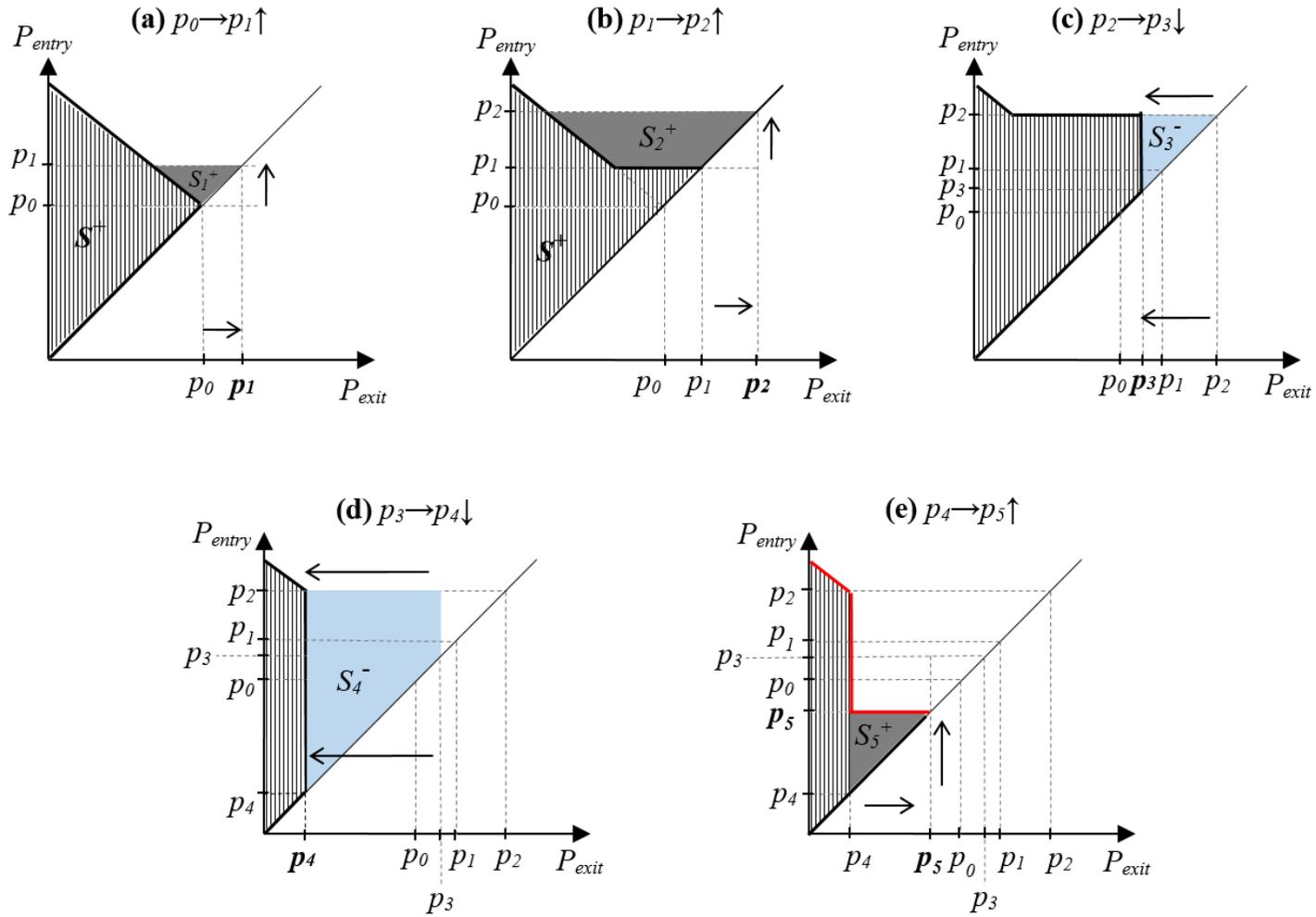
Chapter 6

Linear hysteresis curve, its dynamics and hysteresis losses indicator

6.1 Preisach triangle and dynamics of the hysteresis curve

In this section, the Preisach aggregation procedure is discussed in further detail and in a slightly more complex context than in section 3.2. The aim is to stress important properties of hysteresis that are related to the aggregation process, discuss the dynamics of the hysteresis curve and build the basis for the linear approximation of the hysteresis loop. The aggregation is proceeded assuming a certain economic environment. Rather than using only two price changes like in section 3.2 due to simplicity, in the following several price changes of different extents and directions are considered. The method used for aggregation of micro hysteresis is again based on the Preisach model of hysteresis, whose idea/assumption is that an economy comprises many heterogeneous agents that react discontinuously to the shocks as illustrated in section 3.1.

Figure 6.1: Active and inactive economic agents under volatile a price level



Source: Own representation according to Amable et al. 1991

Following Belke and Göcke 2001, pp. 184 et seq., an example with five changes of the input variable $p(t)$ is considered.¹ The following price changes are assumed: $p_0 \rightarrow p_1 \uparrow \rightarrow p_2 \uparrow \rightarrow p_3 \downarrow \rightarrow p_4 \downarrow \rightarrow p_5 \uparrow$. Fig. 6.1 comprises five P_{entry}/P_{exit} diagrams, each capturing single price changes. Altogether, they provide a geometric interpretation of how the activity of heterogeneous economic agents is aggregated if the market price varies from p_0 to p_5 . As a result, a macro hysteresis loop is generated capturing the aggregated output of all active firms (see fig. 6.3).

We start the aggregation procedure in an initial situation with the price level p_0 and assume that the number of initially active firms can be interpreted as a hatched area of a triangle captured in fig. 6.1a. and marked as S^+ . At first, the market price rises to p_1 meaning a positive albeit quite moderate change of the input variable and thus inducing a weak reaction of economic agents, whereby only a small set of firms additionally enter the market (this set corresponds to the grey triangle marked as S_1^+). As a result, the number of active firms rises from S^+ to $(S^+ + S_1^+)$. In the next period, the market price keeps rising to the level p_2 dominating the previous price change and persuades additional firms whose entry thresholds are favorably passed to enter the market (see grey area in fig. 6.1b., marked with S_2^+). The sum of both - hatched and grey areas captures the number of all currently-active firms.

Part c of fig. 6.1 illustrates the price fall from p_2 to p_3 inducing the exit of firms located in the blue triangle S_3^- . The result is a lower number of active firms (corresponds to the remaining hatched area). If the price level drops to p_4 as captured in fig. 6.1d., a very high fraction of all active agents in the Preisach triangle leave the market (S_4^-), which results in a low aggregate output represented by the hatched area.

The last diagram captures a positive yet quite weak economic reaction due to a small subsequent price increase to p_5 .² The red line in this diagram represents the so-called interface ($L(t)$) of the Preisach triangle, which is shaped by extremum values (both - positive and *negative*) of an input p_t during previous periods. As already mentioned in previous chapters, information about the past is essential to determine the right actual equilibrium. $L(t)$ contains information about all

¹Please note that this section builds on section 3.2.

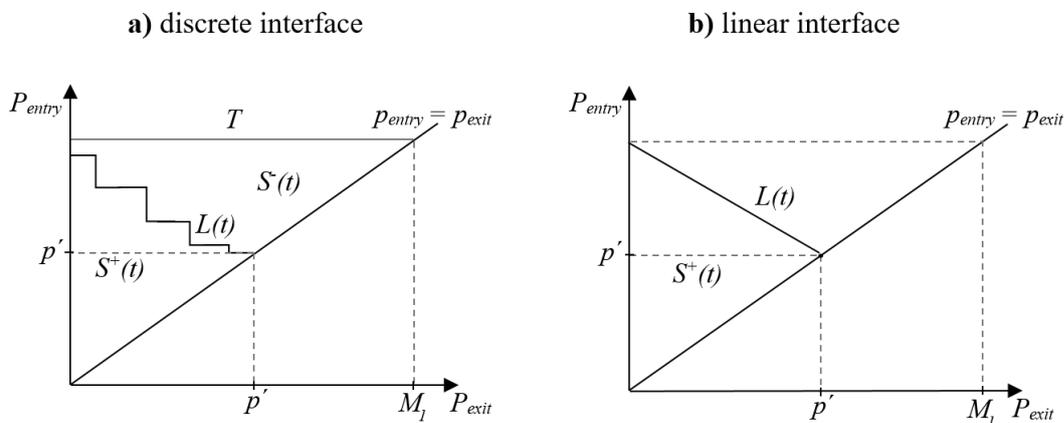
²For further explanations, see Amable et al. 1991, p. 10 ff.

non-dominated past extremum values of the input variable and determines an instantaneous value of output.

This mathematical Preisach-Mayergoyz-Krasnosel'skii aggregation procedure obviously does not accumulate all (extremum) input values; rather, some of them are wiped out if they are dominated by following extremum values of the same direction (wiping-out-property of hysteresis) (see Mayergoyz 1986, p. 605). In the latter example, the price change to p_1 was dominated by the subsequent change in the same direction to p_2 and thus wiped out. The price decrease to p_3 was dominated by an even higher subsequent decrease to p_4 . Therefore, neither p_1 nor p_3 play a part in contributing to the shape of the interface (L_t).

In case of an aggregation process based on more price changes and more local extremum values, an interface $L(t)$ with more stairs would result, as schematically illustrated in fig. 6.2a. Here, T denotes the Preisach triangle. The area above the interface captures inactive ($S^-(t)$) and the area below it illustrates active firms or the aggregate output ($S^+(t)$). In order to have a simple initial situation as illustrated in fig. 6.1, the staircase interface can be approximated by a linear one, as shown in fig. 6.2b.

Figure 6.2: Aggregated activity of heterogeneous economic agents

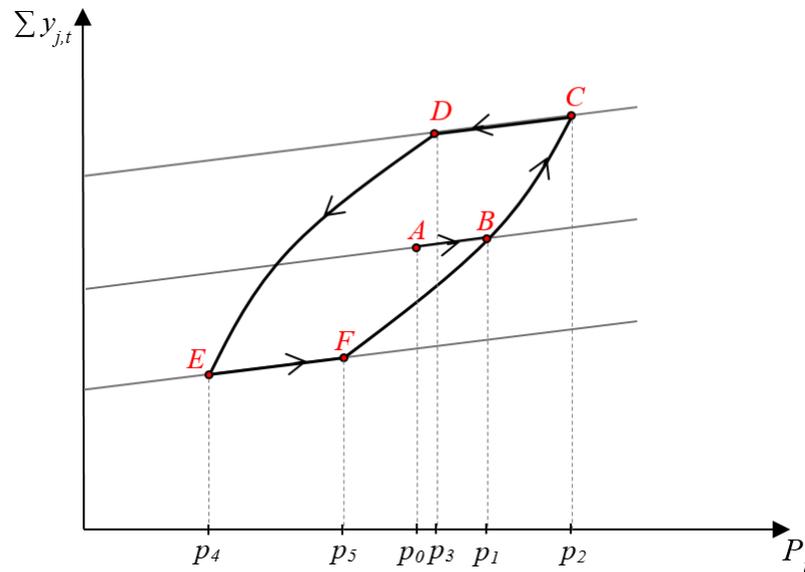


Source: Own representation according to Amable et al. 1991

Economic reactions illustrated in fig. 6.1 that depend on the historical development of output are summarized in a familiar price-output diagram in fig. 6.3 with the price variable on the abscissa: A is our initial situation; a price change

$p_0 \rightarrow p_1 \uparrow$ is accompanied by a weak supply reaction $A \rightarrow B$, which we quantified as S_1^+ in fig. 6.1a.; a further price increase $p_1 \rightarrow p_2 \uparrow$ induces a strong output reaction $B \rightarrow C$, which corresponds to the area S_2^+ in fig. 6.1b.; a following price fall $p_2 \rightarrow p_3 \downarrow$ evokes a small decrease in output $C \rightarrow D$ and $p_3 \rightarrow p_4 \downarrow$ causes a huge drop in supply ($D \rightarrow E$), for comparison see correspondingly S_3^- and S_4^- in fig. 6.1. The reaction of a moderate positive price change to p_5 only generates a small positive output reaction ($E \rightarrow F$). As a result, a macro hysteresis loop $ABCDEF$ is generated.

Figure 6.3: Macroeconomic hysteresis loop under volatile price level



Source: Own representation according to Belke and Gros 1998.

In sum, macro hysteresis exhibits two qualitative properties, namely previously-mentioned wiping-out and congruency properties. According to Mayergoyz's theorem, these properties constitute the necessary and sufficient conditions for a hysteresis transducer to be represented by the formal model in eq. (6.1) and geometrically interpreted as in fig. 6.3. The form of the hysteresis loop - which is illustrated in fig. 6.3 - is based on the congruency property of a hysteresis transducer. This indicates that "all hysteresis loops corresponding to the same extremum values of input are congruent" (see Mayergoyz 1986, p. 605.)

Thus, during the aggregation procedure we sum up individual reactions ($p_{entry}; p_{exit}$)

of an infinite set of economic agents ($\hat{\gamma}_{j,p_{entry};p_{exit}}$) on input (p_t) over time (t), using an arbitrary weight function μ . The model can be formally expressed as follows:³

$$f(t) = \hat{\Gamma}u(t) = \iint_{p_{entry} \geq p_{exit}} \mu(p_{entry}p_{exit}) \hat{\gamma}_{j,p_{entry}p_{exit}} p(t) dp_{entry} dp_{exit} \quad (6.1)$$

The required condition for this function is $p_{entry} \geq p_{exit}$, which means that the entry threshold value of price (p_{entry}) must be at least as high as the exit price value (p_{exit}). Geometrically, it means that we aggregate output of those firms located in the Preisach triangle (between the ordinate and the 45°- line in the first quadrant of the coordinate system).

Based on the positive or negative nature of external shocks, respectively active ($\hat{\gamma}_{j,p_{entry}p_{exit}} = 1$) or passive ($\hat{\gamma}_{j,p_{entry}p_{exit}} = 0$) states of an economic agent are induced if we still use the one-product and one-unit microeconomic model (see section 3.1). As a result, eq. (6.1) accumulating the overall output can be expressed as follows (Mayergoyz 1986, p. 605):

$$f(t) = \hat{\Gamma}u(t) = \iint_{S^+(t)} \mu(p_{entry}p_{exit}) \hat{\gamma}_{j,p_{entry}p_{exit}} p(t) dp_{entry} dp_{exit} \quad (6.2)$$

$S^+(t)$ again captures a set of active economic agents that are placed under the interface $L(t)$ in the Preisach triangle T in fig. 6.2.

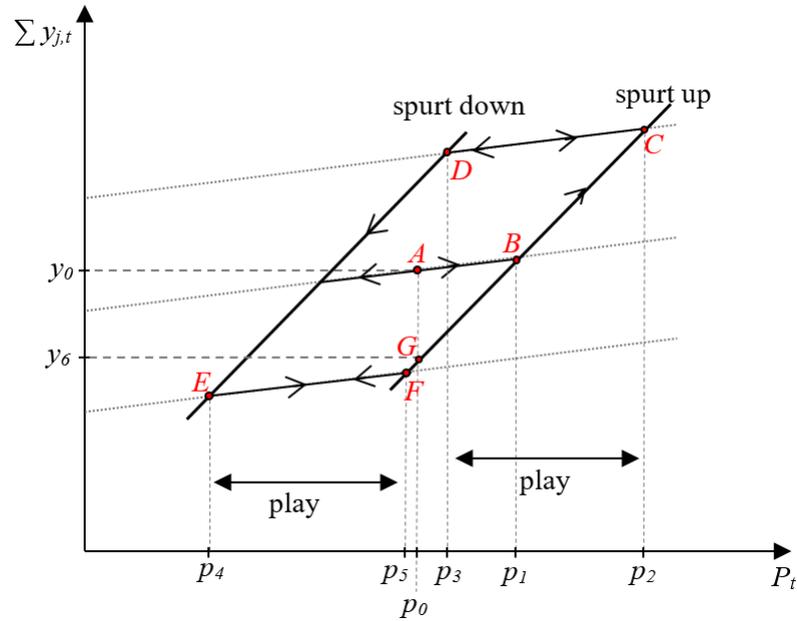
6.2 Play hysteresis

Along the lines of mechanical play in physics, Belke and Göcke 2001 worked out a linear approximation of the macroeconomic hysteresis dynamics capturing strong and weak economic reactions, the so-called play hysteresis. The aim was to simplify the macroeconomic hysteresis approach and to make it feasible for an empirical analysis. Based on play-hysteresis, an algorithm was developed, allowing an empirical investigation of hysteretic systems by implementing it in a

³Mayergoyz 1986, p. 604 derives a mathematical model to describe macro hysteresis in ferromagnetism. Amable et al. 1991 and Cross 1993 import this model to economics and apply it in an analysis of foreign trade.

regression framework. The following explanations of play hysteresis and Belke-Göcke algorithm are based on Belke and Göcke 2001.

Figure 6.4: Play hysteresis: linear spurt lines and constant play width



Source: Belke and Göcke 2001.

Fig. 6.4 illustrates a geometric interpretation of play hysteresis with a constant distance between the two steep lines (area of weak reactions). The model contains two steep lines: an upward-leading spurt up and a downward-leading spurt down, as well as many flatter lines, which have constant length and are located between the two steep lines in the “play area”. Both spurt lines induce strong reactions of supply on even small price changes, whereas only a moderate reaction can be observed in the play area, which is the result of wait-and-see strategies of individual firms (see chapter 3.1).

Let us return to the example with five price changes as discussed in section 6.1. Our initial situation is point A with price level p_0 . As fig. 6.4 shows, we are in a play area where no significant effects of price changes on supply can be observed. As a result, the price change on p_1 generates a moderate increase in supply. As soon as the price exceeds the latter price level, the system reaches the upward-leading spurt line and consequently is very sensible for following even

small price increases. This is illustrated with the supply reaction to the second price increase to p_2 associated with point C . If the price stops rising and starts to move in an opposite direction instead, the system leaves the upward-leading spurt and penetrates the play area located on the left-hand side of the upward-spurt. It remains on the particular play line and exhibits a lazy reaction to price changes, as long as the price varies between p_2 and p_3 (the pain threshold). If market price later exceeds p_2 , the system switches back to the upward spurt. However, in case of a price drop below p_3 , the pain threshold is passed inducing the switch to the downward spurt and thus a strong negative reaction of supply on price changes is observed. In our example, during the fourth change of the input variable the price level falls below p_3 to the level p_4 . This induces the switch to the downward-spurt line and thus a strong negative reaction of aggregated supply. As soon as the price development changes direction and it starts to rise, our system enters the play area again and remains there as long as the price varies between p_4 and p_5 . If the price level returns to its initial level (p_0), a new equilibrium on the spurt-up-line is generated (point G with y_6), where supply is much lower than in the initial equilibrium (point A with y_0).

Hence, the remanence property of hysteresis addressed in section 2.2 becomes obvious. In this example, it can be quantified as a remaining effect on output of the extent corresponding to the difference between y_0 and y_6 , which is negative. However, the remanence effects may also be positive.

If the initial supply level (y_0) is ambicionado, a price increase up to a level close to p_1 is indispensable. If the aim of the economic policy is to bring the economy back to its initial equilibrium A with p_0 and y_0 , first a price increase to p_1 is required to reach the right play line and a following price decrease to p_0 must take place due to reaching the initial output and price level in point A .

From section 3.4 and chapter 5, we know that even risk-neutral economic agents make cautious decisions if the option value of waiting is taken into account. As a result of aggregation, fig. 5.3 illustrates the creation of a play area that is positively correlated with uncertainty. The same logic applies to the play hysteresis model, resulting in a higher width of the play area and thus “outward” shifts of the spurt lines.

The other issue regarding the play-hysteresis model is the variable play width

induced by changes in forcing variable p_t . The play width is determined by and positively depends on the contemporaneous uncertainty. As stated in Belke and Göcke 2001, p.187, in the play hysteresis model only one spurt line can be shifted at the same time. The spurt line that captures the recent economic reactions is fixed and serves as an anchor for the shift of an opposite spurt line to adjust the play width to the degree of uncertainty. For example, if our initial situation is in point C on the spurt-up-line and the degree of contemporaneous uncertainty rises (corresponds to higher play width), the spurt-down line must be horizontally shifted to the left-hand side by the extent of the change in play (see fig. 6.4). However, if the initial situation is in point E , an increase in contemporaneous uncertainty induces a horizontal shift of the upward spurt line to the right-hand side. A reduction in uncertainty leads to shifts of respective spurt lines in opposite directions.

The concept of a variable play can also be captured by the play algorithm developed by Belke and Göcke 2001 and discussed in section 6.3.

6.3 Belke-Göcke algorithm describing path-dependence

This section concerns how to formally describe economic path-dependence based on the linear play-hysteresis approach. It explains in further detail what has been worked out in Belke and Göcke 2001. Fig. 6.4 illustrates a play hysteresis model that comprises play and spurt lines or, respectively, weak and strong reactions of output. Changes in the forcing variable (p_t) can take place in one or even both areas, leading to corresponding output reactions.

Following Belke and Göcke 2001, we start in an initial state on one of the spurt lines, e.g. point C in fig. 6.4. Assuming that a change in the forcing variable (p_t) leads to entering the play area and (by occasion) switching to the opposite spurt line, a change in variable p_t can be formally expressed as follows:

$$\Delta p_j^s = a_j + \Delta s_j \quad (6.3)$$

j captures the number of switches between the upward- and downward-leading

spurt lines; a_j denotes cumulated movements in the play area; Δp_j^s is a price change higher than the width of the play area, leading to the j -th switch of the spurt line; Δs_j captures the fraction of the spurt area in which part of the price change Δp_j^s takes place and it can be formalized as follows:

$$\Delta s_j = \begin{cases} \text{sign}(\Delta p_j^s) \cdot (|\Delta p_j^s| - d), & \text{if } |\Delta p_j^s| > d \\ 0, & \text{if } \textit{else} \end{cases} \quad (6.4)$$

$\text{sign}(\Delta p_j^s)$ captures the direction of the price change and thus specifies the right spurt line. For example, if the price change is larger than the width of the play area (d) and negative, a fraction of it takes place in the area of the downward-leading spurt, and exhibits an extent of difference between the complete price change and the width of the play area (d). However, if the price change is smaller than d , the forcing variable only moves within the play area and $\Delta s_j = 0$.

Depending on the area in which the forcing variable moves, weak and/or strong reactions of output are considerable:

$$\Delta y_j^s = \alpha a_j + (\alpha + \beta) \Delta s_j, |\alpha| < |\alpha + \beta| \quad (6.5)$$

α captures weak economic reactions (defines the slope of play lines, e.g. DC , AB and EF in fig. 6.4); $(\alpha + \beta)$ is the slope of spurt-lines capturing strong economic reactions. Thus, β denotes the difference in slopes of play and spurt lines.

Movements on the spurt lines induce shifts of the play-lines. This can be illustrated using the latter example from fig. 6.4 with subsequent price changes $p_2 \rightarrow p_3 \downarrow \rightarrow p_4 \downarrow \rightarrow p_5 \uparrow \rightarrow p_2 \uparrow$, and choosing e.g. point C as an initial state. In case of the price reduction from p_2 to p_3 , only weak output reactions in the play area can be observed with no shifts of the actual play line DC . A negative price change from p_3 to p_4 taking place in the spurt area leads to a movement on the downward-leading spurt from point D to E and consequently a shift of the play line from DC to EF . A price increase from p_4 to p_5 leads to entering the play area (line EF) but not to any shifts of it. A following change from p_5 back to p_2 induces a strong and positive output reaction (movement on the upward-leading spurt from point F to point C) and a contemporary vertical shift of the play line

from EF to DC .

