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The economic consequences of capacity limitations on the Oresund connection

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Preface

The report is divided into a summary chapter (Chapter 1) and seven technical chapters (chapters 2-8) exploring and analysing various economic relationships presented and summarised in the summary chapter. The summary chapter is recommended reading for everybody, while the remaining chapters primarily are for readers interested in technical aspects and detail.

The report has been prepared by a team consisting of Dr. Claus Kastberg Nielsen (project leader); Mr. Torben Thorø Pedersen, Ms. Grith Skovgaard Ølykke, Mr. Eske Stig Hansen, and Mr. Marcin Winiarczyk. Dr. Henrik Ballebye Olesen and Mr. Christian Jervelund have provided quality assurance.

Copenhagen, 11 December 2006
Claus Kastberg Nielsen, PhD
Managing Director

Summary

Svenska Kraftnät regularly resorts to limiting export capacity on the Oresund-connection in order to solve internal bottleneck problems in the Swedish electricity network. In theory, the practice of limiting transmission capacity on the Oresund-connection may cause economic losses to Danish consumers due to higher spot prices and price volatility; and may benefit Swedish consumers due to lower spot prices and lower costs of network management.

On the basis of these insights, Energinet.dk, the Danish system operator (www.energinet.dk), has asked Copenhagen Economics to verify empirically whether these claims are correct and, if affirmative, to estimate the size of the losses to Danish consumers and the gains to Swedish consumers caused by the behaviour of Swedish Kraftnät.

Overall, we confirm that Svenska Kraftnäts policy of limiting transmission capacity on the Oresund-connection has lead to large-scale losses for Danish consumers and to significant gains for Swedish consumers.

We show that Danish consumers experience large-scale economic losses arising from higher spot prices estimated to be at least 725 million DKK. Prices increase in eastern Denmark because capacity limitations very often lead to congestion such that the marginal power plant must be found among high cost thermal power plants (in East Denmark) instead of low cost hydro or nuclear power plants (in Sweden). This figure in reality underestimates the true economic costs as the costs of price volatility have not been quantified.

We also show that Swedish consumers experience economic gains due to lower costs of network management: By using capacity limitations Svenska Kraftnät can minimize the use of counter trade; the costs of which would be passed-on to Swedish consumers. We estimate the gain (avoided costs) passed-on to Swedish consumers to be 215-265 million DKK.

We do not consider the alternative to counter trade, market splitting, where Sweden becomes divided in two price areas, as this would violate the political principle in Sweden of uniform electricity pricing throughout the country. In contrast, counter trade is clearly consistent with uniform electricity pricing. However, it is generally recognised that - in economic terms - market splitting is superior to counter trade.

Chapter 1 The economic consequences of capacity limitations on the Oresund-connection

Svenska Kraftnät regularly experiences internal bottlenecks in the Swedish transmission network in hours where demand in southern Sweden is high and where this demand must be partly satisfied by power plants located in northern Sweden. In these situations, transmission capacity at certain locations in Sweden is insufficient and Svenska Kraftnät typically resorts to limiting export out of Sweden in order to limit demand on the excess demand side of the bottlenecks. In practice, this is done by artificially limiting transmission capacity – among others - on the Oresund-connection.

On the basis of these insights, Energinet.dk, the Danish system operator (www.energinet.dk), has asked Copenhagen Economics to verify empirically whether these claims are correct and, if affirmative, to estimate the size of the losses to Danish consumers and the gains to Swedish consumers caused by the behaviour of Swedish Kraftnät.

Overall, we confirm that the Svenska Kraftnäts policy of limiting transmission capacity on the Oresund-connection has lead to large-scale losses for Danish consumers and to significant gains for Swedish consumers.[1]

We show that Danish consumers experience large-scale economic losses arising from higher spot prices estimated to be at least 725 million DKK. Prices increase in east Denmark because capacity limitations very often lead to congestion such that the marginal power plant must be found among high cost thermal power plants (in east Denmark) instead of low cost hydro or nuclear power plants (in Sweden). This figure in reality underestimates the true economic costs as the costs of price volatility have not been quantified.

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[1] We assume throughout the paper that Svenska Kraftnät has (latent) dominance on the market for transmission of electricity from Sweden to Denmark on the Oresund-connection cf. Chapter 2.

1.1. Capacity limitation and congestion

We have examined capacity limitation and congestion on the Oresund-connection on hourly data for the period 1 October 2001 - 28 June 2006, in total 50,328 observations. In this period, transmission capacity in the direction *to Denmark* has been limited in 8,262 hours (16.5 percent) giving rise to congestion on the Oresund-connection in 2,808 hours (5.6 percent).[2] The average hourly capacity limitation is about 725 MWh meaning that in each hour where capacity is limited, available capacity for the market is cut by about half.

The frequency of capacity limitations and congestion shrank from 2001 to 2004 as correctly noticed by the Swedish Statens Energimyndighet (STEM)[3], but there has been a significant surge in the occurrence of capacity limitations and congestions after 2004. Even though the period after 2004 only holds about 43 percent of all hours studied, 63 percent of all capacity limitations and 68 percent of all congestions arise in this period.[4]

Both Energinet.dk and Svenska Kraftnät have requested capacity limitations on the Oresund connection, but Svenska Kraftnät has been by far the most active. Since 2004, 90 percent of all actual capacity limitations have been requested by Svenska Kraftnät, only 1 percent by Energinet.dk. The remaining 9 percent are due to joint causes.[5] By far the most common motivation for Svenska Kraftnät requesting capacity limitation on the Oresund-connection has been internal bottlenecks in the Swedish transmission network, in total more than 85 percent of all hours with capacity limitations.

STEM argues that using capacity limitations as a tool to resolve internal bottlenecks has been used frequently by all national system operators, even to a much larger degree than Svenska Kraftnät. STEM illustrates their argument by referring to Eltra, one of the predecessors of Energinet.dk, who has used capacity limitations on the Konti-Skan-connection between Sweden and Jutland in more than 9,000 hours in the period 2003-4, almost one third of all hours.

However, this is a misleading argument for two reasons. *First*, the number of capacity limitations requested by Eltra has declined dramatically since 2004 due to the construction of additional capacity in the west Danish network. Second, by far most capacity limitations on Konti-Skan - above 85 percent - have been requested by *Danish* Eltra in the direction to Denmark leading to self-inflicted higher costs in *Denmark, not* to additional costs in Sweden. The core of the Oresund-case is instead capacity limitations requested by *Swedish* Svenska Kraftnät imposing higher costs on *Danish* consumers; cf. *Chapter 6.*

1.2. The Swedish-Danish electricity market in the absence of capacity limitations

The economic consequences of capacity limitations depend on what will happen on the Swedish and east Danish electricity markets if Svenska Kraftnät ceases to use capacity limitations on the Oresund connection to solve internal Swedish bottleneck problems. Accordingly, we have to predict how the market outcome would have been in all hours with capacity limitation (8,252 hours). We distinguish between two sets of hours: Those hours where capacity limitations did not lead to congestion, and those hours where capacity limitations did lead to congestion.

[2] We limit ourselves to studying hours where the overall flow of power goes from the Nordic countries to the Continent. This is about 26,000 hours or about 52 percent of all hours.

[3] Statens Energimyndighet *"Hantering av begränsningar i det svenska överföringssystemet för el - Ett nordiskt perspektiv"*, ER 2005:11

[4] We count 21,840 hours after 1 January 2004, 5,210 hours with capacity limitations and 1,926 hours with congestion.

[5] There is no data on who requested capacity limitations before 2004.

First, consider hours with capacity limitation but without congestion (6,454 hours). We will ignore these hours. When capacity limitations are lifted and transmission capacity boosted, it is even more unlikely that congestion will arise in those hours. We expect prices to be unaltered.

Second, turn to hours with capacity limitation and congestion (2,808 hours). In those hours there are again two possible outcomes. Either there will still be congestion even though all transmission capacity is available for the market and prices will still be determined independently in separate east Danish and Swedish price areas. Or there will be no congestion leading to a joint Swedish-east Danish price area with a uniform price.

It is unlikely that the former case will arise very frequently. Total transmission capacity on the Oresund-connection is very high compared to the size of the two markets and – in the past – congestion has only arisen in less than 4 percent of all hours with full available capacity. We have estimated the number of capacity limited and congested hours that were still likely to be congested in the absence of capacity limitations, and consistently reach numbers in the neighbourhood of 2-4 percent (corresponding to 50-100 hours). In these hours, prices in east Denmark would still be determined by local demand and supply conditions with a slight tendency for lower prices due to the higher availability of imports. In Sweden, prices would also still be determined by local market conditions with a slight tendency for higher prices due to the larger export. Due to the limited number of hours and limited impact, we ignore these hours in what follows; cf. Chapter 5.

It is likely that the latter case will arise frequently. In most hours with limited transmission capacity, congestion would never occur in the absence of capacity limitation. In these hours, a common price area covering at least east Denmark and Sweden would have been formed and the common market price would have been determined by demand and supply conditions in the entire area. The common market price would be determined by the marginal costs of the marginal power plant. How much prices would change in east Denmark and Sweden depends on whether the (technology of) the 'new' marginal plant would have been different from (technology of) the 'old' marginal plant in either east Denmark or Sweden.

In most cases, the 'old' marginal plant in east Denmark was a high cost thermal power plant. Given that we are studying hours where hydro power is abundant and cheap, we will expect that the likelihood of the 'new' marginal plant being a hydro plant is significant. For this reason, we expect prices in east Denmark would have dropped significantly in the absence of capacity limitations.

In most cases, the 'old' marginal plant in Sweden was a low cost hydro power plant. Again, given that we are studying hours where hydro power was abundant and cheap we expect that the likelihood of the 'new' marginal plant being a hydro plant is significant. For this reason, we will expect that prices in Sweden would remain more or less at the same level in the absence of capacity limitations.

1.3. Danish and Swedish prices in the absence of capacity limitations

We have set up a large number of econometric models to estimate the price in east Denmark and in Sweden contingent on the presence of congestion (caused by capacity limitations requested by Svenska Kraftnät due to internal bottlenecks) and a large number of other explanatory variables. In each of these models, we can isolate the effect of congestion and simulate what the price would have been in the absence of congestion, the so-called but-for price. On this basis, we can calculate the expected change in prices in eastern Denmark and Sweden.

We conclude that prices in Denmark are likely to drop significantly in the absence of congestion. All econometric models consistently reach the conclusion that the impact of congestion is strongly significant and with considerable, albeit varying, economic importance. Our preferred interpretation is that if Svenska Kraftnät decided to stop using capacity limitations, prices in east Denmark would drop by at least 70 percent; cf. Chapter 3.

We also conclude that prices in Sweden are unlikely to change significantly in the absence of congestion (caused by capacity limitations). All econometric models consistently reach the strong conclusion that the impact of congestion on the Swedish price level is either insignificant or border-line significant with limited economic importance. It means that if Svenska Kraftnät decided to stop using capacity limitations, prices in Sweden would roughly stay at the same level; cf. Chapter 3.

Finally, we conclude that the actions of Svenska Kraftnät have increased the volatility of east Danish prices. We estimate econometrically that the (within-day) price volatility since 2004 has been 150 percent larger in congested hours compared to non-congested hours. It means that if we are 90 percent certain that in any given non-congested hour, the spot price will be within a range of 10 DKK/MWh. In congested hours the same statement only holds within a range of 25 DKK/MWh. Price volatility is increased because the price in eastern Denmark in congested hours is determined by a more limited range of power plants with widely different marginal costs of production; cf. Chapter 4.

1.4. Winners and losers

The welfare of consumers in both Eastern Denmark and Sweden are affected by the actions of Svenska Kraftnät. The impact on consumers has a direct and an indirect channel. The direct channel works through changes in consumer prices. Whenever consumer prices change, consumer welfare changes as well. The indirect channel works through changes in the overall costs of the two system operators. When these costs change, consumer welfare may or may not change depending on whether and how system operators channel the cost changes on to the market.

Losers in Eastern Denmark

The higher price level and price volatility increase energy costs to Danish consumers. Energy costs increase directly and proportionally with increased prices. Energy costs also rise because increased volatility makes it more difficult to predict electricity prices pushing up the costs of insuring against price uncertainty.

Since 2000, we estimate the overall *direct* economic loss for Danish consumers arising from the higher price level to be at least 800 million DKK. This figure understates the true economic loss to Danish consumers since it does not include the costs of increased volatility; cf. Chapter 7.

However, whenever capacity limitations give rise to bottlenecks, the Danish system operator receives an additional income from bottleneck tariffs. This additional income is paid back to the distribution companies through lower transmission tariffs. As the transmission tariff is a variable cost in Denmark, it is very likely that these cost savings are passed-on fully to Danish consumers, even in the short run.