In order to capture the current placement of the actual play line, all of its historical shifts must be cumulated corresponding to all previous movements on both spurt lines:

$$V_{j-1} = \beta \sum_{i=0}^{j-1} \Delta s_i \quad (6.6)$$

Output reaction to the current price change can be formalized composing both - historical play shifts V_{j-1} (we know current location of play) and actual output reaction (Δy_j^s):

$$y_j = \bar{C} + V_{j-1} + \Delta y_j^s \quad (6.7)$$

Inserting eqs. (6.5) and (6.6) into eq. (6.7) and combining with eq. (6.3) results in the following output reaction:⁴

$$y_j = \bar{C} + \beta \sum_{i=0}^{j-1} \Delta s_i + \alpha a_j + (\alpha + \beta) \Delta s_j = \bar{C} + \beta \sum_{i=0}^j \Delta s_i + \alpha \Delta p_j \quad (6.8)$$

By adding and subtracting a certain expression $\sum_{i=0}^{j-1} \Delta p_i$, eq. (6.8) can be transformed in a following one:

$$y_j = C + \alpha \sum_{i=0}^j \Delta p_j + \beta \sum_{i=0}^j \Delta s_i = C + \alpha p_j + \beta s_j \quad (6.9)$$

Here, the constant C corresponds to the difference between the original constant \bar{C} and the artificially-added expression $\sum_{i=0}^{j-1} \Delta p_i$. In the final analysis, the output reaction can be defined as a simple linear relationship between the real input variable p_j and an artificial variable s_j capturing only the historical and current movements on the spurt lines or - in other words - all strong output reactions. s_j is essentially an input variable p_j without small changes corresponding to movements within the play area, while the latter values are simply “filtered

⁴For a graphical interpretation see Belke and Göcke 2001, p. 189.

out”. In order to run regressions with the time series of interest, accumulation via indicator j can be replaced by the time structure and indicator t . Moreover, the output function becomes more realistic adding some other explanatory variables, all of which are summarized in variable z_t in the following equation:

$$y_t = C + \alpha p_t + \beta s_t + \gamma z_t \quad (6.10)$$

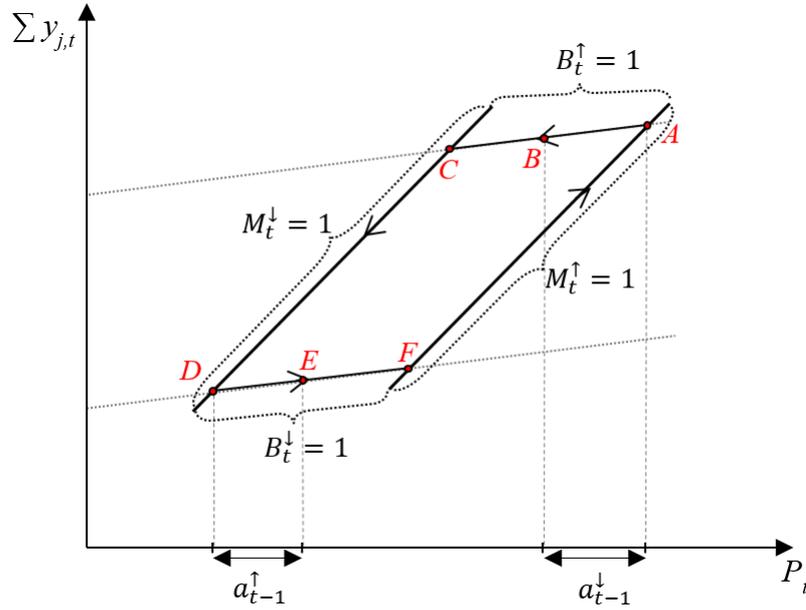
In the following, the procedure of filtering out the movements of the input variable in the play area and thus constructing the artificial spurt variable s_t is discussed in further detail (see Belke and Göcke 2001, p.190f.). For this, three facts about the economic environment are indispensable: [1] the current state of the system, [2] the extent and direction of the current price change and [3] the width of the play area. In order to define the current state of the system, additional information about previous price changes is required. As illustrated in fig. 6.5, an economic system may be located in one of the four areas of play hysteresis: on upward- or downward-leading spurt and on “upper” (AC) or “lower” (DF) play. Even if both positive and negative price changes can take place in the play area, we have to distinguish between the latter play lines to capture the right direction of movements in the previous period. In other words, it is important from which spurt line the system penetrated into the play area.

Each potential state of the system is determined using a dummy variable, which can take the value of either 1 or 0. Variable M_1^\downarrow captures the location of the economy on the downward-leading spurt line (e.g. in point D in fig. 6.5) and can be formalized as a following function:

$$M_t^\downarrow = \begin{cases} 1, & \text{if } \Delta s_{t-1} < 0 \\ 1, & \text{if } (\Delta s_{t-1} = 0) \cap (\Delta p_{t-1} = 0) \cap (\Delta a_{t-1} = 0) \\ 0, & \text{else} \end{cases} \quad (6.11)$$

Eq. (6.11) states that the system is located on the downward-leading spurt if the previous price change was negative and higher in absolute value than the width of play area leading to entering the downward spurt and thus switching to the opposite spurt-line (corresponds to $\Delta s_{t-1} < 0$). M_t^\downarrow can also take the value of

Figure 6.5: Illustration of the Belke-Göcke algorithm



Source: Own representation based on Belke and Göcke 2001.

1 even if no price changes have been observed in a previous period. Such a case captures the circumstances under which the economy exhibits no reaction due to $\Delta p_{t-1} = 0$ but is still located on the downward-leading spurt if Δp_{t-2} took place in the spurt-down area. Otherwise, the dummy variable M_t^\downarrow equals 0, meaning that the system is in one of the remaining three play areas.

Dummy M_t^\uparrow determines the upward-leading spurt as a current location of the system (e.g. in point A in fig. 6.5):

$$M_t^\uparrow = \begin{cases} 1, & \text{if } \Delta s_{t-1} > 0 \\ 1, & \text{if } (\Delta s_{t-1} = 0) \cap (\Delta p_{t-1} = 0) \cap (\Delta a_{t-1} = 0) \\ 0, & \text{else} \end{cases} \quad (6.12)$$

$M_t^\uparrow = 1$ in case the previous price change was positive and larger than the play width d_t , leading to a switch between spurt lines and hence to entering the upward leading spurt area (corresponds to $\Delta s_{t-1} > 0$). Again, if there were no changes in the input variable, the system might eventually be located on the upward spurt if it “stopped” moving in the latter area due to $\Delta p_{t-1} = 0$. In sum, if the input

variable exhibits no changes in the previous period, the economy might be located on one of the spurt lines, depending on the area in which it stopped reacting. This case is insofar important since it plays a role by constructing the algorithm.

Taking the value of 1, dummy variable B_t captures that the system is currently located in the play area and the arrows specify a prevailing (reference) spurt line from which the play area was entered. $B_t^\downarrow = 1$ captures the location of the economy on the “lower” play line (corresponds to the line DF in fig. 6.5) with the downward-leading spurt as the reference spurt line. This is the case if the previous price change induced movements in the spurt-down area ($\Delta s_{t-1} < 0$) or if the system was already located on the “lower” play in $t - 1$, as summarized in function (6.13):

$$B_t^\downarrow = \begin{cases} 1, & \text{if } \Delta s_{t-1} < 0 \\ 1, & \text{if } (\Delta s_{t-1} = 0) \cap (B_{t-1}^\downarrow = 1) \\ 0, & \text{else} \end{cases} \quad (6.13)$$

The system is currently located on the “upper” play line ($B_t^\uparrow = 1$), meaning that the last strong reactions took place in the spurt-up area if the opposite circumstances could be observed than formalized in eq. (6.13):

$$B_t^\uparrow = \begin{cases} 1, & \text{if } \Delta s_{t-1} > 0 \\ 1, & \text{if } (\Delta s_{t-1} = 0) \cap (B_{t-1}^\uparrow = 1) \\ 0, & \text{else} \end{cases} \quad (6.14)$$

Only one of the four location variables can take the value of 1 in a certain period, while the other three dummies must be equal to 0.

In the following, the extent of price movements in the play area (a_t) are defined. We want to filter them out of the price to generate an artificial spurt variable inducing only strong economic reactions. For this purpose, an auxiliary variable b_t must be generated capturing price changes in t that depend on the current state of the system (captured by dummy variables: M_t^\downarrow , M_t^\uparrow , B_t^\downarrow and B_t^\uparrow) and previous movements in the play area (a_{t-1}):

$$b_t = B_{t-1}^\downarrow(1 - M_t^\downarrow)(a_{t-1} + \Delta p_t) + B_{t-1}^\uparrow(1 - M_t^\uparrow)(a_{t-1} - \Delta p_t) \quad (6.15)$$

As mentioned above, only one of the dummy variables can take the value of 1 at the same time. If either M_t^\downarrow or M_t^\uparrow equals 1, the auxiliary variable is 0 regardless of how high or low the price change is. Eq. (6.15) states that in principle two potential situations are relevant for b_t : the current location of the economy on the “lower” play and not on the spurt down (e.g. in point E and not in D in fig. 6.5); and the location on the “upper” play and not on the upper spurt line (e.g. in point B and not in A in 6.5). The current position in point E illustrates the following dynamics: the system previously moved on the downward-leading spurt line and due to an opposite price development penetrated into the “lower” play by an extent of a_{t-1}^\downarrow . Due to a positive price change in t , the extent of movements in play becomes larger or the price change even crosses the threshold and enters the opposite spurt line (upward-leading), resulting in a *positive* value of b_t (movement to the right-hand side from point E). However, if the price falls in t , the system moves to the left-hand side from point E and the extent of movements in play is reduced due to $(a_{t-1} + \Delta p_t)$ or even the “pain-threshold” is passed, leading to entering the spurt down and resulting in a *negative* value of b_t . The second part of eq. (6.15) captures the current location of the economy in e.g. point B , which illustrates the following dynamics: the system previously moved on the upward leading spurt line and due to an opposite price development penetrated into “upper” play by an extent of a_{t-1}^\uparrow (see fig. 6.5). A positive current price change moves the system to the right-hand side from point B , leading to a reduction of movements in play or - in case of larger increase in price - entering the upward-spurt line again. As a result, the auxiliary variable d_t is *positive*. A negative price change results in movement of the system to the left-hand side, penetrating the play area by a larger extent or even passing the “pain-threshold” and entering the downward-leading spurt. Entering the spurt down leads to a *negative* value of b_t . The extent of movements in play area is measured as a distance between the location of economy and the reference spurt line.

Calculating the extent of current movements in play (a_t) results after comparing the auxiliary variable b_t with the width of play area (d_t). Eq. (6.16) summarizes values that a_t can take depending on the current state of the system and price change (both kinds of information are important - direction and extent):

$$a_t = \begin{cases} b_t, & \text{if } 0 < b_t \leq d_t \\ \Delta p_t, & \text{if } (M_t^\downarrow = 1) \cap (\Delta p_t > 0) \cap (\Delta p_t < d_t) \\ -\Delta p_t, & \text{if } (M_t^\uparrow = 1) \cap (\Delta p_t < 0) \cap (-\Delta p_t < d_t) \end{cases} \quad (6.16)$$

According to eq. (6.16), cumulated movement in play equals a value of b_t if the latter is positive and not higher than the play width d_t . This is associated with the current location of the system in the play area (e.g. either on the line CA or DF in fig. 6.5) and price changes (both - positive and/or negative) that do not enter none of the spurt lines. The second and third rows of eq. (6.16) state that a_t is of the same extent as actual price change Δp_t if the economy is currently located on one of the spurt lines and a price change in the opposite direction is observed, leading to a penetration into the play area but not to entering the opposite spurt line due to $\Delta p_t < d_t$ and $-\Delta p_t < d_t$.

The next step is calculating movements in spurt areas. The latter procedure is formalized by eqs. (6.17) and (6.18). The first row in eq. (6.17) captures the case in which the economy is currently located on one of the play-lines with a certain extent of movements in the latter area (a_{t-1}) and the current price change leads to movements towards the reference spurt line and entering it by some extent (corresponds to negative value of b_t). The second row means the same location of the system, albeit the current price change leads to movements in play towards an opposite spurt and entering it (corresponds to $b_t > d_t$). From the construction of the auxiliary variable b_t (see eq. (6.15)) it follows that the extent of movements in spurt in this particular case equals the difference between b_t and the play width d_t .

$$\Delta s_t = \begin{cases} b_t[B_t^\downarrow(1 - M_t^\downarrow) - B_t^\uparrow(1 - M_t^\uparrow)], & \text{if } b_t < 0 \\ (b_t - d_t)[B_t^\downarrow(1 - M_t^\downarrow) - B_t^\uparrow(1 - M_t^\uparrow)], & \text{if } b_t > d_t \end{cases} \quad (6.17)$$

Eq. (6.18) captures the current placement of the system in one of the spurt areas. The first row means that due to a current price change in the same direction as in the previous period, the system remains on the spurt and the complete price change corresponds to the extent of movements in spurt. The

second and last rows capture current price changes in the opposite direction than previously, leading to entering the corresponding play line. Due to the higher extent in comparison to the width of the play area, a fraction of price changes takes place on the opposite spurt and it is equal to the difference between the price change and the play width if $\Delta p > 0$ and the sum of the latter measures if $\Delta p < 0$.

$$\Delta s_t = \begin{cases} \Delta p_t, & \text{if } [(M_t^\downarrow = 1) \cap (\Delta p_t < 0)] \cup [(M_t^\uparrow = 1) \cap (\Delta p_t > 0)] \\ \Delta p_t - d_t, & \text{if } (M_t^\downarrow = 1) \cap (\Delta p_t > d_t) \\ \Delta p_t + d_t, & \text{if } (M_t^\uparrow = 1) \cap ((-\Delta p_t) > d_t) \end{cases} \quad (6.18)$$

Only one measure remains undefined thus, namely the width of the play area d_t . As explained in previous chapters the extent of d_t positively depends not only on sunk adjustment costs but also the degree of uncertainty. Whereas the extent of sunk adjustment costs is difficult to observe from a statistical perspective, one can measure the anticipated degree of uncertainty using e.g. price variance. Hence, Belke and Göcke 2001 model play width as a linear function of uncertainty denoted with a proxy variable u_t :

$$d_t = \mu + \sigma u_t \quad (6.19)$$

The constant μ corresponds to sunk adjustment costs that are typical for a certain market. Gathering such kind of information would help to define the width of the play area quite precisely and lead to very convincing empirical results. Calculating the so-called “pain-thresholds” (leading to exit of firms) using typical sunk adjustment costs in certain markets is a very promising topic. Given that exports play a very important role in terms of balance of payments of each country, preventing passing the “pain-threshold” is an important political question.

6.4 Calculation of hysteresis losses indicator by means of the Belke-Göcke algorithm

This section is based on the paper: Adamonis and Werner forthcoming.

In this section, we aim to calculate an indicator for hysteresis losses that is proportional to the real extent of the losses. Calculating a hysteresis losses indicator underlies a two-step filtering procedure. In section 6.3, the Belke-Göcke algorithm and thus the first step of the twofold filtering procedure of the input variable was discussed in further detail. The first step of filtering aims to capture only strong reactions of the output to input changes. In the following, the second step of filtering is executed to capture only strong negative output reactions associated with hysteresis losses. Following this, the indicator is calculated using the linear play-hysteresis model and replenishing the Belke-Göcke algorithm with some additional calculations.

Aggregation of hysteresis losses over heterogeneous firms has shown in section 4.3 that these dynamic losses are proportional to the area inside the lens-formed hysteresis loop. Using the same logic, we further on argue that hysteresis losses are also proportional to the area inside the approximated linear hysteresis curve (see fig. 6.6). It is obvious that no hysteresis losses are generated if price changes take place either in play or in the upward-leading spurt area. Consequently, two conditions must be fulfilled to generate hysteresis losses: price changes must be negative ($\Delta p_t < 0$) and they (or a part them) have to take place in the downward-leading spurt area ($\Delta s_t < 0$). The following spurt values have to be considered:

$$\Delta s_t = \begin{cases} b_t(B_t^\downarrow(1 - M_t^\downarrow)), & \text{if } B_t^\downarrow = 1 \cap \Delta p_t < 0 \cap -\Delta p_t > a_{t-1} \\ (b_t - d_t)(-B_t^\uparrow(1 - M_t^\uparrow)), & \text{if } B_t^\uparrow = 1 \cap \Delta p_t < 0 \cap (a_{t-1} - \Delta p_t) > d_t \\ \Delta p_t + d_t, & \text{if } M_t^\uparrow = 1 \cap \Delta p_t < 0 \cap -\Delta p_t > d_t \\ \Delta p_t, & \text{if } M_t^\downarrow = 1 \cap \Delta p_t < 0 \end{cases} \quad (6.20)$$

Eq. (6.20) illustrates the second step of the twofold filtering procedure in which the positive changes in input variable as well as the movements in the play

slope of the play lines and ω is the difference between the two. Thus, the system moves from point A to B in the first and from point B to C in the second period. Due to $\Delta p_1 = \Delta s_1 < 0$, hysteresis losses are generated that are proportional to the area of the parallelogram $ABEF$. The value of the hysteresis losses indicator generated only in period $t = 1$ (ΔHLI_1) can be quantified as follows:

$$\Delta HLI_1 = \frac{d}{\cos(\arctan(\omega_p))} \cdot \sqrt{\Delta y_1^2 + (-\Delta s_1^2)} \cdot \sin(\arctan(\omega_s) - \arctan(\omega_p)) \quad (6.21)$$

Analogously, the area of the parallelogram $BCDE$ (see fig. 6.6) that corresponds to the value of hysteresis losses indicator generated only in the period $t = 2$ (ΔHLI_2) can be computed as follows:

$$\Delta HLI_2 = \frac{d}{\cos(\arctan(\omega_p))} \cdot \sqrt{\Delta y_2^2 + (-\Delta s_2^2)} \cdot \sin(\arctan(\omega_s) - \arctan(\omega_p)) \quad (6.22)$$

Thus, an increase in the area that is proportional to hysteresis losses in a particular period t can be generally formalized as follows:

$$\Delta HLI_t = \frac{d}{\cos(\arctan(\omega_p))} \cdot \sqrt{\Delta y_t^2 + (-\Delta s_t^2)} \cdot \sin(\arctan(\omega_s) - \arctan(\omega_p)) \quad (6.23)$$

The hysteresis losses indicator cumulates all of its values that were generated during a particular sample. In our example, the sample encompasses only two periods and both of them are associated with the strongly negative output reactions leading to hysteresis losses. Thus, the value of hysteresis losses indicator in period $t = 2$ is represented by the sum of indicator values additionally generated in both periods, which corresponds to the whole area $ACDF$ (see fig. 6.6):

$$HLI_2 = \frac{d}{\cos(\arctan(\omega_p))} \cdot \sqrt{(\Delta y_1 + \Delta y_2)^2 + (-\Delta s_1 - \Delta s_2)^2} \cdot \sin(\arctan(\omega_s) - \arctan(\omega_p)) \quad (6.24)$$

The function for cumulated hysteresis losses indicator takes the following form:

$$HLLI_t = \begin{cases} \Delta HLLI_t, & \text{if } HLLI_{t-1} = 0 \\ HLLI_{t-1} + \Delta HLLI_t, & \text{if } HLLI_{t-1} > 0 \\ 0, & \text{if } else \end{cases} \quad (6.25)$$

Thus, in the case that the price increased in previous periods, leading to more exports and zero dynamic losses, a price decrease in period t results in hysteresis losses generated only in the current period ($\Delta HLLI_t$). The value of the losses indicator then corresponds to the value that was calculated for period t . However, if the price change was negative in the previous period ($t - 1$) leading to some hysteresis losses ($HLLI_{t-1} > 0$), and it keeps decreasing in period t , we cumulate the value of hysteresis losses indicator of both periods. Ultimately, we can calculate hysteresis losses indicator for the whole time span in which the price was decreasing or moving in the play area. If the price development changes direction in the meantime, crosses the play and penetrates the spurt-up area, no hysteresis losses are generated and the losses indicator simply keeps the value of the previous period.

In order to gain an appreciation about the extent of hysteresis losses indicator, we can build a relative measurement that compares the extent of hysteresis losses indicator with a certain export value (e.g. export value in a selected year):

$$HLLI_t = \frac{\sum \Delta HLLI_t}{Export_j} \cdot 100\% \quad (6.26)$$

In order to illustrate the calculation procedure of the hysteresis losses indicator, see the empirical parts of the manuscript 8.1 and 8.2.

The other possibility to create a hysteresis losses indicator is to use the Preisach aggregation procedure, which is briefly described in section 6.1 and was implemented empirically by Piscitelli et al. 2000. In order to calculate another hysteresis indicator, we could simply plug in the formula of hysteresis losses developed in section 4.3 (see eq. (4.11)) into the Preisach framework provided by Piscitelli et al. 2000. However, since the hysteresis losses formula from eq. (4.11) only includes the values of the input variable (e.g. price, exchange rate), the interpretation of hysteresis losses indicator in relative terms becomes quite difficult. At this point, the hysteresis losses indicator provided in eq. (6.26) seems

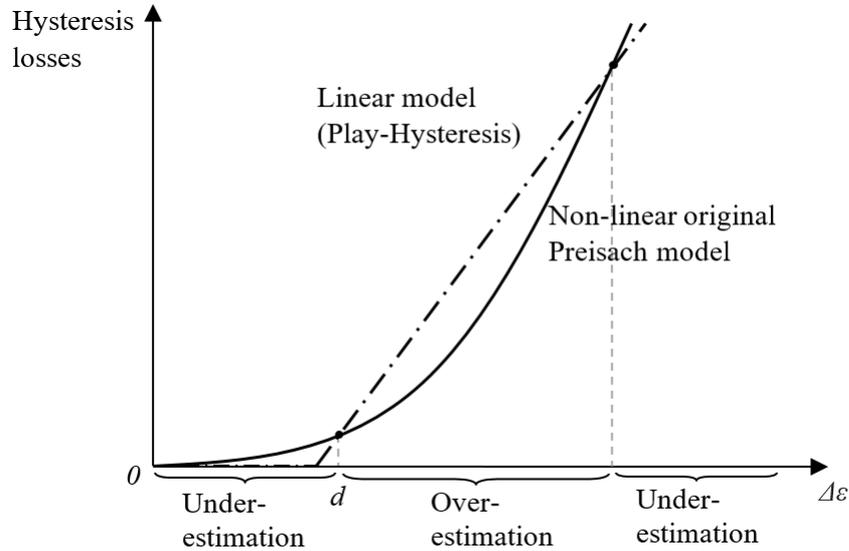
to be more advantageous in comparison to the indicator based on eq. (4.11). In addition, due to many factors that cannot be measured or observed, e.g. firm distribution in the P_{entry}/P_{exit} diagram, uncertainty level, expectations of the economic agents, exchange rate elasticity of foreign prices, etc., the calculation of the real hysteresis losses is not possible. Thus, both hysteresis losses indicators are only approximate measures of proportionality under a simplifying assumption of constant density in the P_{entry}/P_{exit} diagram. For these reasons, no other hysteresis losses indicators are provided in this manuscript as having no potential to improve the measurement.

6.5 Over- and under-estimation areas of the *HLI*

From a mathematical perspective, the calculation of the hysteresis losses indicator by means of the linear play-hysteresis model is quite simple. The challenge at this point is to integrate these calculations into the Belke and Göcke (2001) algorithm and reflect the results reasonably. For the calculations, we only need the slopes of the play and spurt lines (α and $\alpha+\beta$, respectively), which we can calculate using the algorithm, and the historical information about output changes (Δy_t) as captured in eqs. (6.9) and (6.10). Please note that the slope of the spurt line associated with the angle ω_s illustrated in fig. 6.6 corresponds to the sum of coefficients α and β , since β captures the difference between the slopes of the spurt and play areas. The slope of the play line associated with the angle (ω_p) corresponds to the coefficient α .

As mentioned above, the basis for the hysteresis losses indicator is the linear play hysteresis model which represents an approximation of the curved Preisach-loops. Fig. 6.7 illustrates over- and under-estimation areas of the hysteresis losses indicator in comparison to the hysteresis losses captured by the original Preisach model. It captures the relationship between hysteresis losses and the extent of the price change (corresponds to its decrease). The dashed curve schematically captures the hysteresis losses as e.g. area $ABCD$ in the play-hysteresis model (see fig. 6.8) and the solid curve represents the losses as an area in the Preisach model as illustrated in fig. 4.4. Since the lens-formed hysteresis curve is considered to illustrate the more appropriate dynamics of the system (with certain

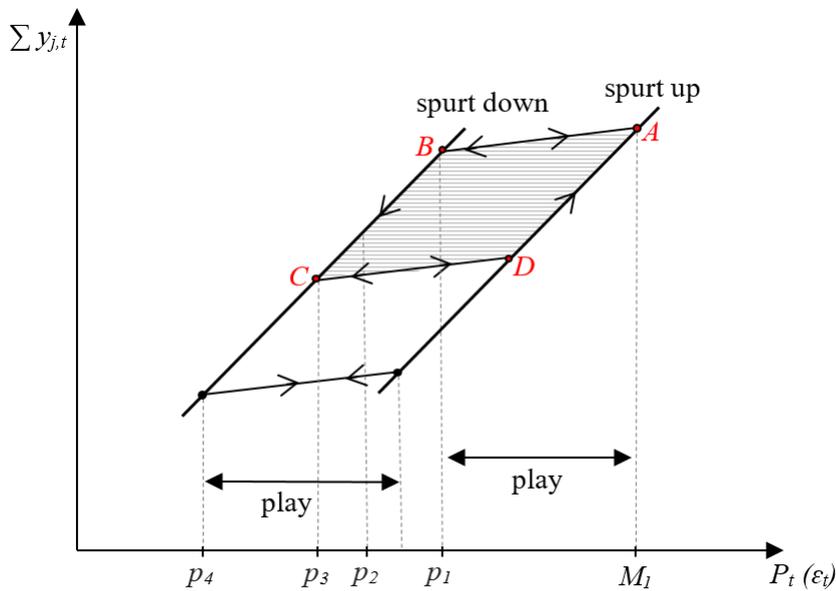
Figure 6.7: Over- and under-estimation areas of hysteresis losses captured by play-hysteresis in comparison to the non-linear original Preisach model



density of firms in the (P_{entry}/P_{exit}) diagram) and the play hysteresis is the linear approximation of the hysteresis curve, we can capture some intervals of over- and under-estimation of hysteresis losses by means of the approximation by the linear model in comparison to the non-linear approach. Thus, the price starts falling in its maximum M_1 (see figs. 4.4 and 6.8). According to the play hysteresis model, there is little or no reaction of the system, since price changes take place in the play area ($M_1 \rightarrow p_1$) in which no hysteresis losses are generated. In contrast to this, the lens-formed hysteresis curve shows some negative output reaction leading to hysteresis losses by the extent of area H_1 . In this interval, the hysteresis losses indicator under-estimates the dynamic losses. After penetrating the spurt-down area ($\Delta p > d$), we slightly over-estimate the losses. However, if negative price changes are of a very large extent, the area within the lens becomes larger than the area in the play-hysteresis trapezoid. This again leads to an under-estimation of hysteresis losses. By interpreting the values of the indicator, we are able to recognize the intervals illustrated in fig. 6.7, since the width of the play area can be estimated using the play algorithm. However, given that some determinants of hysteresis cannot be measured (e.g. the level of uncertainty), the calculated hysteresis losses in both models can only be interpreted as indicators.

The main point of criticism regarding the hysteresis losses indicator is the fact that the hysteresis losses indicators can only be interpreted as proportional to negative welfare effects if we assume that the level of uncertainty as well as the risk-free interest rate do not vary over time, which is quite unrealistic. Changes in uncertainty and/or interest rates shift the entry and exit triggers of individual firms leading to changes in the width of their band of inaction. At the macro level, these microeconomic changes induce modifications in the location and curvature of the hysteresis loops and result in quantitatively different areas inside the hysteresis loops.

Figure 6.8: Play-hysteresis: linear spurt lines, constant play and hysteresis losses



Source: Own representation according to Belke and Göcke 2001.

Chapter 7

Hysteresis losses in the special case of international trade

This chapter essentially builds on chapters 3 and 4, and shows how to interpret hysteresis losses graphically in the model of international trade, where the trade partners use different currencies. As mentioned in section 3.1.1, the non-ideal relay can also be used to illustrate hysteretic behavior of an exporting firm if we look at the exchange rate as a forcing variable. Therefore, the next section briefly discusses the role of the exchange rates in international trade, before the subsequent sections deal with export supply hysteresis forced by exchange rate changes.

7.1 The role of the exchange rate

According to Mankiw and Taylor 2006, p. 647, exchange rates represent prices for international transactions and therefore, they play a vital role in foreign trade, especially for economies with strong openness such as Germany, the U.S., China and many others. Hence, exchange rates are among the most commonly-watched and -analyzed economic measures.

We distinguish between nominal and real exchange rates, which - of course - are closely related. While the nominal exchange rate is the price of the currency of one country in terms of another (bilateral rate) or a group of another countries

(effective rate), the real exchange rate represents the rate at which economic agents can trade the goods and services of one country for the goods and services of another or a group of another countries (see Mankiw and Taylor 2006, p. 648-9). Thus, the real exchange rate is adjusted for the effects of inflation and shows the purchasing power of a currency in comparison to another. In addition, given that nominal exchange rates may deviate from their natural equilibrium rates due to over- or under-valuation of the currencies (e.g. as a consequence of governmental exchange rate manipulations), real exchange rates represent a more powerful measure for the research purposes. For these reasons, we also use the real exchange rate in our empirical analyses.

The exchange rates are important for the economies, since they are associated with advantage gains in international trade. They affect a country's terms of trade whereby a depreciation of the home currency against another indicates a worsening of its terms of trade, since the relative price of exports in terms of imports decreases and vice versa. The worsening of terms of trade is undesirable for the net importers but net exporters like Germany or China prefer it. In general, when the export demand is price inelastic, a depreciation of the home currency of an exporter will not change his revenues in his home currency when the exchange rate passes through completely. However, if export demand is price elastic, it leads to higher revenues of the exporters due to either higher demand owing to lower export prices or a higher profit margin in case of pricing-to-market. Assuming elastic import demand, the home currency depreciation associated with higher import prices induces lower import spending. As a result, the country's aggregate demand increases and improves its balance of payments. This might give an incentive to manipulate the exchange rate to keep the value of the home currency at a low level. To achieve this, the country's central bank has to engage in open market operations in the foreign exchange market, e.g. by buying (currency value rises) or selling (currency value falls) home currency. The most popular examples of such exchange rate policies are the People's Bank of China and the Bank of Japan.

Besides the effects of monetary policy (both conventional and unconventional), the currency movements are driven by a variety of determinants, e.g. inflation, current account deficit, public debt, terms-of-trade, political stability, economic

growth, productivity, exchange rate transactions from international trading of goods, services and financial assets, currency speculations, etc. All of these measures are affiliated with each other and dynamic, which indicates high volatility of the exchange rates. As an important and volatile economic measure, the exchange rate is worth taking the role of the forcing variable of the exports as modeled in sections 7.2, 7.3, 7.4 and empirically investigated in chapter 8.

7.2 Exchange rate pass-through to export prices

There is no doubt that the exchange rate is a very important factor in international trade. However, its changes may affect the export prices and thus the export demand and supply, in different ways. The extent to which the exchange rate passes-through (ERPT) to export prices can be determined by the exchange rate elasticity of export prices. The latter depends on many aspects, e.g. the heterogeneity of goods, market power of the exporter, the elasticity coefficient of demand and many others. Empirical evidence suggests that the ERPT elasticity coefficient is between one and zero (see e.g., Choudhri et al. 2002, Knetter 1989). Numerous studies claim that German exporters price to market and accept shrinking profits in order to defend market shares (see e.g. Choudhri et al. 2002, Falk and Falk 2000, Gagnon and Knetter 1990, Ihrig et al. 2006, 1989, Krugman 1989). Other empirical literature finds very low responsiveness of U.S. import prices to exchange rate movements which is declining over time (see e.g. Gust et al. 2006). Altogether, this empirical evidence incentivizes us to discuss the effects stemming from differences in the exchange rate elasticity of the export prices on the entry and exit decisions of economic agents.

The present section augments the general non-ideal relay model (see fig. 3.1 in section 3.1.1) by the effects of the exchange rate and makes the model fit for the analysis of the special case of international trade where trade partners have different currencies. By way of illustration, we again use an example with German exporters and U.S. importers, meaning that the euro is considered as the home and the dollar - the foreign currency. For the sake of simplicity, we first assume that all relevant costs (variable and sunk costs) have to be paid in the home currency, which is also the case in all previous chapters. This allows

us to keep the price trigger values as well as the width of the individual bands of inaction constant. In general, the relationship between the prices in home and foreign currency can be formalized as follows:

$$p_t = p_t^*(\varepsilon) \cdot \varepsilon_t \quad (7.1)$$

here p denotes the price in euro, ε is the bilateral exchange rate in direct quotation [€/\$], t is a time index and $p^*(\varepsilon)$ is the \$-price function, which takes the following form:

$$p_t^*(\varepsilon) = \alpha \cdot \varepsilon_t^{-\eta} \quad (7.2)$$

α denotes a constant and η is the exchange rate elasticity coefficient of export prices. Combining eqs. (7.1) and (7.2), the following general form of the €-price function results:

$$p_t = \alpha \cdot \varepsilon_t^{1-\eta} \quad (7.3)$$

The exchange rate elasticity of export prices can theoretically vary in the interval $\eta \subseteq [0; 1]$. Thereby, the values $\eta = 0$ and $\eta = 1$ represent two limiting cases of the ERPT - a case of pricing-to-market (PTM), namely the local currency price stabilization (LCPS) and the complete ERPT, respectively. In the case of PTM, the elasticity coefficient takes the value of zero and the foreign prices remain constant despite the exchange rate changes:

$$p_t^*(\varepsilon) = \alpha \cdot \varepsilon_t^0 = \alpha = \bar{p}_t^* \quad (7.4)$$

It follows from the foregoing that:

$$p_t = \alpha \cdot \varepsilon_t = \bar{p}_t^* \cdot \varepsilon_t \quad (7.5)$$

Eqs. (7.4) and (7.5) highlight that all of the exchange rate changes are absorbed by the exporters. More precisely, a firm now sets and maintains its export price in dollar rather than adjusting the prices according to the exchange rate changes (see Krugman 1986). Assuming that an exporting firm j practices the

PTM strategy allows us to simplify the model to a two-dimensional one. Thus, the price in euro changes proportional to the exchange rate changes and the price in dollar remains constant.

The other limiting case represents the opposite to the PTM, namely the complete ERPT. The exchange rate elasticity coefficient of export prices now equals one ($\eta = 1$) and leads to constant prices in euro and thus constant marginal revenues of the exporters:

$$p_t = \alpha \cdot \varepsilon_t^0 = \alpha = \bar{p}_t \quad (7.6)$$

Consequently, the exchange rate changes (as exogenous shocks) are now fully absorbed by the foreign prices:

$$p_t^*(\varepsilon) = \alpha \cdot \varepsilon_t^{-1} = \frac{\alpha}{\varepsilon_t} \quad (7.7)$$

As mentioned above, the exchange rate elasticity of export prices can vary between 0 and 1. Fig. 7.1 illustrates the microeconomic hysteresis in international trade for following values of the elasticity coefficient: 0, $\frac{1}{2}$ and 1.

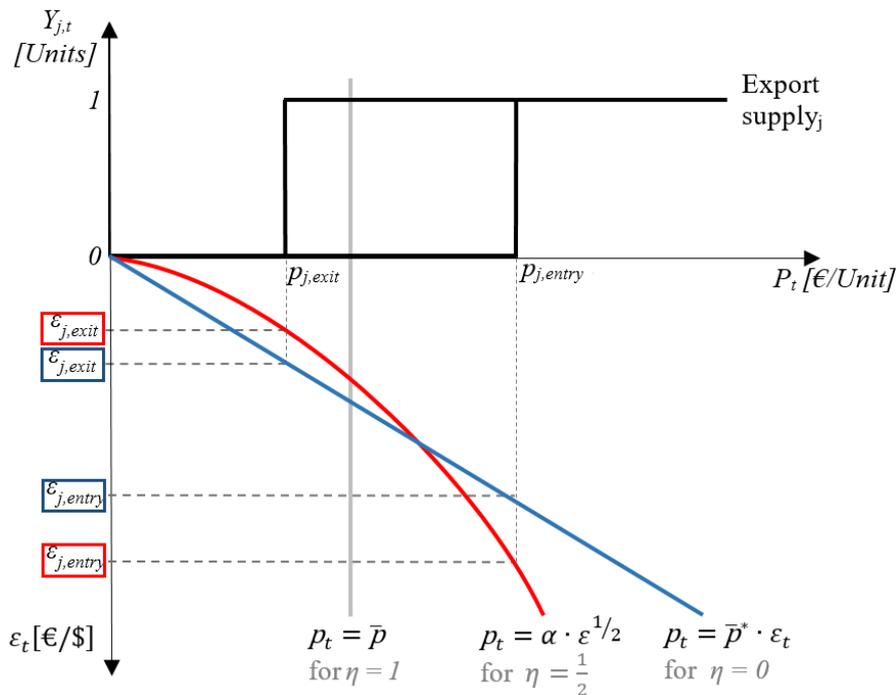
The upper part of fig. 7.1 has been presented in fig. 3.1 in section 3.1.1 and captures the relationship between the output ($Y_{j,t}$) in physical units and the price in home currency (P_t). The lower part of the graph captures the relationship between the prices in euro and the exchange rate (ε_t). Three iso-elastic price functions represent different degrees of the ERPT and illustrate the relationship between the price triggers and the exchange rate trigger values.

The linear price function is captured by the blue line in fig. 7.1 and represents the PTM case with $\eta = 0$ (see eq. (7.5)). The price band of inaction ($BoI_{j,\eta=0}^p$) equals:

$$BoI_{j,\eta=0}^p = p_{j,entry}^{\eta=0} - p_{j,exit}^{\eta=0} = \alpha \cdot (\varepsilon_{j,entry} - \varepsilon_{j,exit}) = \alpha \cdot BoI_{j,\eta=0}^\varepsilon \quad (7.8)$$

Eq. (7.8) makes obvious that the exchange rate band of inaction ($BoI_{j,\eta=0}^\varepsilon$) is proportional to the price band of inaction ($BoI_{j,\eta=0}^p$). Therefore, the general price-output model is 1 : 1 applicable in the special case of international trade.

Figure 7.1: Microeconomic hysteresis in international trade with different exchange rate elasticities of export prices



This limiting case is therefore analyzed in further detail and integrated in the hysteresis losses model in section 7.4.

The red line in fig. 7.1 represents the parabolic price function with the elasticity coefficient of $\eta = \frac{1}{2}$. Thus, the relationship between the price and exchange rate bands of inaction is as follows:

$$BoI_{j,\eta=\frac{1}{2}}^P = p_{j,entry}^{\eta=\frac{1}{2}} - p_{j,exit}^{\eta=\frac{1}{2}} = \alpha \cdot (\sqrt{\varepsilon_{j,entry}} - \sqrt{\varepsilon_{j,exit}}) \quad (7.9)$$

Eq. (7.9) shows that when ε varies between zero and one, there is no proportionality between the bands of inaction, or between the price and exchange rate trigger values, meaning that the general model cannot be applied to international trade without further ado. Consequently, one should take the relationship between the relevant bands of inaction (e.g. as in eq. (7.9)) into account to obtain a more precise measure.

The vertical grey line in fig. 7.1 captures the price function in case that a

complete ERPT applies ($\eta = 1$). Due to the constant nature of the price function, the entry and exit price triggers will never be crossed, meaning that there is no supply hysteresis in this limiting case. However, if we consider the demand effects associated with foreign price variations, it is to be expected that e.g. the foreign demand falls as a consequence of euro appreciation and thus higher foreign prices. In such a case, the firms might either start to price-to-market to save their market shares (this would lead to $\eta > 0$) or even leave the foreign market (or search for the new markets) due to low demand, which is insufficient for covering the production costs. More precisely, the firm will leave the market if the loss from exporting exceeds the sunk exit costs.

7.3 Effects of changing the currency of costs

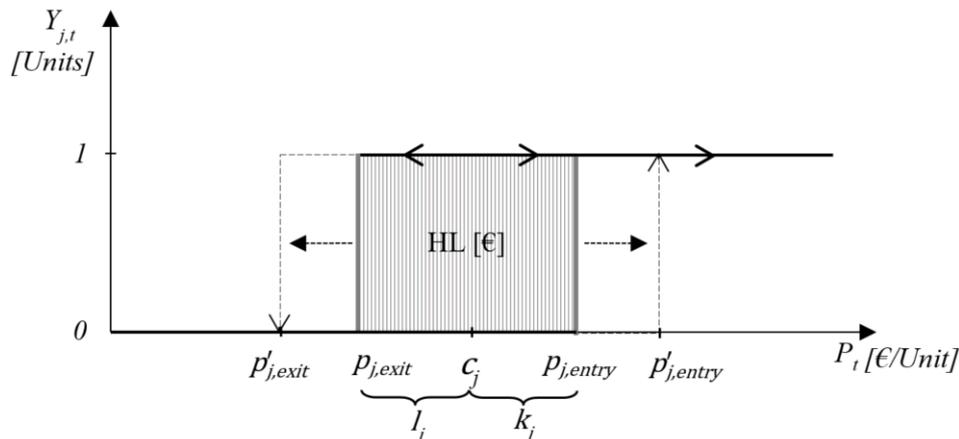
In this section, we will show how the currency of a firm's costs (or part of them) affect the micro and macro hysteresis loop and thus the extent of hysteresis losses.

7.3.1 Variable costs incurred in home and the sunk costs in foreign currency

Within the scope of this chapter, there is one further aspect that we still need to deal with. Thus far, we have assumed that the sunk entry and exit costs are paid in the home currency, which induces a constant width of the price band of inaction. However, it is entirely possible that exporters pay their variable costs in the home currency, although the sunk entry and exit costs - e.g. for accumulating information on foreign markets as well as establishing new market channels, or for firing employees and resigning existing contracts between partners and customers - need to be paid in the foreign currency. This makes the modeling of hysteresis losses slightly more complicated since the width of the price band of inaction also depends on the exchange rate. Fig. 7.2 illustrates the effects of home currency depreciation on the width of the price band of inaction.

Analogous to fig. 7.1 the ordinate in fig. 7.2 captures the export supply of firm j and the abscissa - the price denominated in home currency. As addressed in section 3.1.2, the gap between $p_{j,exit}$ and the variable costs, c_j , in the simplest

Figure 7.2: Microeconomic hysteresis losses with sunk costs paid in foreign currency (\$)



Source: Own representation based on Belke and Göcke 2005.

microeconomic model without uncertainty and with the one-period optimization problem equals the sunk exit costs, l_j . The gap between $p_{j,entry}$ and c_j in the same model equals the sunk entry costs, k_j . We now assume that both sunk costs - k_j and l_j - are incurred in foreign currency (\$). Thus, the entry and exit price triggers are no longer constant but rather depend on the exchange rate due to the conversion of sunk costs to the home currency. c_j has to be paid in euro and thus remains constant. Therefore, a depreciation of the home currency leads to an increase in k_j and l_j expressed in euro.

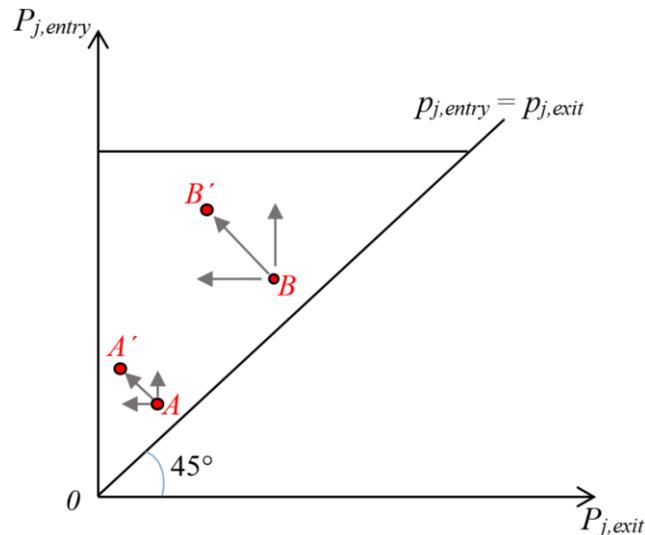
As illustrated in fig. 7.2, this results in a lower exit trigger, $p'_{j,exit}$, and a higher entry trigger, $p'_{j,entry}$. In other words, similar to the introduction of uncertainty, we have an outward shift of the threshold values (compare figs. 5.1 and 7.2). However, there are two main differences between the nature of effects of these two cases. First, the introduction of uncertainty implicates an additive effect due to which the individual triggers of each firm are shifted by the same extent u , which quantifies the effect of uncertainty. In contrast to this, the exchange rate effect on sunk costs is a multiplication - the exit trigger decreases by $(\Delta l_j = l_j^* \cdot \Delta \varepsilon_t)$ and the entry trigger increases by $(\Delta k_j = k_j^* \cdot \Delta \varepsilon_t)$. This makes it obvious that the exchange rate effect is the greater the higher the sunk costs. Second, when the sunk costs are incurred in dollar, a euro depreciation induces a wider band of

inaction, which - in contrast to the case of uncertainty - leads to higher hysteresis losses (the area within the loop) at the microeconomic level. Since the losses are measured in home currency, there are no additional exchange rate effects.

As illustrated in fig. 7.3, the outward shift of the individual trigger values leads to a reallocation of the firms in the Preisach triangle. Due to the euro depreciation, each firm has to be reallocated to the north-west direction. In order to underline the difference of the exchange rate effects on the individual trigger values, two firms are illustrated in fig. 7.3. Firm A is located closer to the 45° -line of the P_{entry}/P_{exit} diagram than the firm B , meaning that the sunk entry and exit costs that it has to pay are lower than those of firm B . As mentioned in the previous paragraph, the currency effect is lower in case of firm A and thus the north-west shift of point A towards point A' is of a smaller extent than the shift of point B towards B' . When all of the firms in the Preisach triangle are considered, it becomes obvious that this kind of shift of each individual firm leads to a change in the firm distribution in the Preisach triangle, which previously was uniform per assumption. After the euro depreciation and thus increased adjustment costs, the density of firms increases, going orthogonal from the 45° -line towards the ordinate. As discussed in section 3.3, this leads to an increase in power of the functions capturing the up- and the downward-leading branches of the macroeconomic hysteresis loop. Section 4.4 shows that increasing the power of the hysteresis function leads to an increasing power of the hysteresis losses function. Fig. 4.5 illustrates the aggregated effects on the shape of the hysteresis loop and the hysteresis losses.

Whereas the effects of uncertainty and home currency depreciation look similar in the non-ideal relay model, they are completely different in the macroeconomic Preisach model. Explicit modeling of uncertainty leads to a play area that is generated due to an outward shift of the hysteresis loops and thus lower hysteresis losses. A depreciation of the home currency leads to higher sunk costs and more humped hysteresis loops, associated with higher hysteresis losses in case of a later home currency appreciation. Hence, a home currency depreciation has a twofold effect on the exporters: on the one hand, it leads to more foreign demand due to lower export prices; while on the other hand, it induces higher barriers to entry and exit due to higher sunk costs.

Figure 7.3: Effects of euro depreciation on aggregation when the sunk costs are incurred in dollar



A euro appreciation leads to an inward shift of the trigger values at the micro level and less humped macro hysteresis loops. Consequently, lower hysteresis losses are generated. In this situation, the entry and exit barriers as well as foreign demand are low.

What this all amounts to is that if the sunk costs are incurred in foreign currency, the band of inaction of each firm becomes variable and it is wider the weaker the home currency, and vice versa. At the macroeconomic level, the variations of the width of individual bands of inaction induce changes in the curvature of hysteresis loops, which is responsible for the extent of hysteresis losses.