Since 2000, we estimate the overall *indirect* gain for Danish consumers arising from lower transmission tariffs to be app. 75 million DKK.

Accordingly, we estimate conservatively the overall total losses for Danish consumers to be at least 725 million DKK over the period end 2001 - mid 2006.

Winners in Sweden
The unaltered energy price in Sweden implies that there is no direct gain to Swedish consumers of capacity limitations on the Oresund-connection. Indeed, the costs of Swedish consumers are not likely to change *directly*.

However, there might be indirect consequences, for two reasons.

First, using capacity limitations to solve internal Swedish bottlenecks imply significant cost savings for Svenska Kraftnät. The internal bottlenecks in the Swedish network are physical and must be eliminated in some manner to assure the integrity of the network. If not by capacity limitations on the Oresund-connection then by other means, for example counter trade.

Counter trade implies that Svenska Kraftnät intervenes in the market on both sides of the bottleneck after the spot market has closed. Svenska Kraftnät pays producers north of the bottleneck to abstain from producing even though their capacity *has* been called by the market. South of the bottleneck, Svenska Kraftnät pays producers to increase their production even though their capacity *has not* been called by the market. These payments are the costs of counter trade and they would have to be covered by Svenska Kraftnät. By not using counter trade, Svenska Kraftnät can save the costs of counter trade and lower the overall costs of network management.

Since 2000, we estimate that Svenska Kraftnät has saved network management costs corresponding to 350-450 million DKK since 2000 assuming that the alternative to the current Swedish policy would be to completely eliminate using capacity limitations on the Oresund-connection to solve internal Swedish bottlenecks. For this reason, Svenska Kraftnät has a clear economic motive to abstain from counter trade and resort to capacity limitations on the Oresund-connection at the expense of Danish consumers.

Second, using capacity limitations implies regular occurrences of bottlenecks giving rise to additional income to Svenska Kraftnät through a share of the bottleneck tax. Since 2000, we estimate the overall *indirect* gain for Svenska Kraftnät arising from bottleneck tax generated on the Oresund-connection to be app. 75 million DKK.

The key question is to which degree the cost savings from not using counter trade and from bottleneck taxes are passed-on to Swedish consumers via lower transmission tariffs paid by distributors and producers of electricity. We don't know whether Svenska Kraftnät actually has lowered transmission tariffs in the period in question, but we assume that this is what they have done *krone-for-krone*.

However, Swedish transmission tariffs are structured in a way that is much less favourable to pass-on than in Denmark. The tariff has two parts: effect and energy. The effect part is a subscription-like tariff that does not change with production. For pricing decisions it is to be considered as a fixed cost that is unlikely to be passed-on to consumers in the short term we are considering. In contrast, the energy part is a variable tariff that is more readily passed-on to Swedish consumers, even in the short run.

We assume that both parts of the tariffs are reduced proportionally. As each of the two parts of the tariff account for 50 percent of the transmission tariffs, we estimate that Swedish consumers since 2000 may have saved 215-265 million DKK from the practice of Svenska Kraftnät.

Chapter 2 The relevant market for electricity transmission between Sweden and east Denmark

During the past years, Energinet.dk has experienced that Svenska Kraftnät increasingly has chosen to limit transmission capacity in westbound direction – from southern Sweden to east Denmark – on the Oresund-connection. In most cases, the cause of the capacity limitations is forecasts of congestion in the internal Swedish transmission network – more precisely in 'Cut 4'.

Energinet.dk is concerned that Svenska Kraftnät through this practice is abusing a dominant position to ensure low electricity prices for Swedish consumers[6] at an economic cost for Danish consumers. Phrased in different terms, Energinet.dk perceives the capacity limitations as a way of redirecting costs of the insufficient internal Swedish transmission network from Swedish to Danish consumers.[7]

The relevant market must be delineated to establish the dominant position of Svenska Kraftnät and classify the capacity limitations as abuse.

Firstly, we conclude that the Oresund-connection is a (set of) relevant market(s) separate from the Swedish and east Danish national transmission network. The reason is that transmission of electricity between Sweden and east Denmark cannot be substituted for transmission within Sweden, alternatively within east Denmark.

Secondly, we conclude that there are separate relevant markets for transmission of electricity in the 'direction' from east Denmark to Sweden and vice versa. The reason is that transmission of electricity in the direction to east Denmark cannot substitute for the transmission of electricity in the opposite direction from east Denmark to Sweden. On the contrary, they are complements as increased flow of electricity in one direction allows for higher flows in the other direction.

Thirdly, despite the fact that the Oresund-connection is jointly owned by Energinet.dk and Svenska Kraftnät, the decision structure is such that one owner alone can determine the maximum allowable transmission capacity in that specific direction without interference from the other owner (if e.g. the one owner has an economic motive to limit capacity in a specific direction). For this reason, each of the owners has a *latent* dominant position on the relevant market that can be turned into a real dominant position if the right economic incentives are in place.

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6 Statens Energimyndighet "*Hantering av begränsningar i det svenska överföringssystemet för el - Ett nordiskt perspektiv*", ER 2005:11, p.108.

7 This is opposed in Statens Energimyndighet "*Hantering av begränsningar i det svenska överföringssystemet för el - Ett nordiskt perspektiv*", ER 2005:11, p. 9, 11 and 125 where Statens Energimyndighet argues that the Swedish transmission network is strong and sufficient for internal Swedish transmissions.

For these reasons, we conclude that Svenska Kraftnät has a (latent) dominant position on the relevant market for transmission of electricity *from* Sweden *to* east Denmark and by unilaterally choosing to limit the transmission capacity in the presence of internal Swedish bottlenecks has turned the latent position into a real dominant position.

The Commissions precedence divides the electricity sector into four relevant product markets (generation/wholesale, transmission, distribution, supply) and in some cases these have been subdivided.[8] The market for transmission of electricity has been delineated in geographical scope to the area of the given member state, since the national networks are only connected to a limited degree. The national transmission networks are considered natural monopolies[9] because it would not be economically viable to duplicate the networks.

We must delineate the relevant market to determine whether Svenska Kraftnät's limitation of capacity on the Oresund-connection can be classified as abuse of a dominant position. We take our starting point in the EU-Commissions precedence, which delineates the relevant market for transmission as a national market and a natural monopoly.

In this way we can focus our analysis on the special circumstances present in the current situation namely:

- Does the Oresund-connection constitute a separate network market?
- Does the Oresund-connection consist of directional submarkets?
- What is the role of the joint ownership between Svenska Kraftnät and Energinet.dk?

2.1. Does the Oresund-connection constitute a separate market?

The Oresund-connection can be perceived in two different ways. Either the Oresund-connection can be seen as an extension of the national transmission network in Sweden and east Denmark respectively, or it can be seen as a separate relevant market.

One the one hand, the Oresund-connection can in terms of relevant market be perceived as an *extension* of the Swedish and east Danish transmission network respectively. Some logic supports this since it is not obvious that the market delineation should be altered simply because each national network is extended marginally. The Oresund-connection is a continuous part of both the Swedish and the east Danish transmission network. [10] This perception is supported by the circumstance that access to westbound transmission on the Oresund-connection is dependent on transmission in the national Swedish transmission network (and vice versa for eastbound transmission).

On the other hand the Oresund-connection can be perceived as a separate relevant market – due to lack of substitutability of transmission internally in Sweden (or in east Denmark) with transmission between Sweden and east Denmark (east Denmark and Sweden). The markets for transmission nationally and between nations respectively can be perceived as complementary because transmission nationally is required to transmit between countries. In other words, no transmission between countries can take place without transmission in a national network, and the two types of transmissions are therefore not substitutable. With these different perceptions in mind we will now turn to the issue of the two different directions that the flow of electricity can take on the Oresund-connection.

[8]COMP/M.3729 – EDF/AEM/EDISON.

[9]COMP/M. 3268, Sydkraft – Graninge, para. 74.

[10] The westbound part of the interconnection would be part of the relevant market for transmission in the Swedish transmission network and the eastbound part of the interconnection would be part of the relevant market for transmission in the east Danish transmission network – see below for this distinction.

2.2. Does the Oresund-connection consist of directional submarkets?

The intuitive reason why we must distinguish between the market for transmission of electricity westbound and eastbound is because there is only access to westbound (eastbound) transmission on the Oresund-connection from the national Swedish (east Danish) transmission network. In other words: Transmission westbound is not the same as transmission eastbound.

This perception is supported by following observations about electricity exchange between Sweden and east Denmark:

Firstly, the Nordic electricity market makes it possible to take advantage from a combined use of hydropower and thermal power.[11] Production on thermal power plants is expensive to regulate and serves as base-load, while hydropower production is low cost and flexible.[12] The various power plants generate electricity from different resources which are available to variable extend. I.e. oil or coal can always be supplied while the supply of water is dependent on the season. Production capacity in Denmark mainly consists of thermal power based on coal or gas while Sweden mainly has hydro power- and nuclear power- but also some thermal power production capacity.[13]

Secondly, but derived from the first observation, the cost of production is different in east Denmark compared to Sweden – some times, when the Nord Pool Elspot system price is relatively low, only few offers of supply from producers of electricity in east Denmark are accepted at Nord Pool – therefore transmission from Sweden to eastern Denmark might be necessary to meet the Danish demand.

Thirdly, demand patterns may vary – sometimes electricity is in demand in southern Sweden while in excess in east Denmark.

Altogether separate relevant markets must be delineated for transmission westbound and eastbound because transmission westbound cannot substitute transmission eastbound (and vice versa).

2.3. What is the role of the joint ownership?

The Oresund-connection is jointly owned by Svenska Kraftnät and Energinet.dk. It is evident though that joint control does not exist – if that was the case, no question of abuse of dominant position would have arisen.

When considering the characteristics of joint ownership there would be some kind of agreement of access to the jointly owned asset, common responsibility for maintenance and insurance and equal shares of the profit.

Only the first of the mentioned characteristics is of interest because it concerns the core of the problem – that Svenska Kraftnät administers the agreement of access allocation in a way which benefits the Swedish market and is harmful to the consumers on the east Danish market. The other mentioned characteristics of joint ownership are not relevant for the analysis because they are not disputed.

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[11] Statens Energimyndighet *"Hantering av begränsningar i det svenska överföringssystemet för el - Ett nordiskt perspektiv"*, ER 2005:11, p. 24 and The Nordic Competition Authorities (2003),"A Powerful Competition Policy", section1.2.3.

[12] Such as oil condensate plants and gas turbines plants, see The Nordic Competition Authorities (2003) "*A Powerful Competition Policy*", section1.2.3.

[13] The Nordic Competition Authorities (2003),"*A Powerful Competition Policy*", sections 1.2.2, 1.3.2 and 1.4.2.

Both Svenska Kraftnät and Energi.dk have separate responsibilities to ensure balance between supply and demand of electricity in Sweden and eastern Denmark respectively. It is agreed between Svenska Kraftnät and Energinet.dk that first Energinet.dk submits its capacity restraints to Svenska Kraftnät. Svenska Kraftnät then returns its (if any) further limitations to Energinet.dk. Then the allowed capacity is submitted to Nord Pool, which administers the allocation of capacity to different buyers and sellers of electricity.[14] The joint capacity limitation is convenient because it allows the TSO who foresees technical problems in the national transmission network to assure low import or export.

Svenska Kraftnät has following criteria for determining capacity allowance on Swedish connections:[15]

- Transmission within Sweden has priority over transmission between Sweden and the surrounding countries.
- Efficiency - which implies two things:
    1. Elimination of expected congestions by limiting capacity on interconnections so the trade between the countries is restricted in the least possible scale.
    2. Capacity limitations which provide highest reduction in transmission through the constrained parts of the network.
- Capacity limitations must be distributed proportionally between the affected interconnections.
- No discrimination must occur.

Svenska Kraftnät has incentives to limit capacity westbound on the Oresund-connection because of the circumstance that Sweden must constitute one price area.[16] The least costly way to obtain that outcome when there is forecasted congestion in 'Cut 4' is for Svenska Kraftnät to limit capacity westbound on the Oresund-connection. In this way costs of counter-trade in 'Cut 4' (and maybe in other cuts) are avoided or substantially reduced and the price in the Swedish market is low compared to the price that would have been, without capacity limitation and congestion.

In contrast Energinet.dk has no incentives to limit capacity westbound, because this would lead to higher prices in east Denmark. The way in which capacity is determined in practice allows Svenska Kraftnät to make an informed decision based on the available capacity submitted by Energinet.dk. This in reality makes it possible for Svenska Kraftnät to solemnly determine the capacity allowance – both west- and eastbound.

The result is that joint ownership entails no implications for the dominant position of Svenska Kraftnät. In practice Svenska Kraftnät has incentives and possibilities to limit capacity on the Oresund-connection. The results of Svenska Kraftnät's capacity limitations are the harmful effects in the Danish market – turbulent wholesale prices and high consumer prices.

[14] http://www.energinet.dk/NR/rdonlyres/9C96083B-47F8-447B-9E9B8DEF64D1C7AB/0/ForskriftA1 Vilkår forbrug af detOestdansketransmissionsnet.pdf

[15] Statens Energimyndighet "*Hantering av begränsningar i det svenska överföringssystemet för el - Ett nordiskt perspektiv*", ER 2005:11, p.34-37. According to Energinet.dk it only limits capacity if any technical issues are present, such as security checks or physical breakdowns. No internal bottlenecks are present in eastern Denmark.

[16] This is confirmed by the finding, that 85% of the capacity limitations from January 2004 to June 2006 are of Swedish origin.

Chapter 3 The effect of congestion on electricity spot prices in east Denmark and Sweden

In this note we investigate the effect of limiting the capacity in the westbound direction on the Oresund-interconnection on the levels of electricity spot prices in eastern Denmark and Sweden.

We conclude that congestion on the Oresund-interconnection in the westbound direction has a significant price-increasing effect on the electricity spot prices in east Denmark, whereas no effect can be observed in Sweden.

We have estimated a huge number of different econometric models and conclude that on average the price in east Denmark increases about 70 percent in the presence of congestion on the Oresund-connection in the westbound direction covering a range of outcomes varying between about 50 percent and 100 percent. For a comparison, the observed prices in east Denmark in congested hours are on average 81 percent larger than the observed prices in Sweden. Moreover, we conclude that the electricity spot prices in Sweden would most likely have be unaffected by capacity limitation and congestion. On average, the Swedish price increases by 0.4 percent covering results ranging from -3 to +7 percent.

3.1. Data description

In this section we describe the most important characteristics of the data that our estimations are based on. We first explain the variables in our dataset, and then we discuss some summary statistics.

The variables

Our data covers the electricity spot market in the Nordic area and Germany, but with the main focus on the spot market for east Denmark and Sweden. The dataset is provided by Energinet.dk and consists of hourly observations. It covers the hours from 1 October 2000 at 00:00hrs to 28 June 2006, 23:59hrs. Thus, our dataset covers 2,097 days and 50,328 hours. For the purpose of estimating price effects, though, we will have to shorten the sample using observations starting from January 1, 2004. The reason is that the information which is necessary to determine how many hours capacity limitations and congestion occur due to the handling of internal bottlenecks by Svenska Kraftnät is only available in this period.

Firstly, we have the electricity spot prices for the markets in east Denmark, west Denmark, Norway, Sweden (Stockholm) and Germany (EEX). In addition, we have the Nord Pool system price. All these spot prices are in nominal DKK/MWh.

Secondly, we have information about all international interconnections between the different spot markets. The information includes the hourly available transmission capacity in both export and import directions on the Oresund-interconnection, the KONTEK interconnection, the west Denmark-Sweden interconnection (Konti-Skan), the west Denmark-Germany interconnection and the west Denmark-Norway interconnection. We also have the corresponding information about the net flow figures for all interconnections. All transmission capacity data is stated in MWh/h.

Thirdly, we have the information about the production of electricity in east Denmark and west Denmark. This data distinguishes between production form wind mills, central production and decentralized production.

Fourthly, we have the hourly consumption data for the electricity spot markets in Sweden, east Denmark and west Denmark

Finally, our data includes the total turnover on the Nord Pool for the electricity spot market in east Denmark and the Danish region.

Summary statistics

In this section we look at some summary statistics for the electricity spot prices for east Denmark and Sweden. We see that through the whole period the electricity spot prices in east Denmark are clearly both higher and more volatile than in Sweden, cf. Table 1 and Table 2.

Firstly, we observe that during the years 2000 to 2006 the mean price for east Denmark has on average been more than 10 DKK/MW higher than the spot price Sweden. The price difference between east Denmark and Sweden was highest in 2005 and 2006 where the mean electricity spot price was about 30 DKK/MWh higher in east Denmark than in Sweden.

Secondly, we observe that the spot price in east Denmark has been more volatile than in Sweden. The maximum recorded price in any given year is always higher in east Denmark. In addition, price volatility measured by the standard deviation of the spot prices, is higher in east Denmark. Again, the difference between east Denmark and Sweden was the largest in 2005, when the standard deviation in east Denmark was more than five times greater than in Sweden.

Thirdly, we see that the electricity spot prices in east Denmark have more extremely high values that in Sweden, especially after 2004. Many extremely high values results in a high skewness and kurtosis. Especially, in the period from 2004 to 2006 both the skewness and the kurtosis are much higher for east Denmark than for Sweden, cf. Table 1 and Table 2.

Table 1: Hourly electricity spot price in east Denmark, October 2000 to June 2006

	2000	2001	2002	2003	2004	2005	2006	Total
Mean	136	176	212	273	211	252	359	232
Median	124	170	169	249	214	225	323	212
Max	549	1,776	2,340	1,418	750	13,460	1,792	13,460
Min	49	15	32	0	0	0	22	0
Std. dev.	49	71	130	118	42	220	139	140
Skewness	3	8	3	3	0	35	3	25
Kurtosis	11	117	20	16	18	1,804	14	1,937

Note: Standard deviations are not annualized. The data covers the period from October 1, 2000 – June 28, 2006
Source: Copenhagen Economics

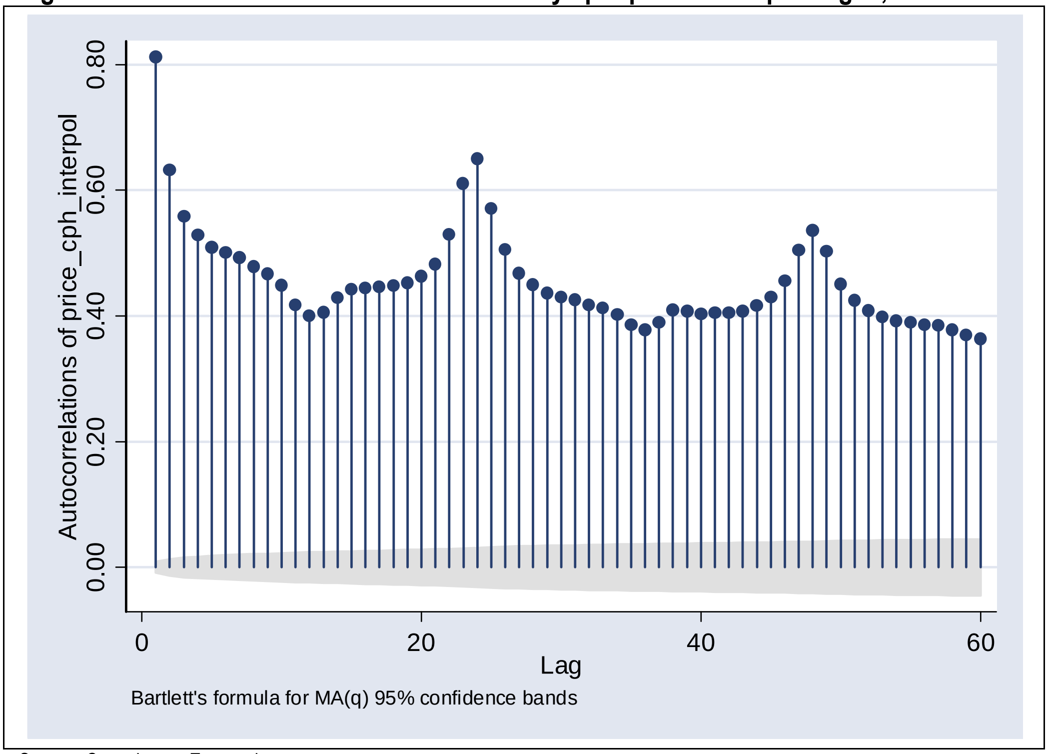
Table 2: Hourly electricity spot price in Sweden, October 2000 to June 2006

	2000	2001	2002	2003	2004	2005	2006	Total
Mean	126	170	205	271	209	222	329	221
Median	124	168	161	249	214	222	321	209
Max	339	1,776	1,290	965	351	774	1,053	1,776
Min	49	15	32	33	2	54	22	2
Std. dev.	25	62	126	113	34	42	72	95
Skewness	2	10	2	3	-2	2	1	3
Kurtosis	16	182	8	15	9	18	13	18

Note: Standard deviations are not annualized. The data covers the period from October 1, 2000 – June 28, 2006
Source: Copenhagen Economics

Finally, we find that both price series are strongly auto-correlated. We tested up to 56 lags which all turned out strongly significant. Autocorrelations imply that the price in one hour typically carries over to the next so that past prices may serve as a predictor of the future price. This is also confirmed by a large R-square of models regressing price on its past values.

Figure 1: Autocorrelation function for electricity spot prices in Copenhagen, 2000-2006



Source: Copenhagen Economics

3.2. The incidence of congestion

In this section, we examine the incidence of congestion on the Oresund-interconnection in the westbound direction. Congestion on the Oresund-interconnection in the westbound direction occurs whenever the demand is so high in east Denmark that the export from Sweden reaches the current capacity limit. Consequently, the spot prices in east Denmark become higher than in Sweden.

Identifying congested hours

We are interested in the price effect of congestion so we need to distinguish the congested hours from the non-congested hours. In this section we explain how we identify the congested hours.

To quantify the alleged capacity limitation problem, we need to know how many hours the electricity flows south, how many hours the capacity on the Oresund-interconnection is limited westbound, and how many hours congestion occurs – as accumulated events.

In our analysis we must determine whether a given capacity limitation causes congestion on the Oresund-interconnection. For that purpose, we need to predict the direction of the electricity flow. When we know the direction of the electricity flow we are able to identify if capacity limitations either westbound or eastbound play a role in the occurrence of the congestion.

Our hourly data allows us to allocate the hours to the different combinations of direction of flow, capacity limitations and congestions in the electricity system, cf. Figure 2.

Firstly, we determine the overall flow of electricity in the Nordic market. Here we utilise the information which the difference in price between Sweden and Germany gives us. A higher electricity spot price in Germany than in Sweden suggests that the overall flow of electricity is south. In contrast, when the electricity spot price is higher in Sweden than in Germany, it is most likely that the overall flow of electricity is north. [17] In the period from October 2000t to June 2006, the flow was north for 48 percent of all hours, cf. Figure 2.

Secondly, we predict the direction of the electricity flow on the Oresund-interconnection by utilizing the data on net transmission. We report the results from a Danish perspective, so when net transmission is positive the flow is eastbound (import occurs). In contrast, when net transmission is negative the flow is westbound (export occurs).[18] The flow on the Oresund-interconnection is mainly eastbound when the overall flow is eastbound and mainly westbound when the overall flow is westbound, cf. Figure 2

Thirdly, we determine whether capacity limitation is employed. In order to do so we compare maximum capacity to the actual trading-capacity available to Nord Pool. Maximum capacity westbound is 1,350 MW and eastbound it is 1,750 MW. The trading-capacity is always limited by 50 MW for security reasons. The maximum trading-capacity is therefore 1,300 MW westbound and 1,700 MW eastbound. In order not to pinpoint insignificant limitations of capacity, we choose to define capacity limitations as when trading-capacity westbound and eastbound on the Oresund-interconnection is below 1,250 MW and 1,650 MW respectively. Above these thresholds no capacity limitation is registered, cf. Figure 2.[19]

Finally, we use the difference in price between east Denmark and Sweden to determine whether the Oresund-interconnection is congested. When there is no congestion, the price in Sweden and the price in east Denmark are equal. If congestion occurs Nord Pool handles this by splitting Sweden and Denmark into two separate price areas with different electricity spot prices, cf. Figure 2.[20]

[17] Therefore the first arguments are: Overall flow north if P(Sweden)≥P(EEX) and overall flow south if P(Sweden)<P(EEX).

[18] The second arguments are: Flow north on the Oresund-interconnection if net transaction ≤0 and flow south on the Oresund-interconnection if net transaction >0.

[19] The third arguments are: No capacity limit north if capacity≤-1650, capacity limit north if capacity>-1650, no capacity limit south if capacity≥1250 and capacity limit south if capacity<1250. Notice that the export capacity from eastern Denmark is reported in negative numbers.

[20] The fourth arguments are: Congestion if P(Edk)≠P(Sweden) and no congestion if P(Edk)=P(Sweden).

Figure 2: Identification of congested hours, Oresund interconnection, October 2000 – June 2006.