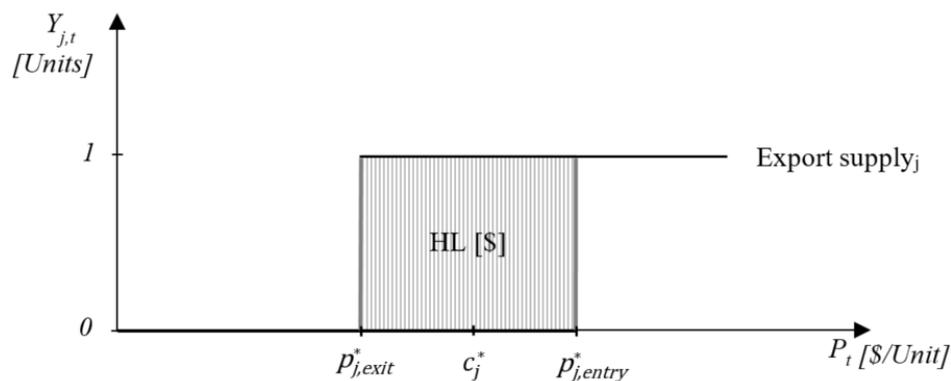
7.3.2 All of the costs are incurred in foreign currency

In this section, we analyze the effects of exchange rate changes on the individual price band of inaction when all of the costs of an exporter have to be paid in foreign currency (e.g. dollar). This example represents a quite unusual yet a possible scenario. Thus, we consider a firm that produces in a country that uses U.S. dollar as its official medium of exchange - e.g. Puerto Rico, Ecuador or Guam - and exports its production to the U.S. The registered office of the

company where the consolidated financial statements are prepared is located e.g. in Luxembourg, meaning that the currency used for the calculations is the euro.

The modeling of this case is quite straightforward. Since all of the costs have to be incurred in dollar, the exchange rate does not play any role for the entry and exit decisions of our exemplar firm j . Therefore, the supply function of firm j (see fig. 7.4) is very similar to that illustrated in fig. 3.1. The only difference is that supply depends only on the export price denominated in the foreign currency (p^*).

Figure 7.4: Microeconomic hysteresis with all of the costs paid in foreign currency (\$)



Source: Own representation based on Belke and Göcke 2001.

As illustrated in fig. 7.4, the extent of hysteresis losses is now measured in dollar and it does not change despite the exchange rate changes. However, the exporter j has to convert his write-offs to his home currency. Consequently, the microeconomic hysteresis losses denominated in euro increase in case of euro depreciation and decrease if the euro appreciates against dollar.

The aggregation procedure of such exporting firms and their losses is analogous to those presented in sections 3.2 and 4.3. The aggregated output (export volume) is only forced by prices denominated in foreign currency. Whereas the exchange rate changes do not play any role for the output reactions, they are important in capturing the hysteresis losses. As at the microeconomic level, they are generated in dollar and have to be converted in euro. Consequently, a euro depreciation (appreciation) is associated with higher (lower) aggregated hysteresis

losses.

7.4 Hysteresis losses in international trade in the model with PTM

For the first attempt to measure hysteresis losses in international trade and apply these considerations empirically, the limiting case of PTM ($\eta = 0$) will be assumed. As shown in section 7.2, the individual price triggers are proportional to the exchange rate triggers and therefore the general model of hysteresis losses can be applied to the analysis of the special case of international trade. Since the hysteresis losses indicator is only a measure of proportionality, these assumptions are reasonable. The aim of this chapter is to develop a preferably simple theory basis for an empirical investigation, which is executed in chapter 8.

A one-sided dynamic model with hysteresis is presented in the following. The PTM assumption allows us to keep prices in dollar constant. Thus, under *ce-teris paribus* conditions, there is no demand price reaction to any exchange rate changes. Due to PTM, the market entry and exit price of an exporting firm j is proportional to the exchange rate value:

$$p_{j,entry} = \bar{p}_t^* \cdot \varepsilon_{j,entry} \quad (7.10)$$

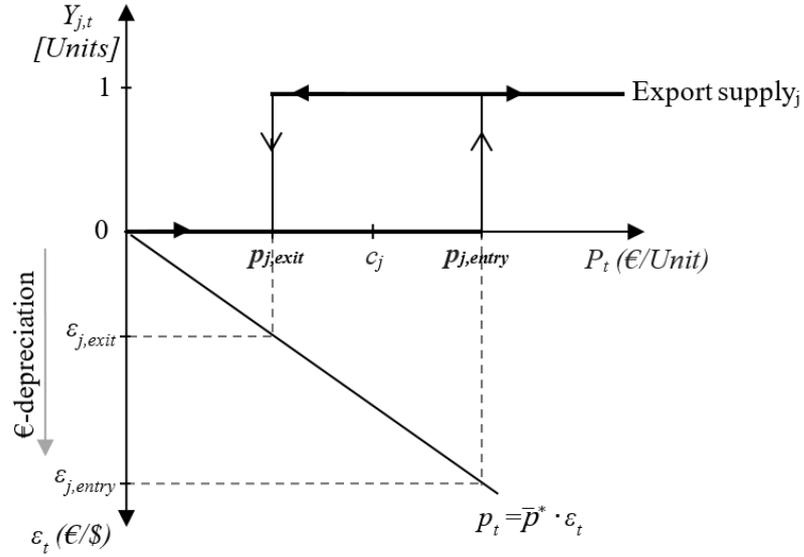
$$p_{j,exit} = \bar{p}_t^* \cdot \varepsilon_{j,exit} \quad (7.11)$$

For the sake of completeness, we assume that the variable and the sunk costs are incurred in the home currency, which in our example is the euro.

Fig. 7.5 illustrates a hysteretic supply of an exporting firm j as a relationship between export volume of the operational unit i ($y_{j,t}$), price in euro (p_t), the bilateral €/\$-exchange rate (ε_t); \bar{p}_t^* captures the constant price in dollar and t is a time index. In the quadrant *IV*, a linear relationship between the exchange rate and the price in euro is illustrated, as well as the proportionality between the price and exchange rate trigger values (see eqs. (7.10) and (7.11)). A euro depreciation (increase of the exchange rate ε) induces higher unit revenues for an

exporting ECU member country. Consequently, analogous to entry and exit price triggers, the exchange rate entry threshold is higher than the exit threshold. The quadrant I captures the export supply of firm j in the form of a non-ideal relay, which is identical to what was presented in section 3.1 (see fig. 3.1).

Figure 7.5: Non-ideal relay model with pricing-to-market in the special case of international trade



In section 4.1, it has been shown that the hysteresis loss (HL) corresponds to the area inside the closed microeconomic hysteresis loop. Therefore, in our special case of international trade, we can calculate the hysteresis loss - denominated in euro - as follows:

$$HL_{j,t} = \Delta y_{j,t} \cdot (p_{j,entry} - p_{j,exit}) \quad (7.12)$$

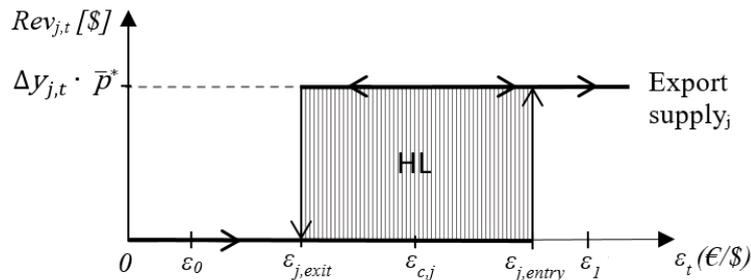
Combining eqs. (7.10), (7.11) and (7.12) the hysteresis loss can be formalized in the following way:

$$HL_{j,t} = \Delta y_{j,t} \cdot \bar{p}_t^* \cdot (\varepsilon_{j,exit} - \varepsilon_{j,entry}) \quad (7.13)$$

According to eq. (7.13), hysteresis loss is a product of firms revenue in dollar and the difference between the exchange rate values that trigger firms market entry and exit. As a result, hysteresis losses can be alternatively illustrated using

two dimensions - as an area within the non-ideal relay loop in the exchange rate-revenue diagram as shown in fig. 7.6, measured in euro.

Figure 7.6: Alternative representation of hysteresis losses in a model with pricing-to-market



Source: Own representation based on Belke and Göcke 2001.

In contrast to the general case with price as the forcing and physical output quantity as the dependent variable, the model of international trade uses the exchange rate as forcing and the export revenue in dollar as the dependent variable. If we normalize prices in dollar to unity, the revenues in dollar correspond to operational units and the number of active exporters on the market. The exchange rate corresponds to prices in euro. Thus, the aggregation of exports and hysteresis losses can be executed again using P_{entry}/P_{exit} diagrams as illustrated in sections 3.2 and 4.3. The outcome is quantitatively the same as shown in section 4.3, namely the euro appreciation generates disproportionately large hysteresis losses compared to exchange rate changes, and these losses are proportional to the area inside a certain closed macroeconomic hysteresis loop.

We modeled hysteresis losses in international trade for a certain world with one-period profit maximization. As we know from chapter 5, uncertainty leads to a more cautious decision-making of firms and thus lowers hysteresis losses. However, multi-period optimization leads to higher hysteresis losses than captured by the area inside the hysteresis loop due to interest costs on the sunk entry and exit investments (see section 4.2). If we do not ignore uncertainty and interest rate effects at the macroeconomic level, we cannot argue that hysteresis losses are proportional to the area inside the loop due to macroeconomic play area that arises. All these factors complicate the interpretation of the hysteresis

losses indicator.

Chapter 8

Empirical analysis of hysteresis losses in economics

8.1 German exports to the United States

This section provides an example how to empirically test for hysteresis using the play algorithm described in section 6.3, as well as how to calculate the hysteresis losses indicator conceptualized in section 6.4. Whereas the empirical testing for hysteresis has been undertaken many times in the literature, the empirical analysis of hysteresis losses - which entails estimating and calculating the hysteresis losses indicator - is novel in the economic literature. Micro and macroeconomic modeling of hysteresis losses in international trade - which is also novel in economics - is discussed in section 7.4.

8.1.1 Motivation

As a first example of an empirical application of the hysteresis losses indicator, we investigate German exports to the U.S. in selected export sectors. Our market choice is based on many factors. First of all, we focus on Germany as an export production site due to a very high openness of the German economy: according to Eurostat, in 2016 more than 50 % of German goods and services were exported (measured in percentage of GDP). Second, given that the U.S. is by far the most important trade partner of Germany, we selected the U.S. the as ex-

port destination country. Since we aim to analyze the exchange rate effects, the trade partners must have different currencies. For this reason, we do not select the Eurozone as the export destination area, although this common market is even more important for the German export sector than the U.S. Moreover, the \$/€ exchange rate is one of the most observed and influential bilateral exchange rates. The first criteria of selecting sectors of interest is their importance for Germany in general. The second criterion is the importance of these sectors in the bilateral trade relationship between Germany and the U.S. Since our aim is to find hysteresis and calculate the hysteresis losses, the quantitative perspective is not the only crucial criterion. The selected export sectors are also special since the goods of depicted German exports are heterogeneous and thus exhibit relatively low price elasticity (see Belke et al. 2015). In combination with high sunk adjustment costs (e.g. for entry and exit), they might lead to hysteretic behavior of exporting firms in their export participation decision-making.

8.1.2 Data characteristics

In the empirical analysis, we use the data that is aggregated on a quarterly basis due to a lower likeliness of a measuring error. According to Canova and De Nicolo 1995, the likeliness of a measuring error is much higher if we use the monthly data. Our sample ranges from 1995Q1 to 2015Q4. The original data is not seasonally adjusted, although the seasonality is modeled including the seasonal dummies into the regression (see eq. (8.1) section 8.1.3).

The phenomenon that we are willing to explain is the participation of German exporters on the U.S. markets for mineral fuels, oils, waxes and bituminous sub (*HS27*), pharmaceutical products (*HS30*), plastics and articles thereof (*HS39*), iron and steel (*HS72*), articles of iron and steel (*HS73*), nuclear reactors, boilers, machinery and mechanical appliances, computers (*HS84*), electrical machinery, telecommunication equipment, sound and television recorders (*HS85*), vehicles other than railway or tramway rolling stock (*HS87*), aircraft, spacecraft and parts thereof (*HS88*) and optical, photographic, cinematographic, measuring, checking, precision, medical or surgical instruments and accessories that will be

abbreviated in the following as high-tech instruments (*HS90*).¹ For all product groups, the data is completely available within the whole sample. All of the export time series are denoted in current euro, deflated by the German export price deflator and measured in mill. EUR. The data stems from the Eurostat database.

Fig. 8.1 provides an overview of the volume and the development of the following time series: German vehicle exports to the U.S. (product group *HS87*) and the exchange rate during the time span 1991 – 2015. The exchange rate exhibits relatively high volatility, since it varies between 1.02 and 1.80 during the depicted sample.² During the period of predominant euro depreciation (1995 – 2002), the German exports were positively stimulated and thus grew strongly and continuously. As the euro appreciation period started in 2002, the exports stopped increasing and remained quasi at the same level as in 2002, until the euro reached its absolute highs of the 21st century. This weak reaction of exports to euro appreciation suggests hysteretic behavior of the exporters, leading to permanent effects induced by exchange rate changes. Strong euro appreciation since 2007 together with the financial crisis and the following recession of the world economy induced a strong decrease of the exports, which fell to the export level of 1997. The recovering world economy and strongly depreciating euro stimulated German exports and contributed to the rapid and continuous increase in German exports since 2009.

The explaining variable - which we call the forcing variable in the context of hysteresis - is represented by the real $\$/\text{€}$ -spot exchange rates as monthly averages. These time series are obtained from the OECD database.

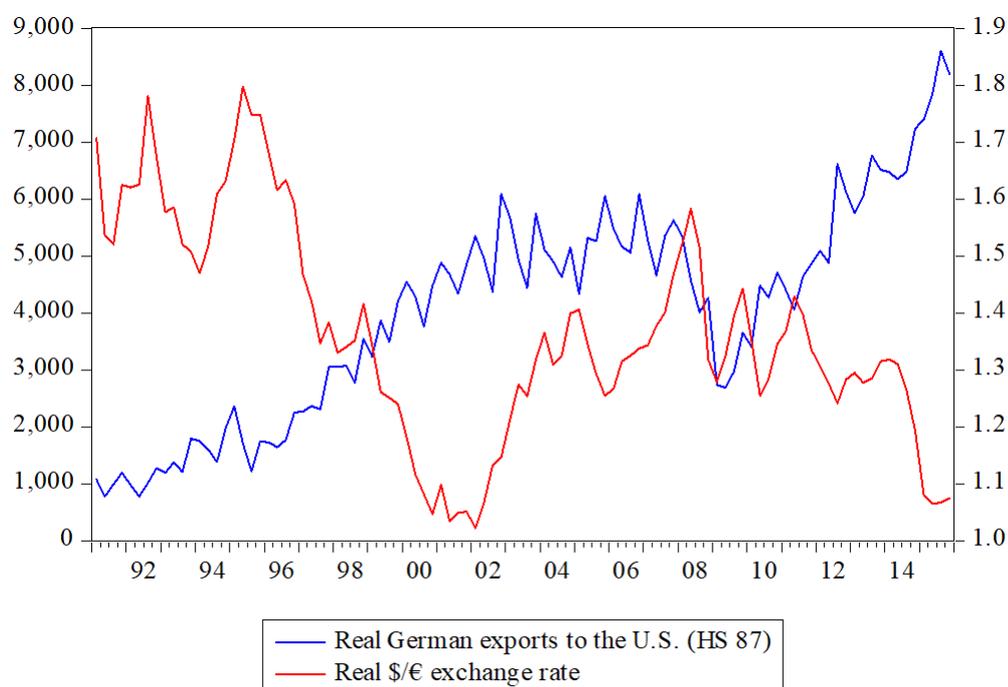
In order to control for the local demand, the real U.S. GDP is used. The nominal U.S. GDP in domestic currency (\$) is deflated using U.S. GDP deflator. The resulting real U.S. GDP is measured in mill. \$. Both time series again stem from the OECD database.

Prior to any analysis, the time series first have to be tested for stationarity. The stationarity ensures that the expected value does not depend on time, the

¹We use the Harmonised System (HS) Classification for traded goods.

²As in Belke et al. 2013, synthetic euro exchange rates are employed before 1999. They are calculated with the DM exchange rates and the fixed DM/€ exchange rate

Figure 8.1: German exports to the U.S. vs. \$/€ exchange rate (1991 – 2015)



Note: German export series are depicted on the left-hand-side ordinate and measured in mill. €; Product group: HS 87: vehicles other than railway or tramway rolling stock; the exchange rate is depicted on the right-hand-side ordinate.

Source: Own representation based on Eurostat 2015 data.

variance is constant and positive, and the covariance depends only on the time distance but not on time itself (Greene 2008, p. 718-719). However, most economic time series contain a trend and thus are non-stationary (Hassler 2003, S. 811). Integrated time series do not tend to fluctuate around a certain level, but rather drift above or beyond each value (see Hassler 2003, p. 812). Hence, the variance increases over time. Estimations based on the non-stationary time series can produce either spurious or nonsensical results (see Granger and Newbold 1974). Therefore, the data is often transformed into stationary time series (e.g. using first differences or logs depending on whether the short- or long-run effects are analyzed, or including trends in the regression). In this regard, the Augmented Dickey-Fuller (ADF) test is employed. Tab. A.1 summarizes the results of the unit root test for all of the time series used in our analysis. The results

show that all of the time series are non-stationary in levels but stationary in first differences, with only one exception, whereby the exports of iron and steel are stationary even in levels. This implies that exports of iron and steel are of $I(0)$ and all of the other variables are of $I(1)$ processes.

In the simple regression analysis, we do not transform the data and estimate them in levels to ultimately interpret the results reasonably. We deal with the non-stationarity problem by the specification of the model including a linear trend into the regression.

8.1.3 Methods

The calculation of the hysteresis losses indicator (*HLI*) underlies a two-step procedure. First, we test whether hysteresis is relevant for the market that we are interested in. If this is the case, hysteresis losses become relevant and we calculate the hysteresis losses indicator using certain estimated parameters from the first step (the estimated slopes of the play and the spurt lines, α and $\alpha + \beta$, respectively, and the estimated play width, d). For our intention, we prefer a method that describes the path-dependence of the system and is based on “strong”³/macro hysteresis. There are only two of them thus far: the Preisach approach described in section 6.1 and empirically implemented by Piscitelli et al. 2000, as well as the already-mentioned play algorithm (see Belke and Göcke 2001), which is presented in detail in section 6.3.⁴ We choose the second approach to be consistent with the logic of the indicator construction. Determining the export market participation by means of the play-hysteresis approach allows us to solve the problem of structural shifts of the system endogenously. The shifting points (e.g. A , B , C or D in fig. 6.8) are determined by the historical exchange rate and output realizations.

Thus, before we can commit ourselves to our ultimate target of calculating the *HLI*, we first have to conduct a number of exercises as in Belke et al. 2013 and

³The definition of “weak” and “strong” hysteresis was introduced in Amable et al. 1991. “Weak” hysteresis defines the microeconomic and “strong” hysteresis - the macroeconomic phenomenon.

⁴For the translation of the algorithm into the EViews batch program, we refer to Belke and Göcke 2001.

Belke et al. 2014 to test for hysteresis as well as estimating the play width and the slopes of the play and spurt lines that are necessary for the *HLI* calculation. For this purpose, we run two linear OLS regressions and compare the estimation results of both for each selected product group:

$$EX_t = C + \alpha \cdot RER_t + \gamma \cdot Z_t + \epsilon_t \quad (8.1)$$

$$EX_t = C + \alpha \cdot RER_t + \beta \cdot SPURT_t(d) + \gamma \cdot Z_t + \epsilon_t \quad (8.2)$$

Eq. (8.1) captures a simple linear regression, which serves as a baseline model explaining the depicted German exports to the U.S. The regression specification is kept simple and includes the following variables: German export values of the selected sector as the dependent variable (EX_t), the real \$/€-exchange rate (RER_t) and other explanatory/controlling variables, summarized in vector Z_t : U.S. GDP (GDP_{t-1}), the linear trend ($Trend_t$) and seasonal dummies for the first three quarters (Q_1, Q_2, Q_3). The U.S. GDP is a proxy for the market demand in the U.S. and is included in the regression with one lag (GDP_{t-1}) to avoid the reverse causality. The linear trend ($Trend_t$) is included in the regression due to the non-stationary nature of the data to eliminate the trend effects. The seasonal dummies for the first three quarters (Q_1, Q_2, Q_3) are used for the purpose of seasonal adjustment of the model. From the regression in eq. (8.1), we expect the U.S. GDP to have a positive and the exchange rate to have a negative impact on the export values, since an increase in the exchange rate means an appreciation of the euro.

The estimation results are regarded as stable if the residuals possess the characteristics of the white noise processes. This means that the residuals must be stationary and thus not autocorrelated, the expected value must be equal to zero, the variance must be constant and the covariance must only depend on the difference between t_n and t_{n+1} , although not on time itself (see Greene 2008, p. 632). The white noise residuals are also normally distributed. These are the central assumptions of all of the tests executed in this empirical chapter. The windows-based econometric software Eviews enables us to test the residuals for autocorrelation, heteroscedasticity and normal distribution.

In order to test for autocorrelation of the residuals, the Q-statistic and the LM test are employed. Fig. A.2 shows the results of the Q-statistics for the first twelve lags of the regression of vehicle exports (*HS87*). The correlogram has spikes at lags up to seven. The Q-statistics are significant at all lags, indicating that there is a significant autocorrelation in the residuals. The Breusch-Pagan serial correlation LM test also rejects the null hypothesis of no autocorrelation. Thus, both - the Q-statistic and the LM test - indicate that the residuals are autocorrelated. Consequently, the OLS estimators will be inefficient and thus no longer BLUE, albeit still unbiased and consistent (see Asteriou and Hall 2007, p. 137). Similar results of the diagnostic tests regarding the serial correlation apply for all of the product groups.

The White heteroscedasticity test is employed to ascertain whether the variance of the residuals is constant over time. The null hypothesis states that the residuals are homoscedastic and thus it is desirable not to reject the null. Table A.5 summarizes the probability values of the White test of the regressions of all of the product groups. The results indicate that with the exception of product group *HS30*, the null cannot be rejected even at the 10% significance level. Thus, the residuals are homoscedastic. In addition, all of the individual residual cross products are also homoscedastic for all of the product groups except *HS30*.

Whether the error terms are normally distributed or not is tested employing the Jarque-Bera test. The focus of the test is on the skewness and kurtosis. The distribution of the error terms is considered as normal if the skewness equals to zero and the kurtosis takes the value of three. The test results in table A.7 indicate that the residuals are normally distributed in the regressions of the product groups *HS73*, *HS85*, *HS88* and *HS90*, although not in the regressions of the remaining product groups. Although the results of the normality test are not perfect for all estimations, we consider them as satisfactory mostly for one reason: our sample is relatively small and thus any statement regarding the normality is very problematic. Every single outlier might have conducted the rejection of the null. The graph of the residuals supports this proposition in the estimation of the most exports. The fact that asymptotical Jarque-Bera tests pose difficulties testing small samples has been demonstrated and proven in e.g. Mantalos 2010.

As an example, table A.12 summarizes the estimation results of the regression

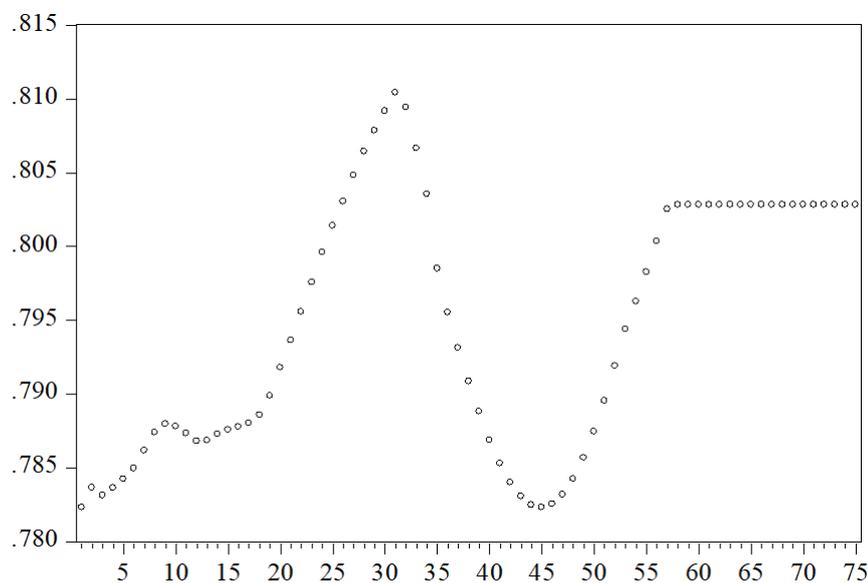
of vehicle exports (*HS87*). The second column refers to the simple OLS regression (see eq. (8.1)). According to t-statistics, only the estimated coefficients of the exchange rate, lagged U.S. GDP and the seasonal dummies Q2 and Q3 are significant. As expected, a euro appreciation against the dollar negatively affects the German exports to the U.S., the increasing U.S. GDP indicates growing demand for German products and thus leads to higher exports. The second and third quarters exert a negative influence on the German exports to the U.S.

Eq. (8.2) captures a modification of the baseline regression, which is now non-linear in its parameters and includes the structural shifts of the export supply represented by the original exchange rate and the artificial *SPURT* variable, which is generated by means of the play algorithm. The filtering procedure and the derivation of eq. (8.2) are presented in section 6.3. The artificial *SPURT* variable captures only large changes of the exchange rate leading to strong export reactions, since the small exchange rate changes (movements in the play area d) are filtered out. We assume that the play width is time-invariant and calculate the most appropriate play width, d , in the following way: based on the exchange rate time series, we define the interval that probably entails the appropriate play width (d). The algorithm then identifies the switching points (e.g. A , B , C or D in fig. 6.8) and generates the corresponding *SPURT* variable for each play width from the defined interval. We assume that the most appropriate play width is associated with the maximum R-squared of the regression specified as formalized in eq. (8.2) (see Belke et al. 2013). Fig. 8.2 illustrates the resulting R-squared as a scatter plot for the play width from the interval $[0; 75]$ ⁵ dividing it in 75 subintervals and the regression of the product group *HS87*. The ordinate captures the R-squared and the abscissa represents the play width. It is clear from the graph that the R-squared takes the highest value of $R^2 = 0.81$ when the play width is $d = 0.31$. The lowest R-squared ($R^2 = 0.78$) - which results when $d = 0$ and $d = 0.45$ - equals the R-squared of the simple linear regression (see table A.12). When the play width equals zero ($d = 0$), there is no hysteresis and the results of the regressions (8.2) and (8.1) are the same.

The same one-dimensional grid search procedure applies for all of the product

⁵The choice of the interval is based on the difference between the minimum and the maximum of the exchange rate in the depicted sample period.

Figure 8.2: R-squared resulting from one-dimensional grid search over constant play width d , product group $HS87$



Source: Own calculations.

groups. Table 8.1 summarizes the results showing the different play lengths for different product groups.

Table 8.1: Estimated play widths associated with the highest R^2

	HS product groups									
	27	30	39	72	73	84	85	87	88	90
Play width (d)	0.39	0.57	0.57	0.57	0.12	0.57	0.57	0.3	0.57	0.31

Source: Own calculations.

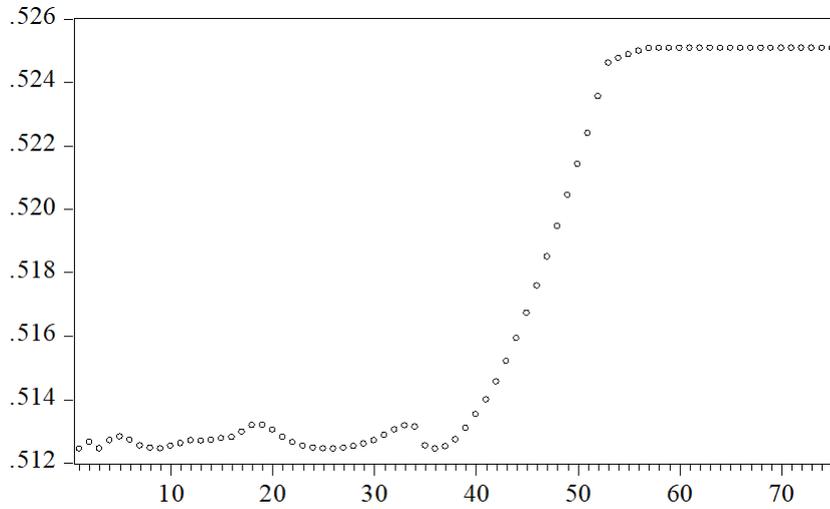
The shortest play was estimated in the regression of the exports of the articles from iron and steel ($HS73$) and very large play widths were estimated for the exports of the HS product groups 30, 39, 72, 84, 85 and 88. The difference between the minimum and maximum of the exchange rate is 0.776, which is not much higher than the estimated highest play width of the extent 0.57. This indicates a very low variation of the $SPURT$ variable. It is possible that the estimated play width is extremely high and the $SPURT$ variable entails a

one-time shift. In the latter case, the *SPURT* converges to a dummy variable indicating a structural break.⁶ The results summarized in table 8.1 indicate a large play width of the same extent for several product groups and this incentivizes us to prove whether there is a structural break in these cases. A closer look at the R-squared plots of the selected product groups made it obvious that without any exception the maximum R-squared associated with the play width 0.57 is an edge-maximum. This is illustrated in fig. 8.3, which depicts the results for product group *HS88*. However, the *SPURT* variable does not entail a one-time shift in any of the considered product groups. As fig. 8.4 shows, with some breaks the *SPURT* falls in the time span 1997 – 2001, whereby an especially strong fall is observed in 1999 as the euro currency was launched. From 2002 until the end of the sample, the *SPURT* variable runs horizontally. Knowing that the algorithm fails in differentiating between structural breaks and play movements - meaning that the structural breaks overwrite the play dynamics - we select the play width that is associated with the second-highest R-squared maximum and run the potentially-affected regressions once again. The results are compared in table A.10. From the logical perspective, the use of the second-highest R-squared in estimating play width in those special cases leads to better results. We will return to the interpretation of these results several paragraphs later.

In order to ascertain whether the selected German export sector exhibits hysteresis, we run the regression from eq. (8.2) with the filtered *SPURT* variable and test the null hypothesis ($H_0: \beta = 0$) against the alternative ($H_1: \beta \neq 0$). Rejecting the null hypotheses means that the *SPURT* variable significantly contributes to the explanation of the export variability. Furthermore, we compare the estimation results of eqs. (8.1) and (8.2) to be certain that eq. (8.2) produces the better fit than eq. (8.1). From regression (8.2), we expect the U.S. GDP to have a positive and the exchange rate - a negative impact on the export values. Since the effects of the exchange rate now are divided into weak - represented by the original exchange rate variable - and strong - reflected by the *SPURT* variable - the common effects are decisive. Accordingly, the sum of the coefficients ($\alpha + \beta$) must be negative. The original exchange rate variable should ideally become smaller and insignificant, since the coefficient of the original exchange

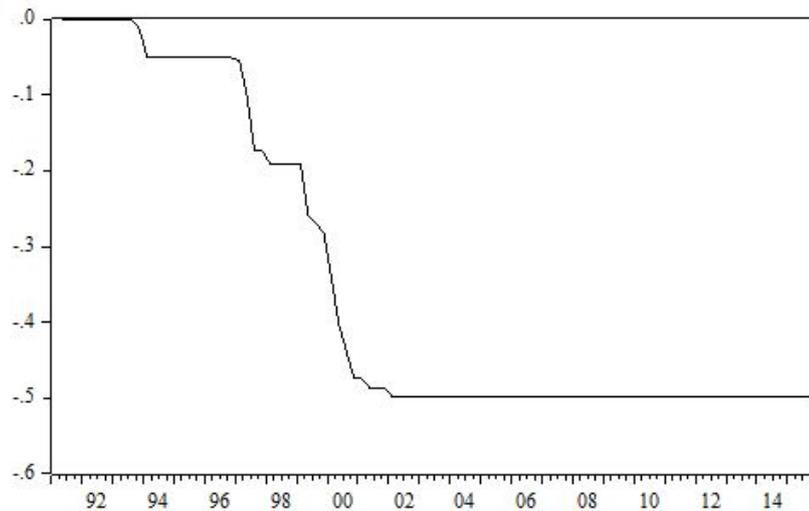
⁶For such examples, see Belke et al. 2013, p. 170.

Figure 8.3: R-squared resulting from one-dimensional grid search over constant play width d , product group $HS88$



Source: Own calculations.

Figure 8.4: *SPURT* variable calculated for the product group $HS87$



Source: Own calculations.

rate variable now reflects the output reactions in the play area. Moreover, the effects of the *SPURT* should both be stronger than those of the exchange rate variable in eq. (8.2) and the benchmark regression (8.1), since the *SPURT* is associated with large output reactions taking place in the spurt area.

The results of conducted residual tests for the regression from eq. (8.2) regarding serial correlation, heteroscedasticity and normal distribution are very similar in deduction in comparison to the results of the residual test conducted for the regression from eq. (8.1): the test hypothesis of no serial correlation must again be rejected, but not the null hypothesis of homoscedasticity. The normal distribution of the residuals could only be declared for several product groups. Moreover, as stated in Belke et al. 2013, the regression model in eq. (8.2) is non-linear in its parameters, since the play width has to be estimated and thus the switching points are not known a-priori. This leads to discontinuities and local maxima in the likelihood function, especially in finite samples. All of these problems make clear that the use of any test statistics is problematic and we should be very careful in making statements about the coefficients regarding their significance and absolute magnitude. However, since there is no better method that we could use for hysteresis testing, we have to be satisfied with this one keeping its shortages in mind.

Table 8.2 summarizes the most important results of the estimated regressions from eqs. (8.1) and (8.2) for all ten product groups. The results make it obvious that only the exports of the product groups *HS87* and *HS90* exhibit hysteresis. As expected, e.g. in the analysis of vehicle exports (*HS87*), the coefficient of the exchange rate in the simple regression model (α_{simple}) is negative and significant. In the regression with the *SPURT* variable, the coefficient of the exchange rate (α_{spurt}) becomes lower in absolute value and insignificant, because the coefficient reflects the weak output reaction, which is represented in the play hysteresis model by the play lines. In contrast to this, the coefficient of the *SPURT* variable (β_{spurt}) is highly significant, negative and much higher in absolute value than α_{simple} , and reflects the slope difference between the spurt and the play lines. The required condition of the negative common influence of the original exchange rate and the *SPURT* variable is also satisfied ($(\alpha + \beta) < 0$). The results of the analysis of the high-tech instrument exports can be interpreted analogously.

As table A.10 shows, the export sector of products from the group *HS39* (plastics) also might exhibit hysteresis if we use the play width associated with the second-highest R-squared to solve the problem of a potential structural break. Even if the common effect of the original exchange rate and the *SPURT* variable

has an expected negative sign ($(\alpha_{spurt} + \beta_{spurt}) < 0$), the statistical insignificance of both coefficients means that we cannot reject the null hypothesis of no hysteresis. However, we are aware of the problems of our estimators regarding the use of statistical tests. Thus, no definite statement can be made for product group *HS39* regarding hysteresis.

Therefore, we now only focus on the interpretation of the estimation results of the exports that exhibit hysteresis, namely product groups *HS87* and *HS90*. For these exports, hysteresis losses become relevant and the hysteresis losses indicator can be calculated as described in section 6.4.

Table 8.2: Summary of the regression results with constant play in different export sectors

	HS product groups				
	27	30	39	72	73
α_{simple}	222.96***	-1216.4***	-124.35***	-14.38	-432.27
α_{spurt}	287.23***	-2023.62***	-181.46***	-96.09***	-461.89***
β_{spurt}	-197.94**	3543.52***	250.70***	358.69***	543.53***
$\beta_{spurt} < \alpha_{simple}$	yes	no	no	no	no
$(\alpha + \beta) < 0$	no	no	no	no	no
$R^2(simple) < R^2(spurt)$	yes	yes	yes	yes	yes
Hysteresis	no	no	no	no	no

	HS product groups				
	84	85	87	88	90
α_{simple}	-1312.61***	-607.68***	-1386.44***	-1432.64***	-92.34**
α_{spurt}	-2066.59***	-813.09***	-930.91	-1580.66***	109.39
β_{spurt}	3309.86***	901.72***	-4592.15***	649.75	-442.90***
$\beta_{spurt} < \alpha_{simple}$	no	no	yes	no	yes
$(\alpha + \beta) < 0$	no	no	yes	yes	yes
$R^2(simple) < R^2(spurt)$	yes	yes	yes	yes	yes
Hysteresis	no	no	yes	no	yes

Note: * denotes significance at 10% level, ** at 5% and *** at 1%.

Source: Author's compilation.

In the following, we need to assess the goodness of fit of our two regression models (see eqs. (8.1) and (8.2)) to judge which of the two regression models is statistically better. Therefore, we use four statistics: R-squared, the overall F-test, the root mean square error (RMSE) and the Theil inequality coefficient. Table A.9 summarizes the test results. We start with the R-squared, which represents a relative measure of fit of the model. Both R-squared and the adjusted R-squared are higher in the regression with the *SPURT* variable in comparison to the simple regression. For *HS87*, the estimated R-squared equals $0.81 > 0.78$ and the adjusted R-squared takes the value of $0.79 > 0.77$. If we consider the product group *HS90*, the R-squared and the adjusted R-squared take the value of $0.98 > 0.97$. This indicates the better fit of the regression that includes the *SPURT* variable. The overall F-test is used to evaluate whether the relationship between the dependent and the explaining variables is statistically reliable. The null hypothesis is that all of the regression coefficients are equal to zero. In both types of regressions and for both product groups, the null hypothesis could be definitely rejected. Consequently, no clear statement can be made regarding the better fit of the regressions. Next, we assess the absolute fit of the regression model to the data, indicated by the RMSE. This statistic represents a criterion for an absolute fit of the model to the data and therefore depends on the scale of the dependent variable. The value of RMSE is lower in the regression with *SPURT* than in the regression without *SPURT* for both product groups. This again indicates the better fit of the *SPURT* regression. Finally, the Theil inequality coefficient is the last investigated indicator of the regression fit. It can vary between 0 and 1, whereas 0 indicates a perfect fit of the regression. The comparison of its values provides another argument that the fit quality of the regression with *SPURT* is better than without.

At the micro level, a modified non-ideal relay model is considered to illustrate hysteresis losses in international trade. The developing procedure and differences between this and the general output-price model are highlighted in chapter 7. Hysteresis losses are now proportional to the area inside the non-ideal relay loop defining the relationship between export values in euro (or exporters revenues) and the exchange rate in indirect quotation ($\$/\text{€}$). Positive exchange rate changes are associated with euro appreciation against the dollar and consequently

with higher export prices denominated in dollar. Developing the microeconomic model of hysteresis losses in international trade, a pricing-to-market (PTM) strategy of firms (in this example, German exporters) was assumed (see section 7.4) to simplify the model to the two-dimensional hysteresis losses approach. As a result, a euro appreciation can be interpreted as a decrease in the profit margins of the exporting firms.

8.1.4 Discussion of the results

The hysteresis hypothesis was tested for German exports to the U.S. for the following *HS* product groups: 27, 30, 39, 72, 73, 84, 85, 87, 88 and 90. The hypothesis could not be rejected only for the product groups 87 (vehicles) and 90 (high-tech instruments). Estimation of different samples and use of different initial situations in the play algorithm have proven the robustness of our results. It begs the question of why these two among all product groups exhibit hysteresis. For one thing, both groups represent heterogeneous goods and thus exhibit relatively low price elasticity, while for another thing the production and the merchandising of these products are associated with very high sunk costs.

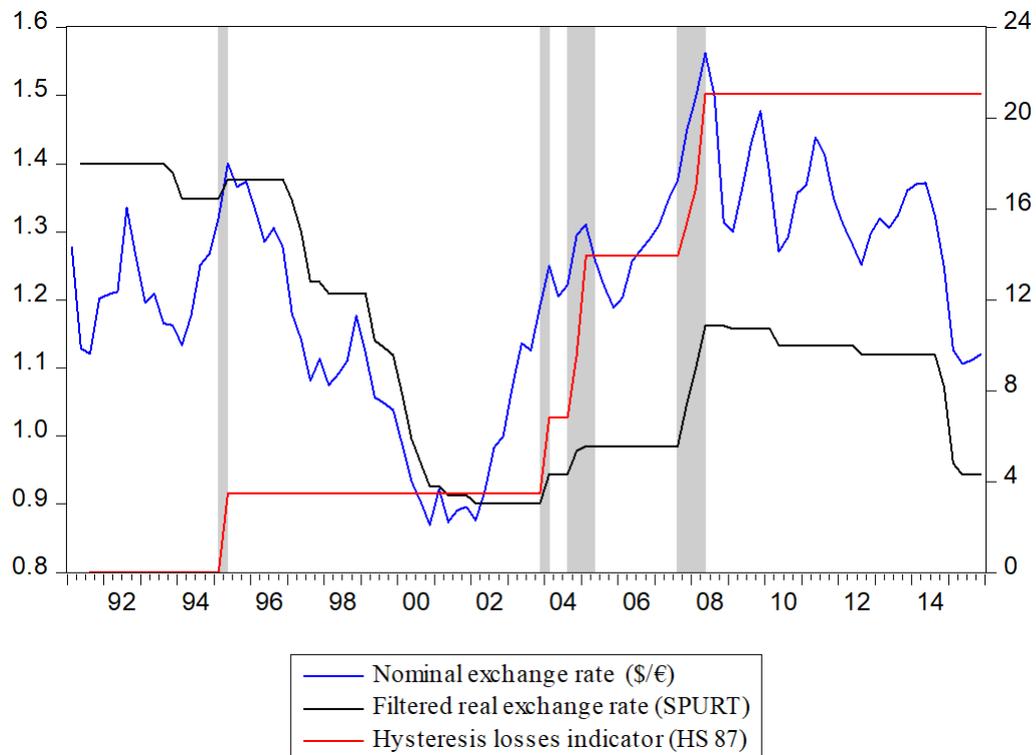
Table A.12 summarizes the results from the OLS regressions for vehicle exports. The first column of the table shows the results from the linear regression without the *SPURT* variable. They meet our expectations: the exchange rate is highly significant and exerts a strongly negative influence on the exports. The influence of the U.S. GDP is positive and significant, albeit relatively moderate. The second column summarizes the results of the regression with the artificial *SPURT* variable and here we have a completely different yet expected and theory-conforming picture: the coefficient of the *SPURT* variable (which is just a filtered RER) is significant, negative and higher in absolute value than the coefficient of the exchange rate variable in the first regression; the coefficient of U.S. GDP is positive again but becomes insignificant; and the RER is no longer significant, since its coefficient represents only the slope of the play lines. Thus, the *SPURT* variable overtakes the explaining power and improves the value of the adjusted R^2 , making the second regression statistically better. Similar effects are found for the German exports of high-tech instruments summarized in table

A.13. Therefore, we conclude that the German export market for vehicles and high-tech instruments exhibits hysteresis and the exporters experience hysteresis losses in case of euro appreciation.

Fig. 8.5 illustrates the main results of the empirical investigation. It captures the development of the nominal $\$/\text{€}$ exchange rate (blue line), the artificial *SPURT* variable (black line) and hysteresis losses indicator (red line) for vehicle exports. During the whole sample, we cumulate the hysteresis losses as described in eq. (6.26). The exchange rate fluctuates during the whole estimation period. However, if we filter out the small fluctuations and consider only strong exchange rate changes leading to strong reactions of the export volume (see development of the *SPURT* variable), the picture becomes less complex. Following the black line in fig. 8.5, we can distinguish four periods: the period of euro depreciation and positive export reactions going from 1996Q1 until 2002Q1; the period of predominantly euro appreciation with heavy hysteresis losses during the time span from 2003Q4 to 2008Q2, the period of fluctuating exchange rate but slightly depreciating euro from 2008Q3 until 2014Q4; and finally, strong euro depreciation lasting from 2014Q4 until the end of the sample. Only the period of euro appreciation is interesting for us, since we focus on negative dynamic losses caused by sunk adjustment costs and taking place due to euro appreciations.

The shady parts of fig. 8.5 capture the four periods of increasing hysteresis losses associated with euro appreciations and strong negative output reactions: 1995Q1 – 1995Q2, 2003Q4 – 2004Q1, 2004Q3 – 2005Q2 and 2007Q3 – 2008Q2. As table 8.3 summarizes, in the time span 1995Q1 – 1995Q2, the exchange rate increased by 6% (0.08 $\$/\text{€}$) and resulted in an increase in the hysteresis losses indicator (*HLI*) by 3.5% of the real export value from 2010Q1. From 2003Q4 to 2004Q1, the euro appreciated by 5% (0.06 $\$/\text{€}$) and this has led to *HLI* increasing by 3.3% of the real export value from 2010Q1. The rise in the exchange rate by 7% (0.09 $\$/\text{€}$) in the 2004Q3–2005Q2 time span resulted in an increase in *HLI* by more than 7%. Finally, during the last shaded period (2007Q3 - 2008Q2) a 13% (0.18 $\$/\text{€}$) increase in the exchange rate generated hysteresis losses to the amount of more than 7.2% of the real export value from 2010Q1, whereas the latter equals 3,407,697,041 €. Thus, the 7.2% corresponds to more than 245 mill. € that were lost in one year. The fact that the euro appreciation by only

Figure 8.5: German vehicle (*HS87*) exports to the U.S.: Hysteresis losses, exchange rate and the *SPURT* variable



Note: The exchange rate and the SPURT variable are depicted on the left-hand side ordinate; hysteresis losses indicator is depicted on the right-hand side ordinate which reflects the percentage of the real export value from the first quarter of 2010.

Source: Own calculations based on the data from OECD (2016) and Eurostat (2016).

0.09 \$/€ can cost approx. 234 Mill. € investments is an incentive to care about the stability of macroeconomic fundamentals. However, it has to be mentioned that the hysteresis losses indicator is not equivalent but only approximately (!) proportional to the real hysteresis losses. Due to simplifying assumptions made by constructing the indicator and due to approximation regarding the aggregated dynamics of the system, we have to be careful in our interpretation. In other words, the hysteresis losses indicator is not interpretable as value. It is more reasonable to compare the hysteresis losses indicator with itself in the context of

exchange rate development and the so called “pain (exit) thresholds”.

Table 8.3: Periods of increasing hysteresis losses caused by euro appreciation

Period	$-\Delta\varepsilon$	ΔHLI	$\Delta\varepsilon_{nominal}$
1995Q1 - 1995Q2	6%	3.5%	1.32 - 1.40 \$/€
2003Q4 - 2004Q1	5%	3.3%	1.19 - 1.25 \$/€
2004Q3 - 2005Q2	7%	7.1%	1.22 - 1.31 \$/€
2007Q3 - 2008Q2	13%	7.2%	1.38 - 1.56 \$/€

Note: $-\Delta\varepsilon$ denotes the negative percentage change in the exchange rate (euro appreciation); ΔHLI reflects increase in hysteresis losses indicator measured in percentage of the real export value from 2010Q1; $\Delta\varepsilon_{nominal}$ denotes the interval of nominal exchange rate changes in given period.

Source: Own calculations.