1		2		3		4		
Overall	Occurrence (hrs) (% of whole period)	Øresund	Occurrence (hrs) (% of whole period)	Capacity	Occurrence (hrs) (% of whole period)	Congestion	Occurrence (hrs)	No.
Overall flow north if P(Sweden)≥P(EEX)	24077 (47.85%)	Øresund - flow north If net transaction is <0	16901 (33.59%)	No capacity limit north if capacity≤ -1600	14286 (28.38)	Congestion If P(Edk)≠ P(Sweden)	75 (0.15%)	1
						No congestion If P(Edk)=P(Sweden)	14211 (28.23%)	2
				Capacity limit north If capacity> -1600	2615 (5.20%)	Congestion If P(Edk)≠ P(Sweden)	323 (0.64%)	3
						No congestion If P(Edk)=P(Sweden)	2292 (4.55%)	4
		Øresund - flow south If net transaction is >0	7176 (14.26%)	No capacity limit south If capacity≥ 1250	5858 (11.64%)	Congestion If P(Edk)≠ P(Sweden)	35 (0.07%)	5
						No congestion If P(Edk)=P(Sweden)	5823 (11.57%)	6
				Capacity limit south If capacity< 1250	1318 (2.62%)	Congestion If P(Edk)≠ P(Sweden)	136 (0.27%)	7
						No congestion If P(Edk)=P(Sweden)	1182 (2.35%)	8
Overall flow south If P(Sweden)<P(EEX)	26251 (52.15%)	Øresund - flow north If net transaction is negative	4196 (8.35%)	No capacity limit north If capacity≤ -1600	3802 (7.55%)	Congestion If P(Edk)≠ P(Sweden)	232 (0.46%)	9
						No congestion If P(Edk)=P(Sweden)	3570 (7.09%)	10
				Capacity limit north If capacity> -1600	394 (0.78%)	Congestion If P(Edk)≠ P(Sweden)	51 (0.10%)	11
						No congestion If P(Edk)=P(Sweden)	343 (0.68%)	12
		Øresund - flow south If net transaction is positive	22055 (43.8%)	No capacity limit south If capacity≥ 1250	13793 (27.40%)	Congestion If P(Edk)≠ P(Sweden)	589 (1.17%)	13
						No congestion If P(Edk)=P(Sweden)	13204 (26.23%)	14
				Capacity limit south If capacity< 1250	8262 (16.42%)	Congestion If P(Edk)≠ P(Sweden)	2808 (5.58%)	15
						No congestion If P(Edk)=P(Sweden)	5454 (10.84%)	16
Total	50328 (100%)		50328 (100%)		50328 (100%)		50328 (100%)	

Note: Outcome no. 15 contains the relevant amount of congested hours.
Source: Copenhagen Economics

When does congestion occur?

Congestion on the Oresund-interconnection in the westbound mainly occurs during the so-called peak hours. Peak hours are the hours between 7 and 20. These are the hours during day where consumption of electricity is at its highest. We find that 91 percent of the hours with congestion on the Oresund-interconnection in the westbound occur during the so-called peak hours, cf. Table 3.

Table 3: Peak and non peak hours with congestion on the Oresund-interconnection in the westbound direction, October 2000 to June 2006

	Peak hours	Non peak hours	All hours
Number of hours	2,555	253	2,808
Percent of	91%	9%	100

Note: Peak hours are hours between 7 and 20 hrs.
Source: Copenhagen Economics

Are there seasonal patterns in the incidence of congestion?

Congestion on the Oresund-interconnection in the westbound direction primarily takes place during the winter quarters, i.e. Q1 and Q4. In the period from October 2000 to June 2006, more than 2/3 of the congested hours were in either Q1 or Q4, cf. Table 4.

Table 4: Quarterly distribution of hours with congestion on the Oresund-interconnection in the westbound direction, October 2000 to June 2006

	Q1	Q2	Q3	Q4	Q1-Q4
Number	989	440	464	915	2,808
Percent	35	16	17	33	100

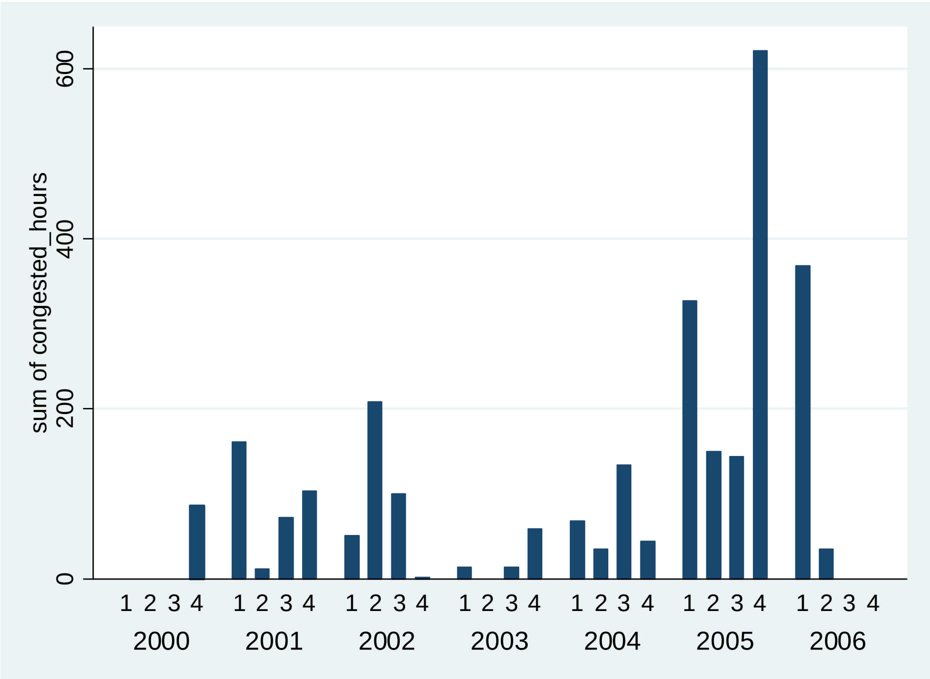
Source: Copenhagen Economics

Is congestion becoming more frequent?

In the years prior to 2005, congestion normally occurred for less than 200 hours per quarter. The years 2003 and 2004 featured a particularly low number congested hours. Thus, the years 2003 and 2004 were in sharp contrast to the year 2005 where the number of congested hours exceeded the total number of congested hours during the years 2000 to 2004, cf. Figure 3.

The year 2006 began with a high frequency of congestion in Q1 where congestion occurred as often as in 2005. In Q2 of 2006, the number of congested hours more resembled the lower number in the preceding years 2003 and 2004, cf. Figure 3.

Figure 3: Number of congested hours on the Oresund-interconnection in westbound direction, Q4 2000 to Q2 2006



Note: The vertical axis represents the quarterly sum of congested hours. On the horizontal axis, the numbers 1, 2, 3 and 4 are the consecutive quarters in the year.

Source: Copenhagen Economics

Are there seasonal patters in the amount of capacity made unavailable in the congested hour?

The amount of transmission capacity which is limited in the hours with congestion on the Oresund-interconnection in the westbound direction shows only little seasonal variation. We have broken down all the congested hours in the period October 2000 to June 2006 to one of the four quarters of the year. For each quarter, we then calculated the average amount of capacity which has been limited in the hours with congestion[21].

We find that the seasonal pattern for the limited capacity is less pronounced than for the hours with congestion. The average amount of limited capacity in the hours with congestion is highest in Q1 and lowest in Q3, cf. Table 5.

Table 5: Average limited capacity on the Oresund-interconnection in the westbound direction in hours with congestion, October 2000 to June 2006

	Q1	Q2	Q3	Q4	Q1-Q4
Average limited capacity, MWh	746	914	644	654	726

Note: The quarterly averages are constructed as the sum of amount of limited capacity divided by the number of hours with congestion in the quarter.
Source: Copenhagen Economics.

Reasons for capacity limitations
Since January 2004, Energinet.dk has for each hour recorded the causes of congestion on the Oresund-interconnection in both directions.

From these records, it is evident that 90 percent of limitations of capacity have originated in Sweden. Furthermore it appears the internal bottleneck problems at Cut 1-4 in Sweden are the most prevalent reason for limitations of capacity on the Oresund-interconnection in the westbound direction. From January 2004 to June 2006, Sweden has limited capacity in the westbound direction for more than 1,600 hours which is almost 85 percent of all hours with reduced capacity on the Oresund-interconnection in the westbound direction, cf. Table 6.

Table 6: The causes of capacity limitations on the Oresund-interconnection in the westbound direction, January 2004 to June 2006

Origin	Cause	Number of hours	Percent
Unaccounted for	Unknown	16	0.8
Denmark	Scheduled outage	20	1.0
Sweden	Scheduled outage	107	5.6
	Bottleneck West Coast cut	2	0.1
	Bottleneck Cuts 1-4	1,612	83.7
Common	Repair and Maintenance	169	8.8
Total		1,926	100

Source: Energinet.dk and Copenhagen Economics

An important note is that in estimations we only focus at the 1612 hours where congestion is due to bottlenecks in Sweden and at Cut 1-4. Congestion caused by these problems coincides with higher and more volatile prices in east Denmark, in comparison to the prices in Sweden, cf. Table 7.

[21] Note that capacity limitations are present outside of congested hours, as well. However as demand for Swedish electricity does not exceed the available supply through the Oresund-interconnection, they are not distorting prices in east Denmark.

Table 7: Electricity spot prices in east Denmark and Sweden during the hours with congestion due to bottleneck problems at Cut 1-4 in Sweden

		Price east DK (DKK/MWh)	Price Sweden (DKK/MWh)	Limited capacity (MWh/h)	Consumption in east DK (MWh/h)
2004	Mean	331	234	721	2,166
	Max	750	314	1,250	2,616
	Min	19	191	17	1,596
	Std.dev.	90	274	279	2,534
2005	Mean	458	245	612	2,064
	Max	13,460	533	1,250	2,542
	Min	166	157	3	1,400
	Std.dev.	563	40	3,068	2,200
2006	Mean	605	340	866	2,258
	Max	1,792	642	1,248	262
	Min	274	270	43	1,731
	Std.dev.	222	55	245	174
Total	Mean	481	267	6801	2,118
	Max	13,460	642	1,250	2,623
	Min	166	157	3	1,400
	Std.dev.	483	59	310	229

Note: The table gives summary statistics for the prices in east Denmark, Sweden, amount of limited capacity on the Oresund, and consumption during the 1612 hours with congestion due to problems at Cut 1-4 in Sweden, as defined in Table 6 above.
Source: Copenhagen Economics

3.3. A simple illustration: Congestion implies higher and more volatile prices

In this section we take a first look at our main hypothesis, i.e. that congestion on the Oresund-interconnection in the westbound direction results in higher and more volatile electricity spot prices in east Denmark.

Less export from Sweden to east Denmark results in higher prices in east Denmark due to two reasons. First, less export implies a smaller supply in east Denmark which gives raise to higher prices. Second, prices are higher because congestion compels Danish consumers to meet their demand from higher cost power plants in Denmark or in Germany.

In addition, the electricity prices in east Denmark become more volatile because the price in east Denmark in the congested hours is determined by a more limited range of power plants with widely different marginal costs of production.

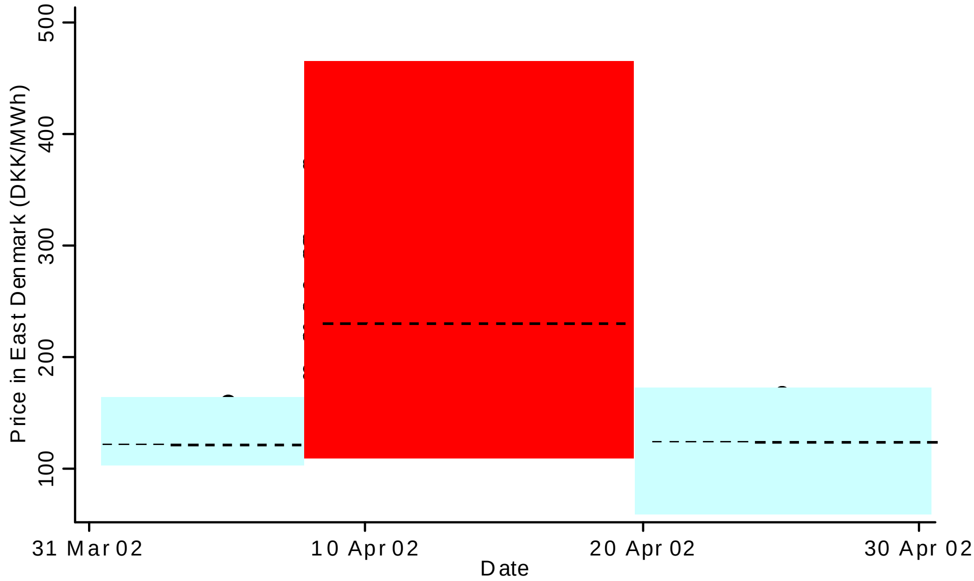
To give a first illustration of this hypothesis, we turn the attention to a specific month. We focus on April 2002. For 12 consecutive days between April 8 and April 19, congestion on the Oresund-interconnection in the westbound direction took place for an average 14h 24 min per day. On the other days of April 2002, the Oresund-interconnection was not congested in the westbound direction.

From April 1 to April 7, where the Oresund-interconnection was not congested, the average electricity spot price in east Denmark was 132 DKK/MWh with a standard deviation of 9.5 DKK/MWh, cf. Figure 4.

From April 8 to April 19, when there was congestion from 8 to 22, both the average spot price and the standard deviation climbed to a much higher level. The average electricity spot price in east Denmark climbed to 227 DKK/MWh. The standard deviation climbed to 101 DKK/MWh, cf. Figure 4.

Eventually, from April 20 to April 30, when there was again no congestion, the average electricity spot price in east Denmark dropped to 130 DKK/MWh with a standard deviation of 31DKK/MWh, cf. Figure 4.

Figure 4: Hourly electricity spot prices in east Denmark, April 2002



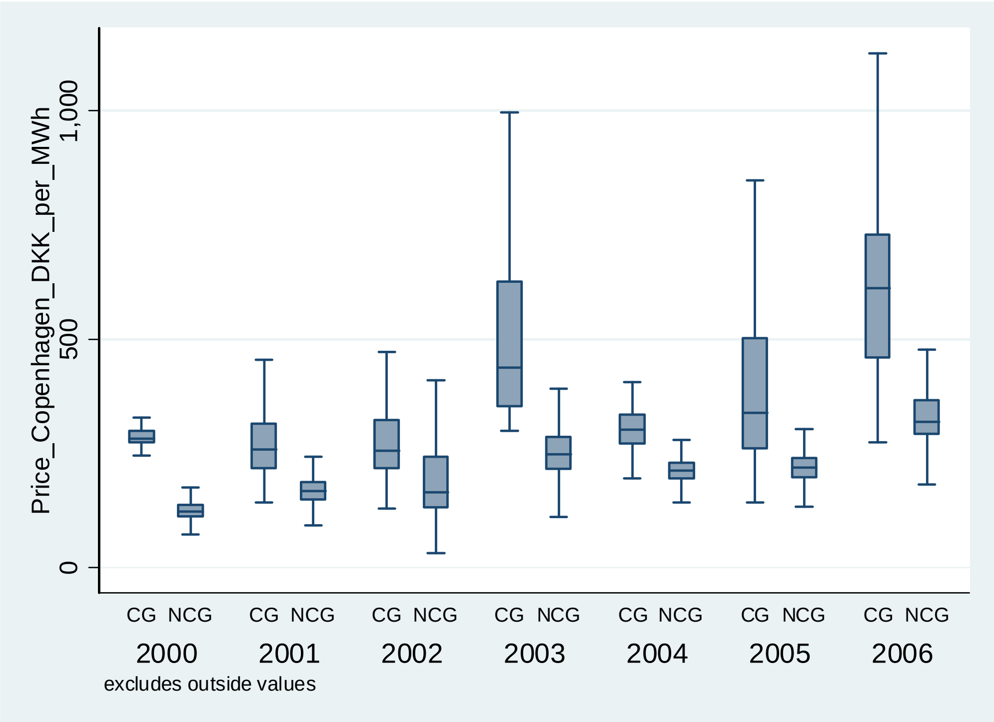
Source: Copenhagen Economics.

We basically observe the same pattern when we study the electricity spot price in east Denmark in the whole period from October 2000 to June 2006.

Firstly, we observe that congestion increases the overall level of hourly prices. For example, in 2006, the median spot price is about 600 DKK/MWh in the congested hours and only about 350 DKK/MWh in the non congested hours, cf. Figure 5.

Secondly, we observe that congestion makes the spot prices more volatile. The difference in volatility is the largest in 2003, 2005 and 2006 where the spot price was roughly three times as volatile in the hours with congestion than in the hours without congestion on the Oresund-interconnection in the westbound direction, cf. Figure 5.

Figure 5: Electricity spot prices in east Denmark in hours with congestion (CG) or without congestion (NCG), October 2000 to June 2006



Note: On the vertical axis, the presence of congestion is indicated by 'CG' while 'NCG' denotes the absence of congestion in the hour, during a given year. The red line inside a box marks the median value. The graph does not include price observations higher than 1,200 DKK/MWh.
Source: Copenhagen Economics.

Box 1: Overview of extreme price observations

In order to obtain a meaningful scale in the Figure 5, we have eliminated the most extreme spot price observations from the dataset. Most of the eliminated outliers were in the year 2005 where 23 extreme spot prices were eliminated. Among the eliminated outliers is the highest price observed in the history of Nord Pool. It was a spot price of 13,460 DKK/MWh which occurred in east Denmark during a congested hour in November 2005, cf. Table 8.

Table 8: Overview of eliminated extreme spot prices in east Denmark, October 2000 to June 2006

	Congested hour?	No. of observations	Mean	Min	Max	Std. deviation
2000	-	0	-	-	-	-
2001	No	6	1,488	1,266	1,776	188
2002	Yes	4	1,699	1,265	2,339	528
2003	Yes	1	1,406	1,406	1,406	n/a
2004	-	0	-	-	-	-
2005	Yes	23	2,759	1,211	13,460	2,879
2006	Yes	4	1,413	1,276	1,792	253

Note: An outlier is defined as a price > 1200 DKK / MWh. In 2001, all 6 outliers did not appear in congested hours, while for the rest of the year they appeared in hours with congestion. N is the number of hours in which prices can be classified as outliers. The mean, maximum, minimum and standard deviation statistics are provided.
Source: Copenhagen Economics

3.4. The estimation method

In this section, we explain the model and the strategy which we use to estimate whether congestion on the Oresund-interconnection leads to higher electricity spot prices in Denmark and lower prices in Sweden. We will set up a range of models to gain more insight into the patterns determining prices in Denmark and Sweden. In addition, we show the pre-estimation diagnostics that we have done.

Pre-estimation diagnostics

Prior to our estimations, we performed some pre-estimation diagnostics which we will now explain. They involve testing the candidate dependent variables for stationarity. If the series are found to be non-stationary, the proposed structural relationship contained in our models may not be stable over time. The result will be a lower explanatory power of the model and potential bias in the coefficients.

As Hadsell and Shawky (2004) argue, stationarity is likely in the hourly electricity prices over the short term. However, in longer samples it is likely that prices will follow a steadily increasing trend, suggesting that prices in earlier periods might have been generated by a different stochastic process than prices in the current period.

Based on our tests, we conclude that prices or log prices contain long-memory meaning that short-run persistence is too low to qualify for a truly integrated process of order 1 (denoted by *I(1)*), but the long-run covariance characteristics have similarities to that of an *I(1)*-process. This is concluded on accounts of the stationarity test proposed by the Kwiatkowski, Phillips, Schmidt and Shin (1992) (KPSS test) and the augmented Dickey-Fuller test.

We start by examining spot prices in east Denmark by applying the augmented Dickey-Fuller test and Phillips-Perron test with the null hypothesis of unit root (non-stationarity). We supplement these by the KPSS-test where the null is stationarity. Our results are as follows:

The null hypothesis of unit root is rejected in both the Dickey-Fuller and the Phillips-Perron tests. This means that the price series were not generated by random walk processes, which is positive from the modelling point of view. Econometric literature is wary of drawing conclusions about stationarity, since the tests in fact are by design only checking for the presence of unit roots. For that reason, we applied the KPSS test, whose null hypothesis is the presence of stationarity in the series. In this sense, it is a positive test of stationarity, and often preferred in literature. The result is a strong rejection of H0 at the 1 percent level which testifies the similarity to an integrated process in the covariance structure, cf. Table 9.

Table 9: Overview of stationary tests of log prices

Test type	Name of test	Price EDK	Log price EDK	Price SE	Log price SE
H0: Non-stationarity H1: Stationarity	Augmented Dickey-Fuller (56 lags)	-10.38**	-8.99**	-5.80**	-7.14**
	Philips Perron (26 lags – Newey-West)	-75.75**	-40.26**	-20.03**	-23.01**
H0: Stationarity H1: Non-stationarity	Kwiatkowski, Phillips, Schmidt and Shin (1992) test (128-134 lags)	1.09**	1.28**	1.23**	1.42**

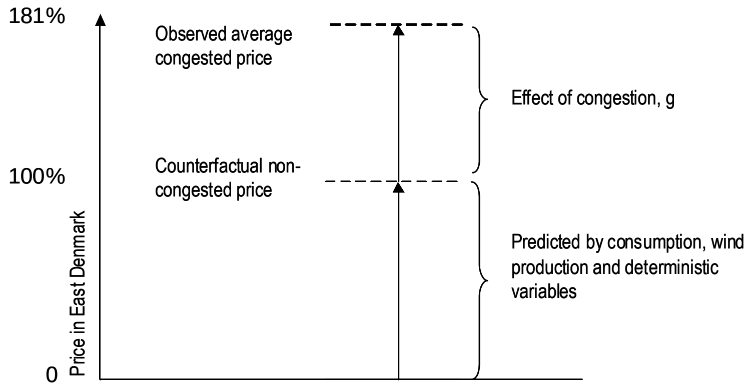
Source: Copenhagen Economics

Note: Two stars (**) indicate significance at the 1 percent level.

Estimation models

The objective of the price models is to estimate the effects on prices when Svenska Kraftnät imposes capacity limits leading to congestion. This implies that we should set up models with prices as the dependent variable, a number of explanatory variables, and a representation of capacity limits as the variable capturing the effect of congestion on prices. In other words, we seek to explain the formation of prices, which we model to be driven by consumption, weather, production technology and seasonal characteristics, and especially the occurrence of congestion in certain hours, cf. Figure 6. We are interested in the effect on both the price level in east Denmark and the price level in Sweden.

Figure 6: Capturing the effect of congestion with econometric models



Source: Copenhagen Economics

The relevant congested hours whose effect on prices our models are designed to explain, arise in the presence of capacity limits. To represent capacity limits, we first define a binary variable, called $caplim$, taking the value of 1 when the Svenska Kraftnät have set capacity limits to handle internal bottlenecks and this had lead to congestion. In all other cases, the variable will take the value of zero. In many of our models, though, we will use more refined measures of capacity limits, but the basic idea remains the same. Apart from the capacity limitation, we will always include corrections for seasonal patterns as electricity markets usually display significant seasonal variations. Thus, our basic model will look like:

Equation 1. Basic model

$$P_t^i = f(hours) + f(week) + f(year) + f(caplim_t) \quad \forall \quad i = Denmark, Sweden$$

where P represents prices in country i, and $hours$, $week$, and $year$ are the components in the seasonal adjustment. We should also stress, that prices can be either the actual price levels or the natural logarithm – in the latter case we will use the standard notation of lower-case p. The argument behind taking logarithms is to "smooth" high positive outliers, i.e. periods with very high prices, and thereby avoiding the risk of making inference that is sensitive to the inclusion of a few observations. On the other hand, it must be acknowledged that the log-transformation may change the estimates as less weight is put on high prices.

Parameterising Equation 1 linearly and expanding by an error term, we derive

Equation 2. Seasonal Deterministic model (SD-OLS)

$$p_t^i = \beta_0 + \sum_{i=1}^{23} \gamma_i^{hour} \cdot I_t^{hour} + \sum_{i=1}^{6} \gamma_i^{day} \cdot I_t^{day} + \sum_{i=1}^{11} \gamma_i^{month} \cdot I_t^{month} + \beta_1 \cdot \text{caplim}_t + \varepsilon_t^i$$

where I_t^j is an indicator function for *j = hour, day, month.*

which can be estimated by OLS. In all later model equations, we will suppress the seasonal components and the values for i.

Obviously, Equation 2 is extremely simplistic and only accounts for seasonal patterns in the data. In order to avoid flawed results due to contemporaneous correlation between other factors, prices and capacity limits, we must include such factors in the analysis. We therefore include the following variables in the model:

- $cons^i$: total electricity consumption in Denmark respectively Sweden;
- $wind$: total wind production in Denmark;
- $central$: central production in Denmark;
- $flow$: a binary variable being one when power is flowing south;
- $SSNCLCG$: a binary variable being one when power is flowing south and congestion occurs without capacity limits;

The variables $cons$ and $central$ may obviously display some endogeneity in the model, since the regression residual could be high when consumption is high. This calls for an IV-estimator where we use lagged consumption and lagged central production (24 lags) as instruments.[22] The model can be written:

Equation 3. Static IV model (SIV)

$$p_t^i = \beta_0 + \beta_1 \cdot \overline{cons_t^i} + \beta_2 \cdot \overline{central}_t + \beta_3 \cdot flow + \beta_4 \cdot SSNCLCG_t + \beta_5 \cdot wind_t + \beta_6 \cdot caplim_t + \varepsilon_t^i$$

where we have indicated the variables that have been instrumented with bars. Remember that deterministics are also included.