Thus to generate hysteresis losses, a large euro appreciation is required. This can be a strong appreciation taking place during a relatively short period of time or many smaller appreciations that sum up to a large exchange rate change, e.g. during the periods from 1994Q1 to 2004Q1 and from 2005Q4 to 2008Q2. Fig. 8.5 makes obvious that “pain (exit) thresholds” exist that are typical for certain periods. As illustrated in theoretical part of this manuscript in fig. 6.8, the “pain threshold” (inducing market exit) is not a constant trigger level, but rather is path-dependent, since the play lines are vertically shifted by movements along the spurt lines (Belke et al. 2013). Our empirical results also let us conclude that “pain thresholds” strongly depend on the recent development of the exchange rate. For example, if we consider the first period of increasing hysteresis losses (1995Q1 – 1995Q2) which is associated with the “pain threshold” of 1.32 \$/€, we observe previously volatile exchange rate development without extremely large euro depreciations (the exchange rate was never lower than 1.12 \$/€). Before the second period of increasing hysteresis losses (2003Q4 – 2004Q1) with the “pain threshold” of only 1.22 \$/€ (significantly lower than the first one), we observe a strong euro depreciation of an extent of 62% during the period from 1995Q2 to 2000Q4 when the exchange rate reached its all time lowest value of 0.87 \$/€. This was a huge incentive for many German exporters to enter the

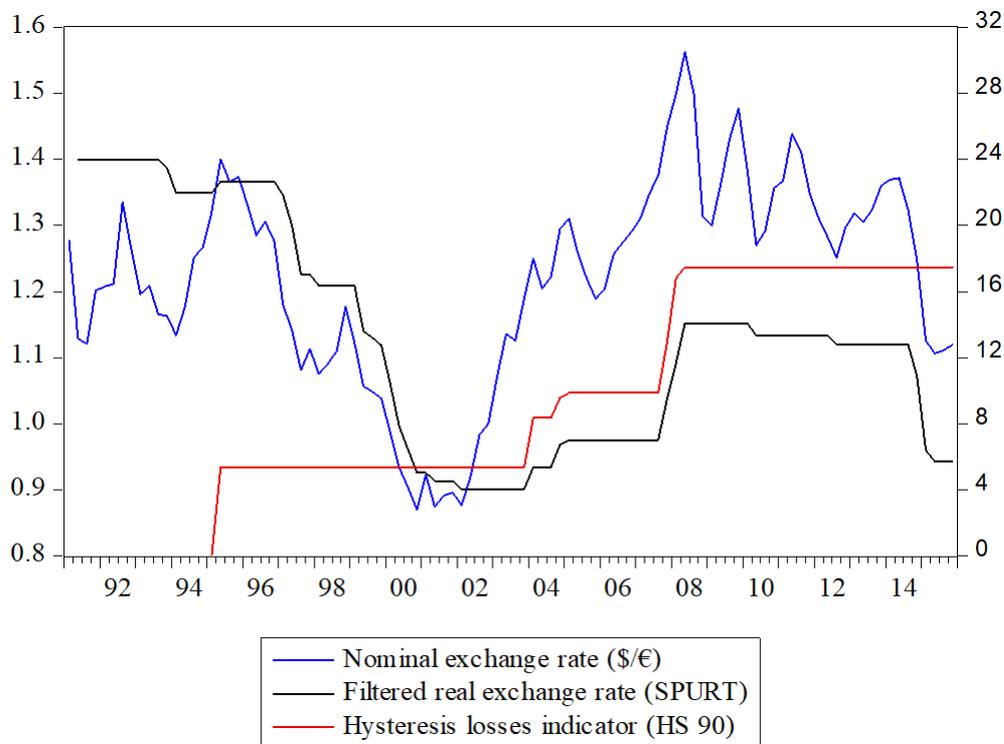
market, even for the unproductive and less competitive ones. These exporters are responsible for the lower pain threshold and high hysteresis losses due to their relatively high sensitivity to the exchange rate changes. If we compare hysteresis losses generated during the periods from 1995Q1 to 1995Q2 (period of relatively strong euro without large depreciations in the recent years) and from 2004Q3 to 2005Q2 (period of relatively weak euro with large depreciations in the recent years), we observe that an increase in hysteresis losses caused by a 1% appreciation of the euro is in the second period by 0.4% higher than in the first period. And finally, if we compare two similar periods of relatively strong euro without large depreciations in the recent years - periods from 1995Q1 to 1995Q2 and from 2007Q3 to 2008Q2 - we can assess a very similar exchange rate effect on hysteresis losses indicator: in both periods an increase in exchange rate (euro appreciation) by 1% accounts for an increase in hysteresis losses indicator by 0.6% of the real export value from 2010Q1.

Fig. 8.5 also illustrates the remanence property of hysteretic system, showing that despite the increasing exchange rate during 2002 – 2003 the export volume does not change: the *SPURT* runs horizontally, meaning that the system moves in the play area (see fig. 6.8). Consequently, the hysteresis losses indicator has the value of 0 and slightly underestimates the dynamic losses of exporters (see fig. 6.7). The further on increasing exchange rate leaves the play area and penetrates the downward-leading spurt in 2003Q4, passing the pain threshold of the least efficient exporters, corresponding to the exchange rate value of about 1.19 \$/€. These exporters probably entered the market during the times of extremely low exchange rates (e.g. during 2000 and 2001) and made misleading forecasts concerning the exchange rate development, or even became relatively unproductive over the years due to e.g. lacking investments in the technology.

Fig. 8.6 captures the development of the nominal \$/€ exchange rate (blue line), the artificial *SPURT* variable (black line) and hysteresis losses indicator (red line) for the exports of high-tech instruments.

Our empirical results prove the theoretical considerations and illustrate the over-proportional dynamic losses in comparison to exchange rate changes and underline how harmful large economic fluctuations are for the economy. Strong depreciations of euro incentivize both productive and unproductive German ex-

Figure 8.6: German high-technology instrument (*HS90*) exports to the U.S.: Hysteresis losses, exchange rate and the *SPURT* variable



Note: The exchange rate and the *SPURT* variable are depicted on the left-hand side ordinate; hysteresis losses indicator is depicted on the right-hand side ordinate which reflects the percentage of the real export value from the first quarter of 2010.

Source: Own calculations based on the data from OECD (2016) and Eurostat (2016).

porters to invest and participate in the export market. The participation of unproductive exporters leads to an inefficient allocation of resources. In addition, such exporters are very sensible to exchange rate fluctuations and are the first that exit the market if the euro appreciates. Consequently, additional resources are wasted in the form of sunk entry and exit costs. The issues of economic policy are discussed in chapter 9.

8.2 Italian wine exports to the United States

This section is based on the following paper: Adamonis and Werner forthcoming.

This section provides another example of an empirical application of the hysteresis losses analyzing a product from a completely different economic area and different country of origin than in the last section. In principle, the empirical and methodological exercises undertaken here are very similar to those in section 8.1. In order to avoid becoming repetitive, in particular places in the text we will refer to the latter section.

8.2.1 Data and motivation

As an agricultural example of an empirical application of the hysteresis indicator, we investigate Italian wine exports to the U.S. The market choice is based on many factors. First of all, we are interested in markets that exhibit hysteresis on the supply side. Agricultural and commodity markets are typically associated with relatively high sunk adjustment costs (in the form of investments and disinvestments) that producers have to face after market entry or expansion, exit or decrease in production intensity and other shocks, such as changing terms-of-trade in case of international trade. Therefore, we expect the suppliers on these markets to behave hysteretic. Being an agricultural good, wine has qualified for our empirical analysis.

Second, the international wine trade has experienced considerable growth in the past two decades, with the exported production of wine reaching 30% of the global production in 2010 (see Mariani et al. 2012). If we consider the competitive performance of wine producers, France and Italy increased the most in terms of value, while Italy and Spain increased the most in terms of volume over the 2000 – 2011 period (see Mariani et al. 2012).

Such an outcome is closely related to the wine export profile of the particular country. If we compare the wine prices of the largest wine exporters over 2014 – 2015, it emerges that Spanish wine is the cheapest (0,38€/l), followed by Chilean (0,68€/l), Australian (0.70€/l) and Italian (0.72€/l) wine. French wine is the

most expensive among the largest exporters and costs 1.75€/l, which is more than twice as expensive as Italian wine (see Mariani et al. 2012). However, the export profiles are changing over the years, as well as wine characteristics. For example, global warming affects some sorts of wine grapes, leading to stronger wine than in the past. This phenomenon is widely discussed among wine producers who even integrate the global warming factor in their strategies (see Couret 2016). Therefore, the underlying dynamics in the wine sector must be taken into account when analyzing the wine market.

According to Eurostat, in 2008 Italy was the largest wine producer worldwide by volume (ca. 46 M hl per year).⁷ Around 40 % of the whole Italian wine production goes abroad, whereby more than half of all exports go to the U.S. (see IWC 2016). Moreover, in 2012 Italy was confirmed as the leading wine supplier in the U.S. (see Gusti d'Italia 2016).

The phenomenon that we are seeking to explain is the participation of Italian wine exporters on the U.S. market. For our estimation, we use three time series: Italian wine exports to the U.S. denoted in current euro and deflated by the export price deflator; real U.S. GDP in mill. euros, converted based on the exchange rates from 2000; and real \$/€ spot exchange rates as monthly averages.

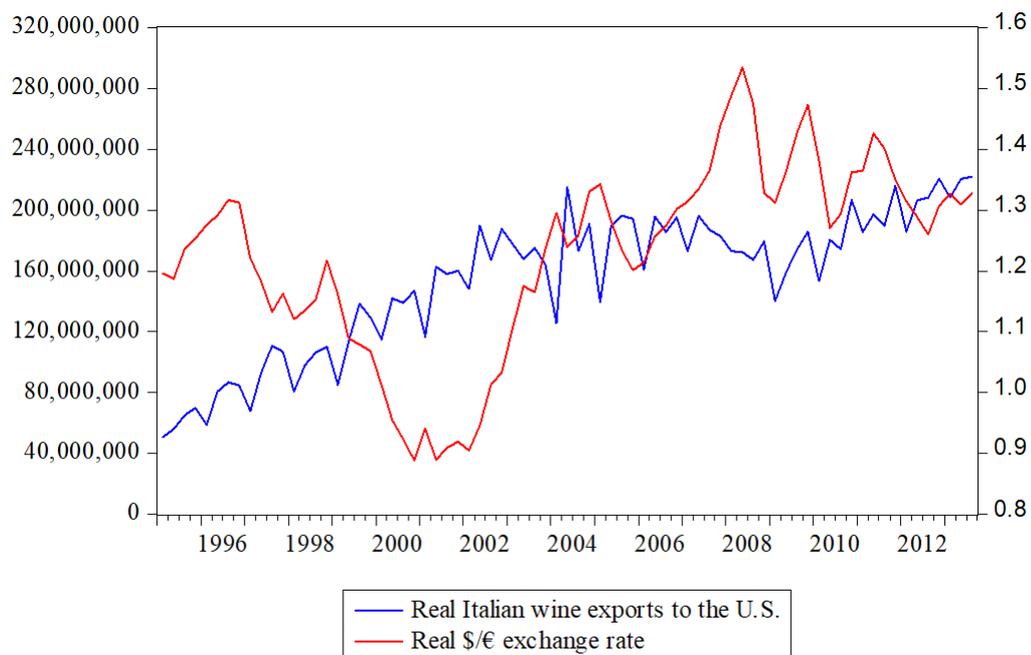
All data is aggregated on a quarterly basis essentially for two reasons: first, the monthly data is not available for all variables and the interpolation of economic data is quite problematic; and second, quarterly data is used due to the lower likeliness of a measuring error. According to Canova and De Nicolo 1995, the likeliness of a measuring error would be much higher if we used monthly data. The first two time series are seasonally and work day adjusted, and taken from the Eurostat database (Eurostat 2015). Exchange rate time series stem from the USDA (2014). Our sample ranges from 1995Q1 to 2013Q3.

Fig. 8.7 provides an overview of the volume and the development in time of Italian wine exports to the U.S. and the real \$/€ exchange rate during the time span 1991 – 2014. If we consider the development of these two time series, we can clearly observe a negative relationship between the exports and the exchange rate until 2002, as the euro strongly and continuously depreciated. In this period, exports were stimulated by the weak euro. However, as the exchange rate

⁷The data for total production of wine is available on Eurostat until 2008 by now.

development changed its direction in 2002 and the euro continuously appreciated until 2005 (returning to the level of 1996), no significant export reaction can be observed. The exports exhibit kind of seasonal fluctuations, although on average they remain at the same level as in 2002 and do not fall back to the level of 1996. Such a remanence of the exports incentivizes us to suggest hysteretic effects on the export supply side. If we further on follow the development of the export series in relation to the exchange rate, we detect negative effects of the financial crisis in 2007 and the following recession. In 2008, the euro reaches its absolute high with respect to the dollar and the exports slightly decline until the world economy starts to recover and the euro depreciates again. As we can see, the variability of the underlying bilateral exchange rate is high, which complicates the trade between Italy and the U.S. and incentivizes applying certain pricing strategies to permanently survive on the foreign market.

Figure 8.7: Italian wine exports to the U.S. vs. real \$/€ exchange rate in the period 1991 – 2014



Note: left-hand-side ordinate: Real Italian wine exports are measured in euro;
right-hand-side ordinate: real \$/€ exchange rate.

Source: Own calculations based on the data from Eurostat 2015 and USDA 2014.

Prior to running an OLS estimation, we first have to test our time series for stationarity. The background for this is explained in section 8.1.1. Table A.14 summarizes the ADF test results, indicating that all of the time series are non-stationary in levels but stationary in first differences and thus are of $I(1)$ processes. Similar to the previous empirical analysis, we do not use the first differences or other transformations of the data and estimate them in levels because we are interested in the long-term effects. Moreover, interpretation of the results of the transformed data would ultimately be very problematic.⁸ We deal with the non-stationarity problem by the specification of the model including a linear trend in the regression.

The U.S. GDP and the Italian wine export time series (representing U.S. Italian wine imports) are cointegrated.

8.2.2 Methods

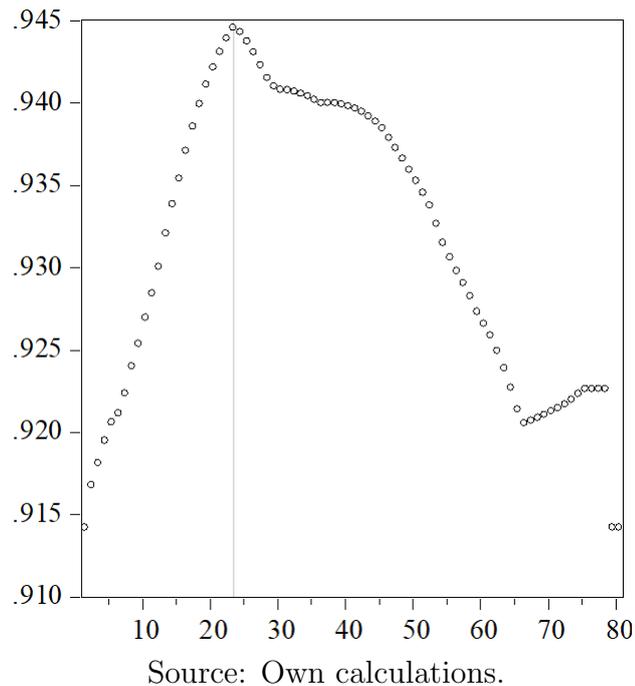
The methods used for the empirical analysis are similar to those presented in section 8.1.3. In order to test the hysteresis hypothesis, we again run two OLS equations as formalized in eqs. (8.1) and (8.2). The regression specification is further on kept simple and includes the following variables: Italian wine export values as the dependent variable (EX_t), the real $\$/\text{€}$ -exchange rate (RER_t) and other explanatory variables, summarized in vector Z_t - U.S. GDP as a measure for the market demand going into regression with one lag (GDP_{t-1}) to avoid reverse causation, a trend variable ($Trend_t$) and seasonal dummies for the first three quarters (Q_1, Q_2, Q_3). From regression in eq. (8.1), we expect the U.S. GDP to have a positive and the exchange rate - a negative impact on the wine export values.

Eq. (8.2) contains an additional *SPURT* variable, which is generated with the help of the play algorithm. The calculation of the most appropriate play width is explained in section 8.1.3. Given the exchange rate development during our sample, the interval for the grid search over constant play in this example is set to $[0; 0.80]$ and divided into 85 subintervals. Fig. 8.8 illustrates the resulting R-squared values as a scatter plot for each play width from the defined interval.

⁸This point represents the problem on which the future research has to tie on.

The graph makes it obvious that the highest R-squared ($R^2 = 0.945$) is reached when the play width (d) equals 0.22. The lowest R-squared ($R^2 = 0.914$) again corresponds to the R-squared of the simple linear regression (see table A.15).

Figure 8.8: R-squared resulting from one-dimensional grid search over constant play width d , Italian wine exports



In order to ascertain whether the Italian wine export market in the U.S. exhibits hysteresis, we again test the null hypothesis ($H_0 : \beta = 0$) against the alternative ($H_1 : \beta \neq 0$). Rejecting the null means that the *SPURT* variable significantly contributes to explaining the export variability. Furthermore, we compare the estimation results of eqs. (8.1) and (8.2) to be certain that eq. (8.2) produces the better fit than eq. (8.1). If the hysteresis hypothesis cannot be rejected, hysteresis losses become relevant. The hysteresis losses indicator is then calculated as described in section 6.4.

In the following the residual tests for both regressions are executed to check whether the residuals possess the characteristics of the white noise leading to stable estimation results. As in previous empirical analysis, here we test the residuals for autocorrelation, heteroscedasticity and normal distribution. In order

to test for autocorrelation of the residuals, the Q-statistic and the LM test are employed.

Tables A.3 and A.4 show the results of the Q-statistics for the first twelve lags of the regressions of Italian wine exports without and with the *SPURT* variable, respectively. The correlogram concerning the simple OLS regression has spikes at lags up to five. The Q-statistics are significant at all lags, indicating that there is a significant autocorrelation in the residuals. The Breusch-Pagan serial correlation LM test also rejects the null hypothesis of no autocorrelation. Thus, both - the Q-statistic and the LM test - indicate that the residuals are autocorrelated. Inclusion of the *SPURT* variable into the regression seems to solve this problem, since the correlogram concerning the regression with *SPURT* does not have spikes at any lags. The Q-statistics are insignificant at all lags, indicating that there is no significant autocorrelation in the residuals. The Breusch-Pagan serial correlation LM test cannot reject the null hypothesis of no autocorrelation, even at any significance levels. Thus, both - the Q-statistic and the LM test - indicate that the residuals are not autocorrelated.

The White heteroscedasticity test is employed to ascertain whether the variance of the residuals is constant over time. The null hypothesis states that the residuals are homoscedastic and therefore it is desirable not to reject the null. Table A.6 summarizes the probability values of the White test of the OLS regressions with and without *SPURT*. The results indicate that the null cannot be rejected even at the 10% significance level. Thus, the residuals of both OLS regressions are homoscedastic. However, the OLS estimators of eq. (8.2) will not be BLUE due to the non-linear nature of the model parameters and finite sample properties. This issue is briefly discussed in section 8.1.3.

Whether the error terms are normally distributed or not is tested employing the Jarque-Bera test. The test results in table A.8 indicate that the residuals are not normally distributed in both OLS regressions. Although the results of the normality test are not perfect, we consider them as satisfactory mostly because our sample is relatively small and therefore any statement regarding the normality is very problematic.

To assess the goodness of fit of our two regression models (see eqs. (8.1) and (8.2)) judge which of the two regression models is statistically better, we use four

statistics: R-squared, the overall F-test, the root mean square error (RMSE) and the Theil inequality coefficient. Table A.11 summarizes the test results. We start with the R-squared: both R-squared and the adjusted R-squared are higher in the regression with the *SPURT* variable in comparison to the simple regression. This indicates the better fit of the *SPURT* regression.

The overall F-test is used to evaluate whether the relationship between the dependent and the explaining variables is statistically reliable. The null hypothesis is that all of the regression coefficients are equal to zero. In both types of regressions, the null hypothesis can definitely be rejected. Consequently, no clear statement can be made regarding the quality of fit of the regressions. Next, we assess the absolute fit of the regression model to the data, indicated by the RMSE. The value of RMSE is lower in the regression with *SPURT* than in the regression without *SPURT*. This again indicates the better fit of the *SPURT* regression. Finally, the Theil inequality coefficient is the last investigated indicator of the regression fit. The comparison of its values provides another argument that the fit quality of the regression including *SPURT* variable is better than that of the simple OLS regression.

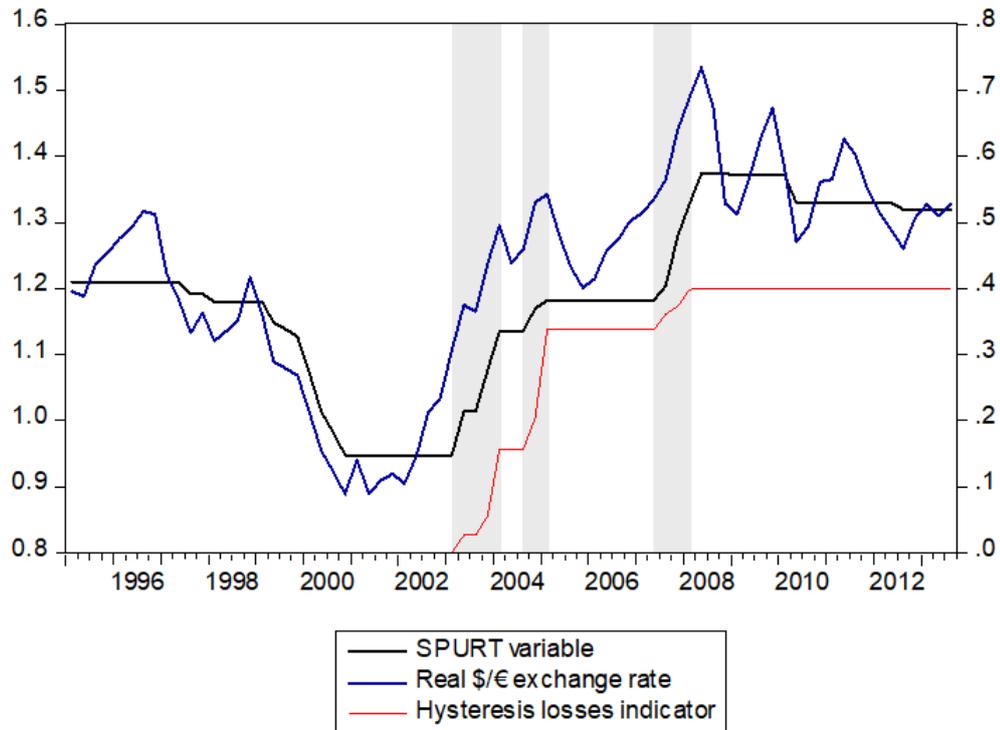
Microeconomic hysteresis losses are proportional to the area inside the non-ideal relay loop defining the relationship between export values in € (or revenues) and the exchange rate in indirect quotation (\$/€). Positive exchange rate changes are associated with euro appreciation against the dollar and consequently higher export prices denominated in dollar. Developing the microeconomic model of hysteresis losses in international trade, a pricing-to-market (PTM) strategy of firms (in this example, Italian wine producers) was assumed (see section 7.4) to simplify the model to the two-dimensional hysteresis. As a result, the increasing exchange rate can be interpreted as the decreasing profit margin of the exporting firms. The use of this assumption is legitimate, since the PTM of Italian exporting firms has been empirically proven in several studies: e.g. Fedoseeva 2014 found PTM in agricultural exports of several European countries including Italy and Verheyen 2013 found exchange rate non-linearities in EMU exports to the U.S. Fertő and Balogh 2016 found PTM in Italian wine exports.

8.2.3 Results

Tab. A.15 summarizes the results from the OLS regressions (see appendix). The first column of the table shows the results from the linear regression without the *SPURT* variable. They meet our expectations: the exchange rate is highly significant and exerts a strongly negative influence on the exports. The influence of the U.S. GDP is positive and significant. The second column summarizes the results of the regression with the *SPURT* variable and here we have a completely different yet expected and theory-conforming picture: the coefficient of the *SPURT* variable (which is just a filtered RER) is significant, negative and higher than the coefficient of the exchange rate variable in the first regression; the coefficient of U.S. GDP is significant and positive again; and the RER is no longer significant, since its coefficient represents only the slope of the play lines. Thus, the *SPURT* variable undertakes the explaining power and improves the value of the adjusted R-squared, making the second regression statistically better. All of this prompts the notion that the Italian wine export market exhibits hysteresis and the wine exporters experience hysteresis losses in case of a positive exchange rate changes. Similar results were found in Werner 2015, in which a different method of describing the path-dependence of the Italian wine exports to the U.S. is used.