The next extension of the model concerns a more refined representation of capacity limits and the way it causes prices to be increased or reduced. Our refinement has three dimensions. First, we model the actual size of the capacity limits under the assumptions that higher capacity limits should lead to higher prices. E.g., if capacity limits are set to 500 MWh in one hour and to 1,000 MWh in another, we would expect the largest increase in the latter hour, and the model should account for that.

Second, we account for non-linearities in this relationship as there could be significant start-up costs for the new marginal plant. We do this by making dummies for four classes of capacity limits (low, medium-low, medium-high, and high).

Third, we include regime-shifts in the model. We define two regimes; the standard regime is defined by a low frequency of capacity limits within a week (less than 25 hours), and the high-impact regime is defined by a high frequency of capacity limits within a week (more than 25 hours). The reason for this division is that capacity limits have not been distributed uniformly over the entire estimation period (January 2004 – July 2006), but seem to be clustered in certain sub-periods within the year, especially in 2005. If we suppress the other explanatory variables from Equation 3 (which has already suppressed the deterministic parts), our new model looks like:

Equation 4. Static Regime-Shifting IV model (SRS-IV)

$$p_t^i = \beta_0 + \sum_{regime=1}^{2} \sum_{class=1}^{4} \beta_{regime,class} \cdot caplim\_size_t^{regime,class} + \varepsilon_t^i$$

where $caplim\_size$ is the size of the capacity limits given a certain class and regime.

All the previous models are static models, but in every case the residuals have a high degree of autocorrelation. For this reason we have always conducted inference in these models using autocorrelation-corrected Newey-West standard errors. In the next model, we will introduce dynamics to account for the autocorrelation. We do this by including a lagged term of the endogenous variable, thereby allowing for some persistence in the model similar to that in the

[22] See e.g. Pindyck and Rubinfeld (1997) for more on IV-estimators.

data. Again suppressing deterministics and other explanatory variables, our new model looks like:

Equation 5. Dynamic Regime-Shifting IV model (DRS-IV)

$$p_t^i = \beta_0 + \alpha \cdot p_{t-1}^i + \sum_{regime=1}^{2} \sum_{class=1}^{4} \beta_{regime,class} \cdot caplim\_size_t^{regime,class} + \varepsilon_t^i$$

We have tried a range of dynamic specifications with a longer lag structure (and we even included MA-terms), but the results of the simpler one-lag specification seemed to be representative of this class of models. It should be noted, that the problem of autocorrelation in the residuals could never be eliminated – only reduced. This must be seen in the light of the high persistency suggested by the KPSS- and augmented Dickey-Fuller tests, and it is the reason that we later turn to more advanced ARFIMA models.

It could also be argued, that Danish and Swedish electricity prices should not be estimated separately from each other, but simultaneously because they are extremely interdependent (and in many hours equal to each other). Thus, we set up a system of equations including most of the advances from the previous models. In the first step, though, we do not include the regime-shifting behaviour. Also, we do not include dynamics. We note, that the simultaneous equation models (SEM) must be estimated by maximum-likelihood (ML) (see e.g. Pindyck and Rubinfeld, 1997), so in order to instrument the potential endogenous variables, we conduct the first-step regressions from a 2SLS-procedure and use the fitted values in the ML-procedure which then constitutes the second step. Suppressing deterministics and exogenous variables, we have the following system of equations:

Equation 6. Static Simultaneous Equation Model (S-SEM)

$$p_t^{Denmark} = \beta_0 + \beta_1 \cdot caplim_t + \varepsilon_t^{Denmark}$$
$$p_t^{Sweden} = \beta_0 + \beta_1 \cdot caplim_t + \varepsilon_t^{Sweden}$$
$$\begin{pmatrix} \varepsilon_t^{Denmark} \\ \varepsilon_t^{Sweden} \end{pmatrix} \sim N(\mathbf{0}, \Omega), \qquad \Omega = \begin{pmatrix} \sigma_1^2 & \sigma_{12} \\ \sigma_{21} & \sigma_2^2 \end{pmatrix}$$

We also estimate a similar model, now accounting for the regime shifts. We call this model Static Regime-Shifting Simultaneous Equation Model (SRS-SEM). We do not write out this model explicitly since the reader can easily substitute the regime-shifting parts from Equation 4 into Equation 6.

As the KPSS- and augmented Dickey-Fuller tests (see below) and the peculiar autocorrelation function for the residuals in our estimated models suggest a long-memory is present in the data. This will lead to inefficient estimation and possibly false inference in the previous models, e.g. spurious regression, and therefore we propose to model the long-memory aspects by an ARFIMA-model (see e.g. Haldrup and Nielsen (2006) for a similar application of ARFIMA models to electricity price data). ARFIMA stands for autoregressive fractional integrated moving average. Thus, it is a dynamic model including long-memory by allowing fractional integration in the dependent variable. For completeness, we will this time include all the exogenous variables (also the instrumented ones) in the vector $\mathbf{x}_t$ when writing up the model:

Equation 7. ARFIMA-model

$$(1 - a(L)) \cdot (1 - L)^{\delta} \cdot p_t^i = \beta_0 + \beta_1 \cdot caplim_t + \mathbf{x}_t \cdot \boldsymbol{\beta} + \varepsilon_t^i$$

where L is the lag-operator, and $a(L)$ is a linear function of L. δ is the parameter capturing the fractional integration. Notice, that we do not specify any MA-terms as this does not seem to be necessary. The optimal lag-length for both Danish and Swedish prices has been found to 7 using the Akaike information criteria.[23] The model can be estimated by ML-methods.

The last three models are simply different versions of Equation 7. In the Regime-Shifting ARFIMA-model (RS-ARFIMA) we include the regime-shifting behaviour as specified above. In the Price-Level ARFIMA (PL-ARFIMA), we return to actual price levels instead of using the log-transformation. Finally, we incorporate the regime-shifting behaviour in the Price-Level Regime-Shifting ARFIMA-model (PL-RS-ARFIMA).

3.5. The price effect in east Denmark and Sweden

We now present the main results from our estimation of the effect of congestion on the electricity spot prices in east Denmark in the period January 2004 to June 2006.

We conclude that the electricity spot price in east Denmark has on average been between 47 and 109 percent higher in the hours where Svenska Kraftnät has reduced the capacity on the Oresund-interconnection due to bottlenecks at Cut 1-4 and congestion have occurred, compared with hours without congestion, cf. Table 10.

We also test whether limited capacity on the Oresund-interconnection in the westbound direction leads to lower spot prices in Sweden. Theoretically, we could expect that to be the case. When the spot price in east Denmark is higher than the spot price in Sweden, the result is higher supply and thus lower price of electricity in Sweden if the capacity on the Oresund-interconnection in the westbound direction is reduced.

We find that the Swedish prices have hardly reacted to the interventions by Svenska Kraftnät. The estimates are in the range -3 to +7 percent, cf. Table 10. While some of the estimates are insignificant at the 5 percent level, a number of estimates are still statistically significant, but any conclusion will depend heavily on the choice of model. Overlooking the 7 percent increase from the SD-OLS model, all estimates can clearly be classified as *economically insignificant*. They are simply not large and certain enough to generate any economic effects. Moreover, a 7 percent increase would actually imply that the Swedish consumers would have been better off if Svenska Kraftnät had not intervened.

Table 10: Average price effect due to capacity limitation and congestion on the Oresund-interconnection, October 2000 to June 2006

Model	Danish prices (percent increase)	Swedish prices (percent increase)	Results in:
SD-OLS	66**	7**	Annex 1
S-IV	47**	-1*	Annex 2
SRS-IV	50**	2**	Annex 3
DRS-IV	109**	0	Annex 4
S-SEM	48**	-1	Annex 5
SRS-SEM	51**	3**	Annex 6
ARFIMA	56**	-3**	Annex 7
RS-ARFIMA	58**	-3*	Annex 8
PL-ARFIMA	64**	-3**	Annex 9
PL-RS-ARFIMA	67**	-2**	Annex 10
Average	66%	0.4%	

Note: The table shows the implied percentage change in prices due to Swedish capacity limits. A single * denotes significance at the 5%-level, whereas ** denotes significance at the 1%-level. In the case of SD-OLS and S-IV models the congestion variable coefficients are transformed in order to obtain the price effect.

Source: Copenhagen Economics

A comparison of the models

Each of the models estimated yields unbiased, consistent and efficient estimates under a corresponding set of assumptions on the data generating process. Unfortunately, we do not

[23] See e.g. Pindyck and Rubinfeld (1997).

know the true data generating process so we can only make indications on the adequateness of each model.

One empirical characteristic is common for all least-squares models as well as SEM-models; they all contain residual autocorrelation. To test for the incidence of serial correlation, we both plotted an AC function and applied the Breusch-Godfrey and the Durbin's h-statistic test.[24] We found that residuals retain strong evidence of serial correlation. On several alternative runs of the model, we implemented various corrections for serial correlation, including lag terms of the independent as well as moving average (regression error) terms.

By using Durbin's h test, we concluded that not all serial correlation is eliminated by the lags of the dependent we include in our dynamic IV model. It is much better eliminated in the ARFIMA class models. The presence of serial correlation once again does not give bias or inconsistency of the estimators. It only affects their efficiency. While serial correlation may render inefficient results (results are still unbiased and consistent), the lag terms are implemented together with Newey-West errors. These precautions are expected to mitigate the problem of serial correlation and ensure interpretable results, cf. Box 2.

Box 2: Properties of the OLS-coefficient under residual autocorrelation.

***Unbiased**: The estimator we apply (OLS with Newey-West errors) allows us to obtain the true coefficient.*

***Consistent**: The estimator allows us to capitalize on the fact that we will have a greater chance of arriving at the true coefficient because the sample we have access to is large.*

***Not efficient**: We acknowledge that residual heteroskedasticity and serial correlation may instil large variance on our coefficient estimate, meaning that the true estimate may be hidden in a large band of uncertainty, nevertheless, the possibility for incorrectly accepting a wrong coefficient estimate as significant, is mitigated by using Newey-West standard errors.*

Source: Copenhagen Economics.

We also conclude that residuals from the estimation are not normal distributed. This should, however, not be a large concern in a large sample as ours. The consequence of non-normal residuals is to resize the intercept. The validity of parameter tests should not be affected (note furthermore that standard errors are Newey-West).

Furthermore, from a Breusch-Pagan test we conclude that heteroskedasticity is present in all of the variables used in the estimation (time, consumption, wind production and capacity limitation). This implies that the parameters are unbiased and consistent, but may not be efficient. Later – in the volatility modelling in Appendix B – we will also show that the prices are characterised by an autoregressive conditional heteroskedasticity (ARCH) structure, which again implies inefficiency of all estimators not incorporating this structure.

Finally, we should clarify that long-memory can cause spurious results in the estimations not taking this into account, i.e. all other models than the ARFIMA. The theoretical literature is currently working on the exact implications of running regressions with fractionally integrated data.

[24] Durbin's h is the relevant test for models with lagged dependents. For our purposes, we test the first 7 lags.

Annex 1

```
**************************************************************
*              The simple seasonal model                     *
**************************************************************

newey ln_price_cph_interpol swesnit dum*, lag(7)

Regression with Newey-West standard errors         Number of obs  =     21840
maximum lag: 7                                     F( 41, 21798)  =     31.63
                                                   Prob > F       =    0.0000

------------------------------------------------------------------------------
             |             Newey-West
ln_price_c~l |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
     swesnit |   .5050964   .0228232    22.13   0.000     .4603612    .5498316
     dum_hr1 |  -.0304383   .0194229    -1.57   0.117    -.0685087     .007632
     dum_hr2 |  -.0766743   .0196182    -3.91   0.000    -.1151275   -.0382212
     dum_hr3 |  -.1109023   .0208511    -5.32   0.000    -.1517719   -.0700327
     dum_hr4 |  -.1429932    .021214    -6.74   0.000    -.1845741   -.1014123
     dum_hr5 |  -.1320856   .0214849    -6.15   0.000    -.1741976   -.0899736
     dum_hr6 |  -.0678053   .0209189    -3.24   0.001     -.108808   -.0268027
     dum_hr7 |  -.0180469   .0197097    -0.92   0.360    -.0566794    .0205856
     dum_hr8 |   .0642485    .017539     3.66   0.000     .0298708    .0986262
     dum_hr9 |   .1226229   .0172438     7.11   0.000     .0888238    .1564219
    dum_hr10 |   .1338122   .0166015     8.06   0.000     .1012721    .1663523
    dum_hr11 |   .1370502   .0165535     8.28   0.000     .1046041    .1694962
    dum_hr12 |   .1319749    .016409     8.04   0.000      .099812    .1641379
    dum_hr13 |   .1051559   .0158447     6.64   0.000     .0740992    .1362126
    dum_hr14 |   .0910192   .0158302     5.75   0.000     .0599908    .1220475
    dum_hr15 |   .0795014   .0159218     4.99   0.000     .0482934    .1107093
    dum_hr16 |   .0731203   .0160302     4.56   0.000     .0416998    .1045407
    dum_hr17 |   .0844949   .0159262     5.31   0.000     .0532784    .1157114
    dum_hr18 |   .1341523   .0168146     7.98   0.000     .1011945      .16711
    dum_hr19 |   .1443421   .0158785     9.09   0.000     .1132191    .1754651
    dum_hr20 |   .0910093    .014177     6.42   0.000     .0632214    .1187973
    dum_hr21 |   .0556763   .0134739     4.13   0.000     .0292664    .0820862
    dum_hr22 |   .0620984   .0124044     5.01   0.000     .0377849    .0864119
    dum_hr23 |   .0507458   .0116222     4.37   0.000     .0279654    .0735262
     dum_sun |  -.0971736   .0273882    -3.55   0.000    -.1508565   -.0434908
     dum_mon |   .0981744   .0175286     5.60   0.000      .063817    .1325318
     dum_tue |   .0924855    .016634     5.56   0.000     .0598817    .1250892
     dum_wed |   .1023763   .0163829     6.25   0.000     .0702646    .1344879
     dum_thu |   .0891292   .0163138     5.46   0.000      .057153    .1211055
     dum_fri |    .041823    .021313     1.96   0.050      .000048     .083598
     dum_jan |   .0103859    .045604     0.23   0.820    -.0790012     .099773
     dum_feb |   .0776929   .0378642     2.05   0.040     .0034763    .1519094
     dum_mar |   .2219825   .0388485     5.71   0.000     .1458365    .2981284
     dum_apr |   .1623238   .0388501     4.18   0.000     .0861748    .2384728
     dum_may |    .051481   .0364982     1.41   0.158    -.0200581    .1230202
     dum_jun |   .1331944   .0373608     3.57   0.000     .0599646    .2064242
     dum_jul |  -.0709256   .0401333    -1.77   0.077    -.1495897    .0077386
     dum_aug |   .1143976   .0341578     3.35   0.001     .0474457    .1813494
     dum_sep |  -.0039182   .0363094    -0.11   0.914    -.0750873    .0672509
     dum_oct |   .0201203   .0347346     0.58   0.562    -.0479621    .0882027
     dum_nov |   .0674099   .0376373     1.79   0.073    -.0063619    .1411816
       _cons |    5.26955   .0343159   153.56   0.000     5.202288    5.336812
------------------------------------------------------------------------------
```

Regression with Newey-West standard errors — Number of obs = 21840
maximum lag: 7 — F(41, 21798) = 22.46
Prob > F = 0.0000

ln_price_s~l	Coef.	Newey-West Std. Err.	t	P>|t|	[95% Conf.	Interval]
swesnit	.0700144	.0113602	6.16	0.000	.0477476	.0922812
dum_hr1	-.0150949	.0056733	-2.66	0.008	-.0262151	-.0039748
dum_hr2	-.0519133	.0080011	-6.49	0.000	-.067596	-.0362306
dum_hr3	-.0872203	.0097276	-8.97	0.000	-.1062871	-.0681536
dum_hr4	-.1203062	.0120591	-9.98	0.000	-.143943	-.0966695
dum_hr5	-.1142028	.0132474	-8.62	0.000	-.1401686	-.088237
dum_hr6	-.0558709	.0124211	-4.50	0.000	-.0802172	-.0315246
dum_hr7	-.0077774	.0117659	-0.66	0.509	-.0308395	.0152846
dum_hr8	.0445488	.012405	3.59	0.000	.0202341	.0688635
dum_hr9	.0937288	.0116502	8.05	0.000	.0708936	.116564
dum_hr10	.1006383	.0107676	9.35	0.000	.0795331	.1217435
dum_hr11	.1028713	.0105192	9.78	0.000	.082253	.1234896
dum_hr12	.0964755	.010426	9.25	0.000	.0760397	.1169113
dum_hr13	.0813	.0103241	7.87	0.000	.061064	.1015359
dum_hr14	.0669711	.0103244	6.49	0.000	.0467345	.0872077
dum_hr15	.0545795	.0105957	5.15	0.000	.0338111	.0753479
dum_hr16	.0523717	.0107747	4.86	0.000	.0312526	.0734909
dum_hr17	.057576	.0102347	5.63	0.000	.0375153	.0776367
dum_hr18	.0753504	.0095364	7.90	0.000	.0566583	.0940425
dum_hr19	.0792693	.008646	9.17	0.000	.0623226	.0962161
dum_hr20	.0654906	.0074806	8.75	0.000	.050828	.0801532
dum_hr21	.054178	.0067011	8.08	0.000	.0410434	.0673126
dum_hr22	.0539904	.0055737	9.69	0.000	.0430655	.0649153
dum_hr23	.0416582	.0042964	9.70	0.000	.033237	.0500794
dum_sun	-.0689359	.0189228	-3.64	0.000	-.1060259	-.0318458
dum_mon	.071552	.0155325	4.61	0.000	.0411072	.1019967
dum_tue	.0742025	.0151314	4.90	0.000	.0445439	.1038612
dum_wed	.0829861	.0149876	5.54	0.000	.0536093	.112363
dum_thu	.0701025	.0149538	4.69	0.000	.0407919	.0994131
dum_fri	.0477459	.0149652	3.19	0.001	.018413	.0770788
dum_jan	.0022016	.0192268	0.11	0.909	-.0354843	.0398875
dum_feb	.0438252	.0206185	2.13	0.034	.0034115	.0842389
dum_mar	.1783226	.0216391	8.24	0.000	.1359084	.2207369
dum_apr	.1433626	.0221731	6.47	0.000	.0999018	.1868234
dum_may	.019542	.0200048	0.98	0.329	-.0196689	.0587529
dum_jun	.1070653	.0204963	5.22	0.000	.066891	.1472395
dum_jul	-.1042509	.0256556	-4.06	0.000	-.1545379	-.053964
dum_aug	.0743483	.0140979	5.27	0.000	.0467155	.1019812
dum_sep	-.0402209	.018842	-2.13	0.033	-.0771526	-.0032891
dum_oct	-.017436	.0163045	-1.07	0.285	-.049394	.0145221
dum_nov	-.020911	.0159781	-1.31	0.191	-.0522292	.0104073
_cons	5.319751	.0175647	302.87	0.000	5.285323	5.35418

Annex 2

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************************************************************
*              The Static IV-Model                         *
************************************************************

 /*Denmark*/

ivreg  ln_price_cph_interpol  swesnit  dum*  wind_prod  flow_direction  SSNCLCG
(consumption central_prod = cons_lag24 c
entrprod_lag24)

Instrumental variables (2SLS) regression

      Source |       SS       df       MS              Number of obs =   21816
-------------+------------------------------           F( 46, 21769) =  268.55
       Model |  1533.92126    46  33.3461144           Prob > F      =  0.0000
    Residual |  2563.46175 21769  .117757442           R-squared     =  0.3744
-------------+------------------------------           Adj R-squared =  0.3730
       Total |  4097.38302 21815  .187824113           Root MSE      =  .34316

------------------------------------------------------------------------------
ln_price_c~l |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
 consumption |   .0004039   .0000383    10.56   0.000     .0003289    .0004789
central_prod |   .0005863   .0000137    42.74   0.000     .0005594    .0006132
     swesnit |   .3875365   .0101095    38.33   0.000     .3677211    .4073519
     dum_hr1 |   .0229562   .0165861     1.38   0.166    -.0095537    .0554662
     dum_hr2 |   .0048818   .0173141     0.28   0.778    -.0290551    .0388188
     dum_hr3 |  -.0172831    .017753    -0.97   0.330    -.0520803     .017514
     dum_hr4 |  -.0477866   .0178505    -2.68   0.007    -.0827749   -.0127982
     dum_hr5 |  -.0480844   .0176802    -2.72   0.007    -.0827388     -.01343
     dum_hr6 |  -.0190924   .0169084    -1.13   0.259    -.0522341    .0140493
     dum_hr7 |  -.0549037   .0161595    -3.40   0.001    -.0865776   -.0232299
     dum_hr8 |  -.0755985   .0186214    -4.06   0.000    -.1120978   -.0390993
     dum_hr9 |  -.0827553   .0214326    -3.86   0.000    -.1247647   -.0407459
    dum_hr10 |  -.0983447   .0229967    -4.28   0.000    -.1434199   -.0532696
    dum_hr11 |  -.1071777   .0237465    -4.51   0.000    -.1537225   -.0606329
    dum_hr12 |  -.1012138   .0234661    -4.31   0.000    -.1472091   -.0552186
    dum_hr13 |  -.1160771   .0229894    -5.05   0.000     -.161138   -.0710162
    dum_hr14 |  -.1227416   .0226362    -5.42   0.000    -.1671102   -.0783731
    dum_hr15 |  -.1211229   .0219361    -5.52   0.000    -.1641192   -.0781266
    dum_hr16 |  -.1148754   .0211614    -5.43   0.000    -.1563533   -.0733975
    dum_hr17 |  -.1165063   .0218154    -5.34   0.000     -.159266   -.0737465
    dum_hr18 |  -.1146862   .0247755    -4.63   0.000    -.1632479   -.0661245
    dum_hr19 |  -.1046692   .0247048    -4.24   0.000    -.1530925    -.056246
    dum_hr20 |  -.1149655   .0221547    -5.19   0.000    -.1583904   -.0715406
    dum_hr21 |  -.0994262   .0198169    -5.02   0.000    -.1382687   -.0605837
    dum_hr22 |   -.057906   .0183692    -3.15   0.002    -.0939109   -.0219011
    dum_hr23 |  -.0135875    .016813    -0.81   0.419    -.0465422    .0193672
     dum_sun |  -.0720006   .0088205    -8.16   0.000    -.0892893   -.0547119
     dum_mon |  -.0545956   .0107756    -5.07   0.000    -.0757167   -.0334745
     dum_tue |  -.0933387   .0113258    -8.24   0.000     -.115538   -.0711393
     dum_wed |  -.0937179   .0114586    -8.18   0.000    -.1161776   -.0712582
     dum_thu |  -.0906067   .0112811    -8.03   0.000    -.1127184   -.0684949
     dum_fri |  -.1036532   .0105194    -9.85   0.000     -.124272   -.0830344
     dum_jan |  -.0376377   .0119558    -3.15   0.002    -.0610719   -.0142035
     dum_feb |  -.0172777   .0119056    -1.45   0.147    -.0406135    .0060581
     dum_mar |   .1154185   .0118273     9.76   0.000     .0922361     .138601
     dum_apr |   .3383066   .0137683    24.57   0.000     .3113196    .3652935
     dum_may |   .4140165   .0160048    25.87   0.000     .3826459     .445387
     dum_jun |   .3882173   .0170572    22.76   0.000      .354784    .4216506
     dum_jul |   .4974881   .0201737    24.66   0.000     .4579461    .5370301
     dum_aug |    .550626   .0171881    32.04   0.000     .5169362    .5843159
     dum_sep |   .4192561    .016549    25.33   0.000      .386819    .4516933
     dum_oct |    .316245   .0144612    21.87   0.000     .2879001    .3445899
     dum_nov |   .1037511   .0128339     8.08   0.000     .0785956    .1289066
   wind_prod |  -.0001734   .0000157   -11.02   0.000    -.0002042   -.0001425
flow_direc~n |  -.0581417   .0066878    -8.69   0.000    -.0712502   -.0450332
     SSNCLCG |   .0919925    .023351     3.94   0.000     .0462229    .1377622
       _cons |   4.088919   .0498651    82.00   0.000      3.99118    4.186658
```

```
/*Sweden*/

ivreg  ln_price_swe_interpol  swesnit  dum*  wind_prod  flow_direction  SSNCLCG
(cons_se central_prod = cons_selag24 cen
> trprod_lag24)

Instrumental variables (2SLS) regression

      Source |       SS       df       MS              Number of obs =   21816
-------------+------------------------------           F( 46, 21769) =  307.82
       Model |  714.125929    46  15.5244767           Prob > F      =  0.0000
    Residual |   1044.4454 21769  .047978566           R-squared     =  0.4061
-------------+------------------------------           Adj R-squared =  0.4048
       Total |  1758.57133 21815  .080612942           Root MSE      =  .21904