According to the annual vineyard surveys of the International Organisation of Vine and Wine (OIV), the vineyards in Italy are shrinking from year to year. In 2003 there were 868 thousand hectares of vineyard whereas in 2009 for example there were just 812 thousand hectares and 705 thousand hectares in 2013. In addition, the number of winegrowers in 2010 was smaller more than by half compared to the year 2000. All of this is associated with market exits of many wine producers and thus lost sunk (dis)investments that are relatively high in wine production. These facts support our results captured by the hysteresis losses indicator. It shows a continuous increase in losses in the time span from 2003Q1 to 2008Q1, captured by the dark grey curve in fig. 8.9. According to the OIV, during 2003-2008, the area under wine-grape vines in production contracted by more than 33,000 ha. The blue line in fig. 8.9 represents the development of the real $\$/\text{€}$ exchange rate, while the hysteresis losses indicator is captured by the red

Figure 8.9: Italian wine exports to the U.S.: Hysteresis losses, exchange rate and the *SPURT* variable



Note: The exchange rate and the SPURT variable are depicted on the left-hand side ordinate; hysteresis losses indicator is depicted on the right-hand side ordinate.

Source: Own calculations based on the data from USDA 2014 and Eurostat 2015.

line. The time series of the artificial SPURT variable is captured by the black line. During the whole sample, we cumulate the hysteresis losses as described in eq. (6.25). This time we want to show another possibility to calculate the hysteresis losses indicator which does not represent a relative measure. In contrast to eq. (6.25), we do not divide the cumulated measure by the selected export value and do not multiply it by 100%. This way of measuring hysteresis losses indicator only allows us to compare the indicator with itself.

The exchange rate fluctuates during the whole estimation period. However, if we consider only strong exchange rate changes leading to some reactions of the export volume, we can distinguish three periods: the period of predominantly neg-

ative exchange rate changes (euro depreciation against dollar) and non-negative export reactions going from 1995Q1 until 2001Q4; the period of predominantly positive exchange rate development (euro appreciation against dollar) with heavy hysteresis losses during the time span from 2003Q1 to 2008Q2; and finally, the period of fluctuating but slightly negative exchange rate changes (depreciation of euro) from 2008Q3 until the end of the sample. Only the period of predominantly positive exchange rate development is interesting for us, since we focus on negative dynamic losses caused by sunk adjustment costs and taking place due to positive exchange rate changes.

The shady parts of fig. 8.9 capture the three periods of increasing hysteresis losses: 2003Q1-2004Q1, 2004Q3-2005Q1 and 2007Q2-2008Q1. An additional aspect captured in fig. 8.9 is that despite the increasing exchange rate during the last quarters of 2002, the export volume barely changes: the *SPURT* runs horizontally, meaning that the system moves in the play area (see fig. 6.8). Consequently, the hysteresis losses indicator has the value of 0 and slightly underestimates the dynamic losses of exporters (see fig. 6.7). The further on increasing exchange rate leaves the play area and penetrates the downward-leading spurt in 2003Q1, passing the pain threshold of the least efficient exporters, corresponding to the exchange rate value of around 1.1 $\$/\text{€}$. These exporters might have entered the market during the times of extremely low exchange rates (e.g. during 2000 and 2002). Until 2004Q1, the exchange rate increased by 0.2 $\$/\text{€}$ and accounted for increased hysteresis losses indicator by 0.15. The second period of hysteresis losses increase starts in 2004Q3 and ends in 2005Q1, leading to the exit of a large number of exporters and thus extremely heavy dynamic losses. A quite moderate exchange rate increase by 0.1 $\$/\text{€}$ (only half as large as the previous shock), this time inducing an over-proportionally large increase in the hysteresis losses indicator by 0.2 (which is one-third larger than the previous increase). The subsequent negative exchange rate changes starting in 2005Q1 lead to a horizontal run of the *SPURT* associated with exchange rate movements within the play area, which can only be crossed in 2007Q2. Since the pain threshold of efficient firms is passed (corresponds to the exchange rate value 1.33 $\$/\text{€}$), further exits take place and additional losses are generated. However, the effect of this exchange rate increase is far from the extent of effects caused by the two previous periods of

exchange rate increase. Summing up, a rising exchange rate corresponds to small hysteresis losses if the exchange rate has not yet reached an extremely high level (e.g. 1.35 \$/€ in our example) at which only the most productive firms (namely, those with high exit threshold values) can survive on the market. Since such a level is reached, only moderate hysteresis losses are generated.

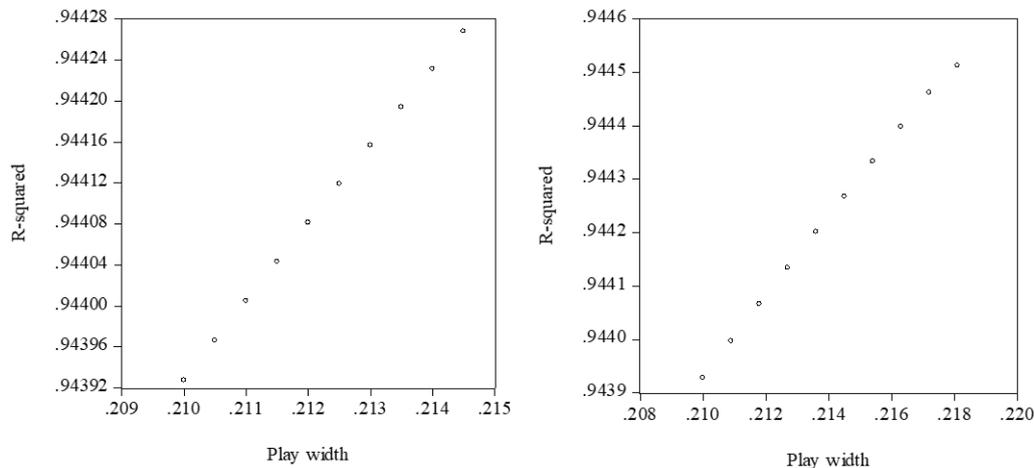
In the context of the sunk costs, it has to be mentioned that Italy and France are strongly affected by vine diseases that lead to yield losses. The dead wine-grape plants must be replaced by the new ones and this leads to lost sunk costs for dead plants, as well as sunk investments into new plants. The costs for a replantation (removal of the dead vine, hole digging, new vine plant, protection, fertilization and 1st year plant care) are between 4.7-5.8€/plant. The costs for re-grafting account for 2.17-2.47€/plant and the curetage additionally costs 2.5€/plant (see Adrian et al. 2016). Diseases are associated with additional sunk costs and higher uncertainty, additive to price or exchange rate uncertainty. One way to improve our regression model would be to generate a new variable capturing the vine diseases to account for this form of uncertainty.

8.2.4 Robustness and sensitivity tests

In order to check for robustness of the results, we used four approaches. First, we changed the specification of the regression and excluded the trend variable. The estimation results can be found in tables A.15 and A.16. The results proved robust.

Second, we tested for sensitivity of the results to small changes in the estimated play width. On the one hand, we allowed the play width to be slightly below the original play width ($d = 0.22$). In case of a smaller play width, the play search intervals are set to $[0.21; 0.215]$ and $[0.21; 0.219]$, and divided in ten sub-intervals. Fig. 8.10 illustrates the procedure of search for the optimal play width. We assume that the optimal play is associated with the highest R-squared. Here, we can see that the closer the play width is to the original one, the higher the R-squared. The upper limit of the first play search interval is 0.215 and the upper limit of the second play search interval is slightly higher, namely, 0.219. Both represent the estimated optimal play widths. The estimation results using

Figure 8.10: R-squared resulting for different play widths using play search intervals $[0.21; 0.215]$ and $[0.21; 0.219]$



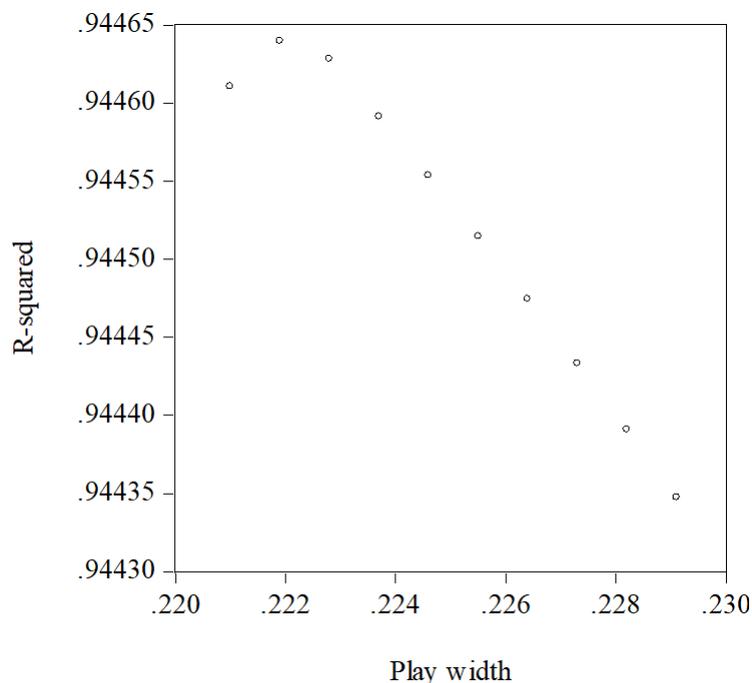
Source: Own calculations.

lower play widths are very similar to the results presented in table A.15, where the original play width ($d = 0.22$) is used. The same applies to the resulting *SPURT* variables, which are also comparable to our original spurt variable.

In case of a larger play width, the play search interval is set to $[0.221 - 0.23]$ and divided in ten sub-intervals. The estimation results are again very similar to our original results presented in table A.15. The same applies for the spurt variable. As fig. 8.11 illustrates, the chosen play width $d = 0.2219$ is associated with a slightly higher R-squared than the play width $d = 0.22$ presented in the paper. The reason for this is that the underlying sub-intervals used for the grid search are larger in the approach presented in the paper. The interval $[0; 0.8]$ was divided into 85 sub-intervals. Nevertheless, the estimation results using these play widths are very close to each other and therefore the use of a more accurate play width does not significantly improve the results. In sum, these tests show that the results are not sensitive to small changes in the play width.

Third, we took some steps to validate the hysteresis identifying procedure and replaced the *SPURT* variable with the white noise to investigate the rejection rate of this random variable. To test whether the play hysteresis testing procedure rejects white noise as non-hysteretic, we ran two Monte Carlo simulations. In a first step, we generated 1,000 white noise processes and put them into the model

Figure 8.11: R-squared resulting for different play widths using play search interval $[0.221 - 0.23]$



Source: Own calculations.

instead of the spurt variable. In the second step, we generated 100,000 white noises and estimated 100,000 regressions. Table 8.4 presents randomly-chosen output of these estimations. We compared the number of such estimation outputs and most of them were very similar. In about 90% of the estimations, the white noise variable was insignificant at the 10% significance level. However, if the underlying significance level is 1%, the white noise proves insignificant in more than 99% of the cases.

The R-squared in the regression with the white noise instead of the *SPURT* variable is never higher than the R-squared in the regression with *SPURT*. As table 8.5 shows, the maximum R-squared of the regression with different white noise processes equals 0.93, which is smaller than the R-squared in the regression with our optimal *SPURT*, being 0.94 (see table A.15). The mean and the median equal 0.91, which is comparable with the baseline simple OLS regression in eq. (8.1).

Table 8.4: Exemplary estimation results using white noise instead of spurt, number of replications is 100,000

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-119000000	45891352	-2.602679	0.0114
RER	-63868240	13420119	-4.759141	0.0000
White noise	949491.1	1463541.	0.648763	0.5187
U.S. GDP(-1)	118.9817	19.05033	6.245653	0.0000
Trend	122828.9	340885.7	0.360323	0.7197
D1	-26189386	4727528.	-5539764	0.0000
D2	-2380283.	4704240.	-0.505987	0.6145
D3	-5657513.	4694994.	-1.205010	0.2324
R-squared	0.914739	Mean dependent var	154000000	
Adj. R-squared	0.905831	S.D. dependent var	46425587	
S.E.	14246622	Log likelihood	-1337.593	
SSR	1.36E+16	F-statistic	102.6885	

Note: the U.S. GDP is measured in mill. € and the wine export series is measured in euro.

Source: Own calculations.

The histograms in fig. 8.12 illustrate the distribution and frequency of the p-values of the white noise variable in the regressions with 1,000 and 100,000 replications. Comparing these results with the test for hysteresis by Hallett and Piscitelli 2002 who compared the Preisach-Piscitelli method and a former version of the Göcke play-method regarding their ability to detect hysteresis, we conclude that in this regard the play algorithm we use represents a decent instrument to identify hysteresis.

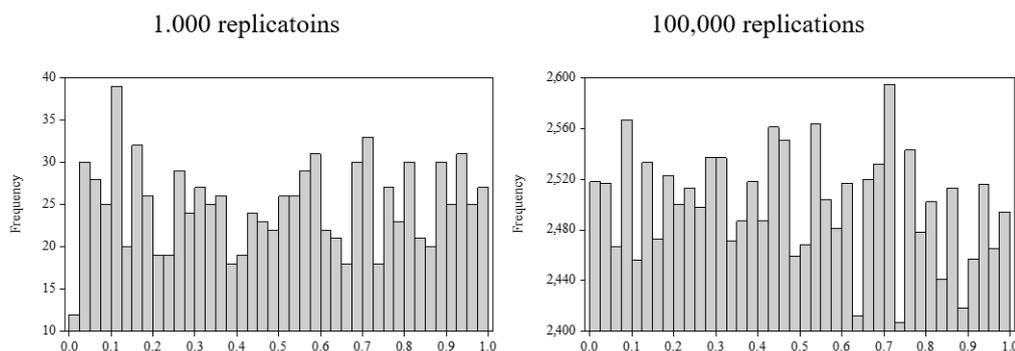
Finally, we addressed the issue of searching for the optimal *SPURT* variable based on the highest R-squared of the regression. As before, we replaced the

Table 8.5: Descriptive statistics of the vector of R-squared values of the regressions with white noise instead of the spurt variable

	Number of observations	
	1,000	100,000
Mean	0.912263	0.912304
Median	0.911705	0.911729
Maximum	0.920060	0.930810
Minimum	0.911230	0.911230
Std. Dev.	0.001345	0.001491

Source: Own calculations.

Figure 8.12: Distribution and frequency of the p-values of the white noise variable in 1,000 and 100,000 replications



Source: Own calculations.

SPURT variable with white noise, and ran 80 replications (as in the search for the optimal *SPURT* based on the highest R-squared). We selected the equations with the highest R-squared out of 80 and checked whether the white noise is significant in those cases. Additionally, we reviewed whether the other criteria associated with hysteresis are satisfied. We repeated this procedure 25 times. The results are summarized in table 8.6. The table is organized as follows: the first column shows the number of the repetition; the second column captures the highest R-squared of all 80 replications; and the third column shows the p-value of the white noise variable, which is a strong criterion to conclude that the market

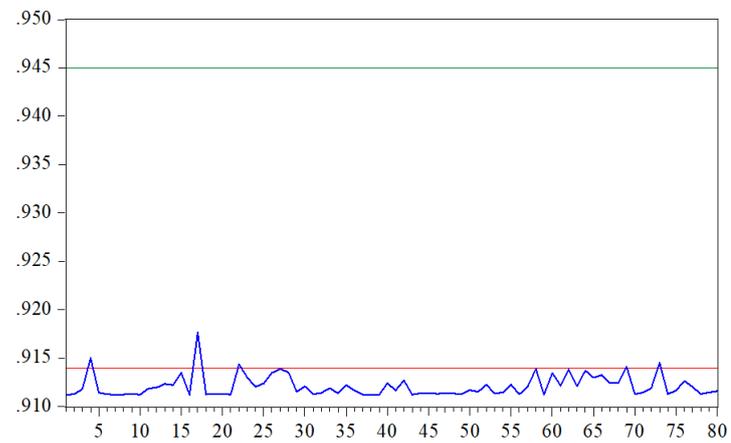
exhibits hysteresis. The fourth column captures one of the additional conditions that should be fulfilled for the existence of hysteresis. It is required that the coefficient of the original exchange rate variable from the simple OLS regression (α_{simple}) is lower in absolute value than the coefficient of the *SPURT* variable (β). The logic behind this is that the slope of the spurt line should be higher than the slope of the play line (see Belke and Göcke 2001 or Belke et al. 2013). In other words, the output should react much more strongly in the spurt than in the play area. Since the appreciation of the euro should be associated with negative effects on the Italian wine exports, both coefficients – the coefficient of the original real exchange rate from the simple OLS regression (α_{simple}) and of the artificial *SPURT* variable (β) – must be negative, especially the *SPURT* coefficient. Therefore, the sign of the coefficient β is reported in column five.

Although in the most cases the white noise variable associated with the highest R-squared of the regression is statistically significant, the other criteria regarding the direction and the magnitude of the influence of the variables are not satisfied. We have highlighted in bold the unsatisfied criteria that induced the rejection of the hysteresis hypothesis. Summarizing the outcomes of this test, we find evidence that our estimation procedure is able to differentiate between the *SPURT* variable and the white noise.

In the most cases, the R-squared that maximized the regression is below 0.92. Although this value is higher than 0.914 (R-squared of the regression without *SPURT* variable or white noise), it is much less than 0.945, which is the value of the regression with the spurt variable. The following fig. 8.13 captures the distributions of R-squared of an exemplary procedure (blue line). The red line highlights the R-squared of the regression without *SPURT* and the green line captures the R-squared of the regression with *SPURT* variable. As can be seen, the R-squared of the regression with *SPURT* is much higher than any R-squared of the regressions with the white noise.

As a result of all of these tests, we can conclude that the hysteresis identification procedure based on the play algorithm is a decent approach.

Figure 8.13: Distribution of the R-squared in the 6th estimation procedure with 80 white noise replications



Source: Own calculations.

Table 8.6: Hysteresis identification procedure using white noise processes instead of using the artificial *SPURT* variable associated with estimated optimal play width

No. of repetition	R-squared	p-value of β	$ \alpha_{simple} < \beta $	$\beta < 0$
1	0.9183	0.0092***	no	no
2	0.9163	0.0278**	no	yes
3	0.9184	0.0086***	no	yes
4	0.9177	0.0131**	no	yes
5	0.9177	0.0129**	no	no
6	0.9149	0.0620*	no	yes
7	0.9196	0.0045***	no	yes
8	0.9209	0.0021***	no	no
9	0.9194	0.0050***	no	no
10	0.9162	0.0304**	no	no
11	0.9185	0.0085***	no	no
12	0.9179	0.0116**	no	no
13	0.9163	0.0294**	no	yes
14	0.9207	0.0025***	no	no
15	0.9168	0.0211**	no	yes
16	0.9157	0.0407**	no	yes
17	0.9189	0.0068***	no	no
18	0.9112	0.9815	no	no
19	0.9164	0.0265**	no	no
20	0.9179	0.0117**	no	no
21	0.9167	0.0232**	no	yes
22	0.9169	0.0200**	no	yes
23	0.9190	0.0062**	no	no
24	0.9163	0.0285**	no	yes
25	0.9194	0.0050***	no	no

Note: α_{simple} denotes the exchange rate coefficient from the simple OLS regression (see eq. 8.1) and β is the coefficient of the white noise variable from the non-linear regression (see eq. 8.2). *, ** and *** denote the significance of the coefficient β at 1%, 2% and 10% level, respectively.

Source: Own calculations.

Chapter 9

Discussion and political implications

9.1 Theoretical reduction of hysteresis losses

The discussion about how the hysteresis losses can be possibly reduced starts with some theoretical considerations about the effects of influencing the two most important hysteresis determinants, namely sunk adjustment costs and uncertainty.

9.1.1 Reduction of sunk adjustment costs

The microeconomic foundation of path-dependent behavior of firms is described in section 3.1 and illustrated in fig. 3.1. In order to focus on the sunk costs, the stochastic nature of prices is also ignored in this section. Thus, the band of inaction of a certain firm j equals the sum of sunk entry and exit costs, which is the hysteresis loss of this firm if a complete entry-exit cycle has been run through, i.e. if the hysteresis loop has been completed. As stated in section 4.3 and illustrated in fig. 4.1, one certain firm j can be geometrically interpreted as a point in the (P_{entry}/P_{exit}) diagram. All of the hysteretic firms are located in the so-called Preisach triangle on the left-hand side from the 45°-line and the distance (both - vertical and horizontal) from this line to the firm point is the hysteresis loss. Fig. 9.1 illustrates how the location of a hysteretic firm changes if the sunk entry and exit costs are reduced by the same extent.

Point A_0 illustrates firm A with its original entry and exit triggers (A_{entry} and A_{exit}) and its hysteresis loss (h_A) at time period $t = 0$ (see the left-hand diagram in fig. 9.1). In $t = 1$, policy-makers take some specific measures to ensure that the analyzed market becomes more flexible in terms of reduced barriers to entry and exit for suppliers. Due to lower sunk entry and exit costs, the entry and exit trigger values of firm A are shifted closer to point c_A , which captures the unit variable costs of this firm. New trigger values result ($A_{1,entry}$ and $A_{1,exit}$), inducing lower hysteresis loss (h_{A1}). From the geometric perspective, the distance from the firm point A to the 45° -line now is smaller, meaning that point A must be reallocated to point A_1 - shifted downwards by the extent of reduction in sunk entry costs (Δk_j) and to the right-hand side by the extent of reduction in sunk exit costs (Δl_j). The right-hand side diagram in fig. 9.1 illustrates the same procedure with three different firms A , B and C to provide a view of how the distribution density of several heterogeneous firms in Preisach diagram changes lowering the sunk entry and exit costs. Such a policy measure leads to a higher concentration of firms closer to the 45° -line than close to the ordinate. If policy-makers could manage to preserve flexible markets with quite low sunk adjustment costs, the distribution density of firms in the Preisach triangle would decrease going from the 45° -line towards the ordinate. This would lead to a narrower hysteresis curve with a smaller area inside it and thus smaller hysteresis losses. In sum, lowering entry and exit costs reduces hysteresis losses directly at both the micro and macro levels.

9.1.2 Reduction of uncertainty

In the following, effects of lower variations on the markets on the extent of hysteresis losses at both the micro and macro levels are identified.

If we think about the augmented non-ideal relay capturing microeconomic hysteresis under uncertainty (see fig. 5.1), we can deduce that riskiness does not affect actual hysteresis losses directly. Although the inclusion of uncertainty into the model leads to a wider band of inaction and thus a larger area inside the hysteresis loop, the extent of hysteresis loss does not change (see dashed area in fig. 5.1 and eq. (5.8)). In this respect, uncertainty plays a role only by interpreting hysteresis losses as part of the area inside the hysteresis loop. The lower the riskiness, the higher the hysteresis loss compared to the area inside the loop. For sake of completeness, it must be stated that microeconomic hysteresis loss only in case of uncertainty is not proportional to the area inside the loop. At the macro level (with and without uncertainty), the proportionality of both is valid again.

At the aggregated level, we observe a different and quite interesting picture. Eq. (5.11) shows that the inclusion of uncertainty lowers hysteresis losses in comparison to the area within the hysteresis loop. Such an outcome is quite comprehensible, since we know that economic agents even being risk-neutral behave cautious (see section 3.4) due to the option value of waiting and maximization of the expected value. Consequently, fewer firms enter and exit the market by equal price changes, inducing “sticky” economic reactions at both the micro and macro level in comparison to the case without uncertainty.¹

Despite this outcome, supporting variations on markets is not what can be recommended for the policy-makers. On the contrary, “sticky” economic reactions mostly due to risk distort optimal allocation of scarce resources. On the one hand, productive firms delay their entry too much and loose opportunities through being inactive. On the other hand, unproductive firms that entered the market in booms or became unproductive over time delay their exit, aiming to avoid experiencing hysteresis losses and hoping for better times. Moreover, high

¹That corresponds to uncertainty-dependent play area, $2u$, in fig. 5.4, resulting from “depopulated” part in the Preisach triangle in fig. 5.2 due to increased “band of inaction” as showed in fig. 5.1

variations on markets leading to non-stable profits make those markets unattractive for investors and potential suppliers. This builds a barrier for exhausting possibilities and creating welfare for both - producers and consumers. In sum, the reduction of uncertainty alone does not help to reduce hysteresis losses. However, combining both - lowering the entry and exit barriers and reducing market risk leads to a “weakening” of path-dependence in terms of narrower hysteresis loops and low dynamic adjustment losses.

9.2 Discussion and conclusions

This manuscript deals with economic hysteresis on the supply side caused by sunk adjustment (e.g. entry and exit) costs. The aim of the theoretical part of the thesis was to model and calculate the dynamic losses in the entire market in case of price fluctuations. As a first step, a hysteretic dynamics of firm-level reactions based on one-period optimization was presented (see chapter 3). Here, the hysteretic behavior of one firm was explained according to the existing literature regarding hysteresis in economics (see Krasnosel’skii and Pokrovskii 1989, Baldwin 1989, Baldwin 1990, Göcke 2002). Since the unit/marginal costs as well as sunk entry and exit (dis)investments are firm specific, for heterogeneous firms individual entry and exit price trigger values result, leading to a “non-ideal relay” reaction pattern to price changes. The distance between these triggers/thresholds constitutes a so-called “band of inaction” (see fig. 3.1) and is proportional to the sum of sunk entry and exit costs. Thus, the area inside the non-ideal relay triggers is proportional to the firm’s dynamic loss during a complete entry-exit cycle (see sections 4.1 and 4.2). Considering that firms are heterogeneous, we applied an adequate aggregation procedure to describe the aggregate supply hysteresis loop of all heterogeneous firms related to price changes (see Amable et al. 1991, Göcke 2002). As an innovation in economics and the first novelty in this manuscript, we showed how the hysteresis loss of the entire market is calculated based on the aggregated hysteresis loop (see section 4.3). If the system passes through the complete hysteresis loop, under certain assumptions the dynamic loss is graphically represented by the geometrical area enclosed by the loop (see e.g. fig. 4.3a). Since this enclosed area is a cubic function of the price variation, hysteresis losses

over-proportionally increase with the size of price fluctuations. However, the size of this area depends on the curvature of the hysteresis loop: the wider the loop, the larger the hysteresis losses. The curvature of the aggregated hysteresis loop is determined by the distribution of firms in the P_{entry}/P_{exit} diagram (see section 3.3). For simplicity reasons, we assume a uniform distribution of firms in the upper-left area in this diagram. However, if most of the hysteretic firms had low sunk entry and exit costs in their cost structure, these firms would be more concentrated close to the 45°-line (which represents non-hysteretic firms). Consequently, in this case of a more flexible market, the aggregated behavior of hysteretic firms would be represented by a more “narrow” shape of the aggregated loop and thus by lower hysteresis losses during a cycle. In an opposite scenario of a very inflexible market where most of the firms experience very high sunk costs for entry and exit, this would result in a distribution of firms with a higher density in the north-west part of the diagram (“far apart” from the 45°line). Consequently, the result would be a wider (more “inflated”) shape of the aggregate hysteresis loop, c.p. resulting in relatively large hysteresis losses resulting from an entry-exit cycle.

In order to allow for the uncertain stochastic nature of the future price level, uncertainty was explicitly included in the model (see chapter 5). Related to the standard theory of hysteresis (in mathematics or physics), the inclusion of economic option effects on the size of hysteresis losses is a second novelty of this manuscript. Including stochastic effects results in “wait-and-see” strategies based on option values (see Pindyck 1988, Pindyck 1991, Dixit 1989, Dixit 1990, Dixit 1992, Dixit 1995, Krugman 1989, Dixit and Pindyck 1994, Belke and Gros 1998, Belke and Göcke 1999, Sarkar 2000, Wong 2007). Since a wait-and-see strategy in a stochastic environment may prevent sunk entry and exit costs from actually being written off, option value effects reduce dynamic hysteresis losses in relation to the area enclosed by the hysteresis loop. This dynamic loss-reducing effect was demonstrated for the microeconomic and macroeconomic level. Especially for small fluctuations in the price level, option value effects result in a kind of “play” (or “backlash”²) type of a sticky reaction of the market to price changes and thus prevent the actual generation of hysteresis losses. Consequently, in

²For an illustration of friction-controlled backlash, see Visintin 1994, p. 15.

a situation with uncertainty, only large price fluctuations will generate severe hysteresis losses.

The model that we presented in chapters 4 and 5 is widely applicable. In the presented version, the only forcing variable is the price, whereas other macroeconomic fundamentals per assumption remain constant over time. However, the model can be modified to analyze different specific markets or focus on other determinants of hysteresis, i.e. taking other economic fundamentals as the forcing variables, e.g. exchange rates or interest rates. For example, in the case of international trade, an appreciation of the home currency may lead to negative profits of exporting firms. A firm that was active on the foreign market leaves these export markets when its exchange rate exit trigger is passed, and will lose the market entry investment it has spent in the past. On labor markets, due to a recession firing staff will be associated with paying sunk firing costs and writing off former hiring expenses (e.g. for training and accumulating firm-specific human capital).

The creation of a hysteresis losses indicator in section 6.4 represents the third novelty of this manuscript. This measure allows us to examine the theoretical findings empirically, which is done in chapter 8. Here, hysteresis losses theory is applied to international trade. As a first example, we calculated the hysteresis losses indicator (*HLI*) for the most important German exports to the U.S. First, we checked the hysteresis hypothesis of the selected markets empirically by running two OLS regressions: one with and the other without the path-dependent component (artificial *SPURT* variable). The existence of hysteresis was proved only for German exports of vehicles and high-tech instruments. This induced us to calculate the indicator for the hysteresis losses for these markets. In case of vehicle exports, the *HLI* increase is measured in the following periods of € appreciation: 1995Q1 – 1995Q2, 2003Q4 – 2004Q1, 2004Q3 – 2005Q2 and 2007Q3 – 2008Q2. To give an example, the third period is associated with a € appreciation against the \$ by 7% (0.09 \$/€) and the proximate *HLI* increment in the amount of 7% of the real export value from 2010Q1, corresponding to approx. 234 mill. €. All of these lost investments are associated with smaller wealth of investors, leading to less intensive investment activity in the next period. At the same time, we talk about closed or scaled-down factories, which are associated with firing staff,

paying sunk firing costs and writing off the hiring expenses (e.g. for training and accumulating firm-specific human capital). At the macroeconomic level, we observe increased unemployment and public spending for social security as well as a decline in tax income.

As a second example, we calculated the hysteresis losses for Italian wine exports to the U.S. In contrast to the first empirical analysis, this one deals with the exports of an agricultural good and considers a different exporting country. The existence of hysteresis on this particular export market made the calculation of the *HLI* relevant. The results show a continuous increase in hysteresis losses in the time span from 2003Q1 to 2008Q2. According to Eurostat, the vineyards in Italy are shrinking from year to year. In addition, the number of winegrowers in 2010 was less than half compared to 2000. All this is associated with lost sunk (dis)investments, which are relatively high in wine production. These facts supported our results captured by the indicator. They illustrate the over-proportional dynamic losses in comparison to exchange rate changes and underline how harmful large economic fluctuations are for the economy.

Our analysis shows that due to the cubic effect of price changes of the relevant economic determinants on the size of the dynamic losses, large economic fluctuations generate disproportionately high adjustment costs. This may be part of the problems related to large economic fluctuations in markets where substantial sunk investments are relevant, with the “crises” of the last decade, with financial market instability and recent oil price fluctuations (where many fracking oil producers in the U.S. have to write off their investments due to low oil prices) being examples. In the context of “large” fluctuations, it should be highlighted that both directions of changes in observed macroeconomic fundamentals are harmful to the economy. Large “positive” shocks, heating up the economy and resulting in an “excessive” market entry may later on – after the positive shock has gone by – end up in a market exit of the firms that have entered during the boom. As a result, many resources are wasted only for sunk adjustment costs (this represents a problem with e.g. a real estate bubble). From an economic policy perspective, in principle there are two ways to reduce hysteresis losses. The first one is to reduce/prevent variations on markets via implementing stabilizing measures. Thus, an active macroeconomic stabilization policy especially combating the oc-

currence and the negative consequences of “large” economic shocks is advisable to avoid the over proportional adjustment losses. Our argumentation shows that smoothening macroeconomic variations strongly reduces the amount of hysteresis losses. Examples of such stabilizing (dynamic loss-avoiding) policies could be: (1) stabilizing exchange rates to avoid extreme de- or re-valuation, e.g. by (stable) fixed exchange rates; (2) avoiding large fluctuations in (un)employment, e.g. by effective short-time compensation schemes (as successfully applied in Germany during the last recession); (3) by financial market regulations, preventing asset bubbles as well as financial crises; or (4) policies reducing price variations on international commodity markets, as e.g. two-price buffer stock schemes (though with a wide ceiling and floor difference).

The second alternative is to preserve flexible markets, i.e. to reduce the sunk costs as barriers for market entry and exit, leading to a “narrow” aggregated hysteresis loop and smaller hysteresis losses. Aray 2015 argues that the reduction of “institutional uncertainty” through information policies on the part of the government (e.g. promoting the exchange of information among firms) would reduce sunk entry costs.

Hysteresis losses should be taken into account because they increase welfare losses in a way that has not previously been considered. Since hysteresis is an empirically-proven phenomenon not only in foreign trade but also in other economic fields like labor markets (e.g. Mota et al. 2012), the hysteresis losses theory and the new indicator have many applications. The latter can also be calculated for a very general case using price as the forcing variable.

Appendices

Appendix A

Tables

Table A.1: ADF test for integration, German exports to the U.S.

Time series	Specification	Levels	First diff.	Order of int.
Real exp.,	Intercept	-2.072	-12.600***	1
HS 27	Intercept & trend	-1.958	-12.621***	1
Real exp.,	Intercept	1.230	-11.161***	1
HS 30	Intercept & trend	-0.680	-11.531***	1
Real exp.,	Intercept	-0.057	-3.319**	1
HS 39	Intercept & trend	-2.917	-3.340*	0
Real exp.,	Intercept	-4.290***	-	0
HS 72	Intercept & trend	-4.391***	-	0
Real exp.,	Intercept	-0.925	-8.408***	1
HS 73	Intercept & trend	-4.237***	-8.361***	0
Real exp.,	Intercept	-0.823	-11.378***	1
HS 84	Intercept & trend	-2.254	-11.327***	1
Real exp.,	Intercept	-0.400	-11.046***	1
HS 85	Intercept & trend	-2.253	-11.038***	1
Real exp.,	Intercept	-0.641	-3.944***	1
HS 87	Intercept & trend	-2.000	-3.949**	1
Real exp.,	Intercept	-1.623	-14.418***	1
HS 88	Intercept & trend	-1.908	-14.359***	1
Real exp.,	Intercept	0.380	-10.130***	1
HS 90	Intercept & trend	-3.241	-10.142***	1
Real exch.	Intercept	-1.737	-8.042***	1
rate	Intercept & trend	-2.316	-8.002***	1
Real U.S.	Intercept	-1.162	-6.722***	1
GDP	Intercept & trend	-1.405	-6.778***	1
Test critical values:		1%	5%	10%
Intercept:		-3.501	-2.892	-2.583
Intercept and trend:		-4.054	-3.456	-3.154

Note: * means the rejection of the null hypothesis at 10% level, ** at 5% and *** at 1%.

Source: Author's compilation.

Table A.2: Correlogram of residuals, German vehicle exports to the U.S. (product group *HS87*), simple OLS regression

Sample: 1995Q1 2015Q4
Included observations: 84

Autocorrelation	Partial Correlation	AC	PAC	Q-Stat	Prob	
		1	0.754	0.754	49.510	0.000
		2	0.586	0.040	79.793	0.000
		3	0.503	0.111	102.32	0.000
		4	0.465	0.102	121.84	0.000
		5	0.303	-0.255	130.22	0.000
		6	0.241	0.112	135.62	0.000
		7	0.214	0.013	139.90	0.000
		8	0.171	-0.047	142.67	0.000
		9	0.066	-0.084	143.09	0.000
		10	-0.025	-0.150	143.16	0.000
		11	0.011	0.214	143.17	0.000
		12	-0.054	-0.222	143.46	0.000

Source: Own calculations.

Table A.3: Correlogram of residuals, Italian wine exports to the U.S., simple OLS regression

Sample: 1995Q1 2013Q3
Included observations: 75

Autocorrelation	Partial Correlation	AC	PAC	Q-Stat	Prob	
		1	0.397	0.397	12.290	0.000
		2	0.321	0.195	20.467	0.000
		3	0.231	0.062	24.731	0.000
		4	0.229	0.095	28.978	0.000
		5	0.266	0.140	34.797	0.000
		6	0.122	-0.083	36.039	0.000
		7	0.044	-0.093	36.200	0.000
		8	0.052	0.015	36.436	0.000
		9	-0.067	-0.144	36.830	0.000
		10	-0.060	-0.055	37.148	0.000
		11	-0.065	0.017	37.526	0.000
		12	-0.153	-0.111	39.662	0.000

Source: Own calculations.

Table A.4: Correlogram of residuals, Italian wine exports to the U.S., OLS regression with *SPURT*

Sample: 1995Q1 2013Q3
Included observations: 75

Autocorrelation	Partial Correlation	AC	PAC	Q-Stat	Prob
		1 0.073	0.073	0.4105	0.522
		2 0.052	0.047	0.6283	0.730
		3 0.020	0.013	0.6613	0.882
		4 0.074	0.070	1.1082	0.893
		5 0.087	0.077	1.7370	0.884
		6 -0.031	-0.050	1.8185	0.936
		7 -0.136	-0.144	3.3977	0.846
		8 0.039	0.056	3.5306	0.897
		9 -0.043	-0.046	3.6901	0.931
		10 0.005	0.008	3.6923	0.960
		11 0.010	0.041	3.7011	0.978
		12 -0.065	-0.054	4.0913	0.982

Source: Own calculations.

Table A.5: White test for heteroscedasticity of the residuals, German exports to the U.S.

	HS product groups				
	27	30	39	72	73
Prob. Chi-square	0.202	0.000	0.331	0.800	0.200
Prob. (F-statistic)	0.190	0.000	0.344	0.815	0.204

	HS product groups				
	84	85	87	88	90
Prob. Chi-square	0.132	0.501	0.169	0.185	0.182
Prob. (F-statistic)	0.132	0.520	0.171	0.189	0.185

Source: Own calculations.

Table A.6: White test for heteroscedasticity of the residuals, Italian wine exports to the U.S.

	Simple OLS regression	Spurt regression
Prob. Chi-square	0.691	0.789
Prob(F-statistic)	0.753	0.868

Source: Own calculations.

Table A.7: Jarque-Bera test for normal distribution of the residuals, German exports to the U.S.

	HS product groups									
	27	30	39	72	73	84	85	87	88	90
Skewness	0.54	0.65	-1.11	-0.86	-0.40	-0.74	-0.19	-0.71	0.53	-0.04
Kurtosis	6.09	4.74	6.93	4.50	3.32	4.56	3.70	4.50	2.73	3.84
J-B	37.43	16.56	71.27	18.16	2.60	16.10	2.23	14.86	4.12	2.48
Prob.	0.000	0.000	0.000	0.000	0.273	0.000	0.328	0.001	0.127	0.290

Source: Own calculations.

Table A.8: Jarque-Bera test for normal distribution of the residuals, Italian wine exports to the U.S.

	Simple OLS regression	Spurt regression
Skewness	0.776	0.730
Kurtosis	4.676	4.861
J-B	16.305	17.478
Prob.	0.0003	0.0002

Source: Own calculations.

Table A.9: Comparison tests for the fit quality of the regressions with and without the SPURT variable, German exports to the U.S. (product groups HS 87 and HS 90)

Statistics	HS 87		HS 90	
	Simple OLS	+SPURT	Simple OLS	+SPURT
R-squared	0.782	0.810	0.972	0.977
Adj. R-squared	0.765	0.793	0.970	0.975
F-statistic	46.114	46.406	452.914	454.465
Prob(F-statistic)	0.000	0.000	0.000	0.000
RMSE	717.492	669.891	65.763	61.202
Theil	0.076	0.071	0.027	0.025

Source: Own calculations.

Table A.10: Comparison of the regression results with constant play associated with the highest and a second-highest R-squared for HS product groups 30, 39, 72, 84, 85 and 88

	HS product groups					
	30 (d=0.57)	30 (d=0.05)	39 (d=0.57)	39 (d=0.30)	72 (d=0.57)	72 (d=0.11)
α_{simple}	-1216.4***	-1216.4***	-124.35***	-124.35***	-14.38	14.38
α_{spurt}	-2023.62***	-4071.2**	-181.46***	-54.52	-96.09***	-365.86***
β_{spurt}	3543.52***	2991.9*	250.70***	146.26	358.69***	409.47***
$\beta_{spurt} < \alpha_{simple}$	yes	no	no	no	no	
$(\alpha + \beta) < 0$	no	yes	no	yes	no	no
$R^2_{(simple)} < R^2_{(spurt)}$	yes	yes	yes	yes	yes	yes
Hysteresis	no	no	no	?	no	no

	HS product groups					
	84 (d=0.57)	84 (d=0.12)	85 (d=0.57)	85 (d=0.03)	88 (d=0.57)	88 (d=0.18)
α_{simple}	-1312.61***	-1312.61***	-607.68***	-607.68***	-1432.64***	-1432.64***
α_{spurt}	-2066.59***	-2644.89***	-813.09***	-1734.16	-1565.80***	-1580.66***
β_{spurt}	3309.86***	1582.57*	901.72***	1154.92	182.04	649.75
$\beta_{spurt} < \alpha_{simple}$	no	no	no	no	no	no
$(\alpha + \beta) < 0$	no	yes	no	yes	yes	yes
$R^2_{(simple)} < R^2_{(spurt)}$	yes	yes	yes	yes	yes	yes
Hysteresis	no	no	no	no	no	no

Note: * denotes significance at 10% level, ** at 5% and *** at 1%. d denotes the estimated play width.

Source: Author's compilation.

Table A.11: Comparison tests for the fit quality of the regressions with and without the SPURT variable, Italian wine exports to the U.S.

Statistics	Simple OLS	+SPURT
R-squared	0.914	0.945
Adj. R-squared	0.907	0.939
F-statistic	120.762	163.129
Prob(F-statistic)	0.000	0.000
RMSE	13.508	10.856
Theil	0.042	0.034

Source: Own calculations.

Table A.12: Linear Regression of German vehicle export values to the U.S. with and without the SPURT variable (product group HS 87)

<i>Dependent variable: German export values</i> (vehicle exports, HS 87)		
	Without SPURT	With SPURT
RER	-3123.221*** (552.547)	-930.906 (834.247)
SPURT	-	-4592.151*** (1368.084)
GDP(-1)	0.0034*** (0.00089)	0.00014 (0.00128)
Trend	-19.464 (15.993)	35.388 (22.197)
d1	-335.586 (236.548)	-319.406 (222.250)
d2	-440.441* (236.602)	-463.028** (222.350)
d3	-497.872** (236.374)	-504.488** (222.044)
Constant	-1386.439 (2510.132)	-2188.403 (2587.223)
Observations	84	84
R-squared	0.782	0.810
Adjusted R-squared	0.765	0.793
S.E. of regression (df=77)	765.719	719.267

Note: the values in parentheses below the coefficients are the standard errors. Following notation is used to denote significance of the coefficients: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

Source: Own calculations with data from Eurostat and OECD.

Table A.13: Linear Regression of German high-tech instruments export values to the U.S. with and without the SPURT variable (product group HS 90)

<i>Dependent variable: German export values</i> (high-tech instrument export, HS 90)		
	Without SPURT	With SPURT
RER	-92.340* (49.079)	109.390 (70.893)
SPURT	-	-442.901*** (119.436)
GDP(-1)	0.000675*** (0.0000792)	0.000347*** (0.000115)
Trend	3.266* (1420.522)	8.792*** (1.988)
d1	-50.330** (21.011)	-48.627* (19.467)
d2	-28.192 (21.016)	-30.497 (19.476)
d3	0.465 (20.995)	-0.252 (19.448)
Constant	-1147.509 (222.957)	-758.467*** (231.633)
Observations	84	84
R-squared	0.972	0.977
Adjusted R-squared	0.970	0.975
S.E. of regression (df=77)	68.01	62.99

Note: the values in parentheses below the coefficients are the standard errors.

Following notation is used in order to denote significance of the coefficients:

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

Source: Own calculations with data from Eurostat and OECD.

Table A.14: ADF test for integration, Italian wine exports to the U.S.

Time series	Model specification	Levels	First diff.	Order of int.
Real wine exp.	Intercept	-0.863	-12.238***	1
	Intercept and trend	-1.219	-12.172***	1
Real exch. rate	Intercept	-1.818	-6.368***	1
	Intercept and trend	-2.385	-6.342***	1
Real U.S. GDP	Intercept	-1.451	-5.503***	1
	Intercept and trend	-1.530	-5.610***	1

Test critical values:	1%	5%	10%
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Intercept:	-3.520	-2.901	-2.588
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Intercept and trend:	-4.085	-3.471	-3.162
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Note: * means the rejection of the null hypothesis at 10% level, ** at 5% and *** at 1%.

Source: Author's compilation.

Table A.15: Linear Regression of Italian wine export values to the U.S. with and without the SPURT variable

<i>Dependent variable: Italian Wine Export Values</i>		
	Without SPURT	With SPURT
RER	-66,031,297.00*** (12,943,883.00)	29,668,428.00 (18,954,038.00)
SPURT	-	-153,654,978.00*** (25,356,805.00)
GDP	118.11*** (18.92)	51.98*** (18.81)
Trend	145,930.40 (337,574.10)	1,382,115.00*** (341,067.70)
d1	-26,585,933.00*** (4,667,843.00)	-25,577,587.00*** (3,783,203.00)
d2	-2,557,228.00 (4,676,287.00)	-1,568,521.00 (3,789,893.00)
d3	-5,555,623.00 (4,672,343.00)	-5,199,324.00 (3,783,643.00)
Constant	-112,000,000.00** (44,255,942.00)	-150,000,000.00*** (36,369,913.00)
Observations	75	75
R-squared	0.914	0.945
Adjusted R-squared	0.907	0.939
S.E. of regression (df=68)	14,185,828.00	11,486,233.00
F-Statistic (df=6;68)	120.76	163.13

Note: the values in parentheses below the coefficients are the standard errors.

Following notation is used in order to denote significance of the coefficients:

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

Source: Own calculations with data from Eurostat and USDA (2014).

Table A.16: Linear Regression of Italian wine export values to the U.S. with and without the SPURT variable (robustness check 1: exclusion of trend variable)

<i>Dependent variable: Italian Wine Export Values</i>		
	Without SPURT	With SPURT
RER	-63,949,290.00*** (11,943,498.00)	38,914,707.00 (25,258,054.00)
SPURT	-	-133,000,000.00*** (29,650,400.00)
GDP	125.99*** (5.05)	128.96*** (4.52)
d1	-26,548,160.00*** (4,639,444.00)	-25,133,758.00*** (4,117,800.00)
d2	-2,438,593.00 (4,640,639.00)	-428,342.6 (4,131,156.00)
d3	-5,469,813.00 (4,640,538.00)	-4,321,421.00 (4,114,647.00)
Constant	-130,000,000.00*** (15,377,365.00)	-313,000,000.00*** (42,957,056.00)
Observations	75	75
R-squared	0.914	0.934
Adjusted R-squared	0.908	0.928
S.E. of regression (df=68)	14,101,995.00	12,479,634.00
F-Statistic (df=6;68)	146.60	159.35

Note * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Source: Own calculations with data from Eurostat and USDA (2014).

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Erklärung gemäß § 10 (7) der Promotionsordnung

„Ich erkläre hiermit, dass ich die vorgelegte Dissertation selbstständig und nur mit den Hilfen angefertigt, die ich in der Dissertation angegeben habe. In der Zusammenarbeit mit den angeführten Koautoren war ich mindestens anteilig beteiligt. Bei den von mir durchgeführten und in der Dissertation erwähnten Untersuchungen habe ich die Grundsätze guter wissenschaftlicher Praxis, wie sie in der Satzung der Justus-Liebig-Universität Gießen zur Sicherung guter wissenschaftlicher Praxis niedergelegt sind, eingehalten.“

Ort, Datum

Unterschrift