------------------------------------------------------------------------------
ln_price_s~l |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
     cons_se |   .0000264   2.07e-06    12.77   0.000     .0000224    .0000305
central_prod |   .0004962   9.07e-06    54.68   0.000     .0004784     .000514
     swesnit |  -.0133697   .0063211    -2.12   0.034    -.0257595   -.0009799
     dum_hr1 |   .0059901   .0103389     0.58   0.562    -.0142749     .026255
     dum_hr2 |  -.0237307   .0104196    -2.28   0.023    -.0441539   -.0033075
     dum_hr3 |  -.0556026   .0104725    -5.31   0.000    -.0761295   -.0350757
     dum_hr4 |  -.0916071   .0104697    -8.75   0.000    -.1121283   -.0710858
     dum_hr5 |  -.0936409   .0104538    -8.96   0.000     -.114131   -.0731507
     dum_hr6 |   -.053926   .0103325    -5.22   0.000    -.0741785   -.0336736
     dum_hr7 |  -.0470444   .0103807    -4.53   0.000    -.0673912   -.0266975
     dum_hr8 |  -.0317654   .0109082    -2.91   0.004    -.0531463   -.0103844
     dum_hr9 |  -.0040944   .0112014    -0.37   0.715    -.0260501    .0178612
    dum_hr10 |  -.0002021   .0113053    -0.02   0.986    -.0223613    .0219572
    dum_hr11 |  -.0011425    .011408    -0.10   0.920     -.023503    .0212179
    dum_hr12 |   .0011868   .0113657     0.10   0.917    -.0210909    .0234644
    dum_hr13 |  -.0070261   .0112448    -0.62   0.532    -.0290667    .0150145
    dum_hr14 |  -.0172554   .0111295    -1.55   0.121      -.03907    .0045592
    dum_hr15 |  -.0268631   .0110553    -2.43   0.015    -.0485322    -.005194
    dum_hr16 |  -.0321878   .0110917    -2.90   0.004    -.0539283   -.0104473
    dum_hr17 |  -.0306119    .011113    -2.75   0.006    -.0523943   -.0088295
    dum_hr18 |  -.0166741   .0111949    -1.49   0.136    -.0386168    .0052687
    dum_hr19 |  -.0110564   .0111343    -0.99   0.321    -.0328806    .0107677
    dum_hr20 |  -.0166358   .0110111    -1.51   0.131    -.0382184    .0049467
    dum_hr21 |  -.0090544   .0108297    -0.84   0.403    -.0302814    .0121725
    dum_hr22 |   .0027553   .0106266     0.26   0.795    -.0180737    .0235843
    dum_hr23 |   .0163949   .0103843     1.58   0.114    -.0039591    .0367489
     dum_sun |  -.0620863   .0055894   -11.11   0.000    -.0730419   -.0511306
     dum_mon |  -.0356967   .0063202    -5.65   0.000    -.0480848   -.0233087
     dum_tue |  -.0521322   .0063665    -8.19   0.000     -.064611   -.0396534
     dum_wed |  -.0488111   .0063581    -7.68   0.000    -.0612735   -.0363487
     dum_thu |  -.0508091   .0063271    -8.03   0.000    -.0632106   -.0384075
     dum_fri |   -.045998    .006012    -7.65   0.000     -.057782    -.034214
     dum_jan |  -.0297118   .0075187    -3.95   0.000     -.044449   -.0149746
     dum_feb |  -.0373495   .0076528    -4.88   0.000    -.0523495   -.0223495
     dum_mar |   .0831263   .0075221    11.05   0.000     .0683824    .0978702
     dum_apr |   .3038015   .0094988    31.98   0.000     .2851832    .3224198
     dum_may |   .3478595   .0116333    29.90   0.000     .3250574    .3706615
     dum_jun |    .366154   .0141124    25.95   0.000     .3384927    .3938153
     dum_jul |   .4301668    .015864    27.12   0.000     .3990722    .4612614
     dum_aug |   .5010124   .0141096    35.51   0.000     .4733565    .5286683
     dum_sep |   .3611801   .0125553    28.77   0.000     .3365709    .3857893
     dum_oct |   .2521092   .0098725    25.54   0.000     .2327583      .27146
     dum_nov |   .0238209   .0084007     2.84   0.005     .0073549    .0402869
   wind_prod |  -.0000654   9.69e-06    -6.74   0.000    -.0000844   -.0000463
flow_direc~n |  -.0671397   .0040074   -16.75   0.000    -.0749945   -.0592849
     SSNCLCG |   .0260366   .0148774     1.75   0.080    -.0031241    .0551973
       _cons |    4.35038   .0323134   134.63   0.000     4.287043    4.413716
------------------------------------------------------------------------------
```

Annex 3

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*************************************************************
*         The Regime-Shifting IV-specification              *
*************************************************************


/*Denmark*/
sort time

ivreg  ln_price_cph_interpol  dum*  wind_prod  cross*  flow_direction  SSNCLCG
(consumption central_prod = cons_lag24 ce
ntrprod_lag24)

Instrumental variables (2SLS) regression

      Source |       SS       df       MS              Number of obs =   21816
-------------+------------------------------           F( 53, 21762) =  246.16
       Model |  1585.81985    53  29.9211293           Prob > F      =  0.0000
    Residual |  2511.56317 21762  .115410494           R-squared     =  0.3870
-------------+------------------------------           Adj R-squared =  0.3855
       Total |  4097.38302 21815  .187824113           Root MSE      =  .33972

------------------------------------------------------------------------------
ln_price_c~l |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
 consumption |   .0004017   .0000378    10.63   0.000     .0003276    .0004757
central_prod |   .0005542   .0000138    40.18   0.000     .0005271    .0005812
     dum_hr1 |   .0217589   .0164182     1.33   0.185     -.010422    .0539398
     dum_hr2 |   .0030511   .0171361     0.18   0.859     -.030537    .0366392
     dum_hr3 |  -.0193202   .0175689    -1.10   0.271    -.0537566    .0151161
     dum_hr4 |  -.0500044   .0176651    -2.83   0.005    -.0846292   -.0153795
     dum_hr5 |  -.0500734   .0174969    -2.86   0.004    -.0843686   -.0157782
     dum_hr6 |  -.0200374   .0167358    -1.20   0.231    -.0528407     .012766
     dum_hr7 |   -.055071   .0159987    -3.44   0.001    -.0864296   -.0237125
     dum_hr8 |  -.0746995   .0184286    -4.05   0.000    -.1108209   -.0385781
     dum_hr9 |   -.079507   .0211962    -3.75   0.000    -.1210531   -.0379608
    dum_hr10 |  -.0914944   .0227528    -4.02   0.000    -.1360915   -.0468973
    dum_hr11 |  -.0971682    .023489    -4.14   0.000    -.1432083   -.0511281
    dum_hr12 |  -.0916766    .023208    -3.95   0.000     -.137166   -.0461872
    dum_hr13 |  -.1093798   .0227475    -4.81   0.000    -.1539665    -.064793
    dum_hr14 |  -.1184451   .0224041    -5.29   0.000    -.1623587   -.0745315
    dum_hr15 |  -.1178768   .0217112    -5.43   0.000    -.1604322   -.0753213
    dum_hr16 |  -.1122213   .0209376    -5.36   0.000    -.1532605   -.0711821
    dum_hr17 |  -.1130628   .0215959    -5.24   0.000    -.1553923   -.0707332
    dum_hr18 |  -.1086508   .0245223    -4.43   0.000    -.1567162   -.0605853
    dum_hr19 |  -.0988587   .0244458    -4.04   0.000    -.1467742   -.0509432
    dum_hr20 |  -.1139046   .0219247    -5.20   0.000    -.1568787   -.0709306
    dum_hr21 |   -.096999   .0196258    -4.94   0.000    -.1354671   -.0585309
    dum_hr22 |  -.0550658   .0181887    -3.03   0.002     -.090717   -.0194146
    dum_hr23 |  -.0123551   .0166437    -0.74   0.458     -.044978    .0202678
     dum_sun |  -.0718431   .0087327    -8.23   0.000    -.0889597   -.0547265
     dum_mon |  -.0485172   .0106644    -4.55   0.000    -.0694203   -.0276142
     dum_tue |  -.0881238   .0112078    -7.86   0.000     -.110092   -.0661557
     dum_wed |  -.0892724   .0113426    -7.87   0.000    -.1115048     -.06704
     dum_thu |   -.085008   .0111584    -7.62   0.000    -.1068793   -.0631367
     dum_fri |  -.0987684   .0104131    -9.48   0.000    -.1191789    -.078358
     dum_jan |  -.0304324   .0118777    -2.56   0.010    -.0537137   -.0071511
     dum_feb |  -.0043057   .0118345    -0.36   0.716    -.0275023    .0188909
     dum_mar |   .1094536   .0117679     9.30   0.000     .0863876    .1325196
     dum_apr |   .3352517   .0136873    24.49   0.000     .3084237    .3620798
     dum_may |   .4036506   .0159278    25.34   0.000     .3724311    .4348702
     dum_jun |   .3868435   .0169554    22.82   0.000     .3536097    .4200773
     dum_jul |   .4778823   .0200887    23.79   0.000      .438507    .5172576
     dum_aug |   .5414258   .0171147    31.64   0.000     .5078797    .5749719
     dum_sep |   .4053479   .0165272    24.53   0.000     .3729535    .4377424
     dum_oct |   .3133609   .0143414    21.85   0.000     .2852506    .3414711
     dum_nov |   .0997412   .0127224     7.84   0.000     .0748043    .1246781
   wind_prod |  -.0001858   .0000156   -11.91   0.000    -.0002164   -.0001552
   cross_h_1 |   .0009017   .0000894    10.09   0.000     .0007265    .0010769
     cross_1 |   .0003943   .0000887     4.44   0.000     .0002204    .0005682
   cross_h_2 |   .0007383   .0000336    21.95   0.000     .0006723    .0008042
     cross_2 |   .0003378   .0000612     5.52   0.000     .0002178    .0004577
   cross_h_3 |   .0006662    .000023    28.98   0.000     .0006211    .0007113
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     cross_3 |   .0004568   .0000647     7.06   0.000     .0003299    .0005837
   cross_h_4 |   .0004893   .0000183    26.80   0.000     .0004535     .000525
     cross_4 |   .0002617   .0000442     5.92   0.000     .0001751    .0003483
flow_direc~n |  -.0599474   .0066268    -9.05   0.000    -.0729364   -.0469584
     SSNCLCG |   .0850332   .0231164     3.68   0.000     .0397233    .1303431
       _cons |    4.12892   .0494482    83.50   0.000     4.031998    4.225842
------------------------------------------------------------------------------


    Variable |       Obs        Mean    Std. Dev.       Min        Max
-------------+--------------------------------------------------------
      effect |      1612    .4968715    .2415887   .0011837   .8618404



/*Sweden*/

ivreg  ln_price_swe_interpol  dum*  wind_prod  cross*  flow_direction  SSNCLCG
(cons_se central_prod = cons_selag24 cent
> rprod_lag24)

Instrumental variables (2SLS) regression
      Source |       SS       df       MS              Number of obs =   21816
-------------+------------------------------           F( 53, 21762) =  269.35
       Model |  718.593088    53  13.5583602           Prob > F      =  0.0000
    Residual |  1039.97824 21762  .047788725           R-squared     =  0.4086
-------------+------------------------------           Adj R-squared =  0.4072
       Total |  1758.57133 21815  .080612942           Root MSE      =  .21861

------------------------------------------------------------------------------
ln_price_s~l |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
     cons_se |   .0000269   2.07e-06    13.04   0.000     .0000229     .000031
central_prod |   .0004976   9.19e-06    54.17   0.000     .0004796    .0005156
     dum_hr1 |    .006382   .0103186     0.62   0.536    -.0138433    .0266072
     dum_hr2 |  -.0231929   .0103994    -2.23   0.026    -.0435765   -.0028094
     dum_hr3 |   -.054982   .0104523    -5.26   0.000    -.0754692   -.0344948
     dum_hr4 |  -.0910102   .0104495    -8.71   0.000    -.1114919   -.0705285
     dum_hr5 |  -.0931022   .0104335    -8.92   0.000    -.1135526   -.0726518
     dum_hr6 |   -.053626   .0103121    -5.20   0.000    -.0738385   -.0334135
     dum_hr7 |  -.0481302   .0103613    -4.65   0.000    -.0684391   -.0278214
     dum_hr8 |  -.0322449   .0108869    -2.96   0.003     -.053584   -.0109058
     dum_hr9 |  -.0043877   .0111784    -0.39   0.695    -.0262983    .0175229
    dum_hr10 |  -.0010664   .0112863    -0.09   0.925    -.0231884    .0210556
    dum_hr11 |  -.0012281   .0113901    -0.11   0.914    -.0235535    .0210972
    dum_hr12 |   .0015393   .0113447     0.14   0.892    -.0206972    .0237758
    dum_hr13 |  -.0082188   .0112262    -0.73   0.464     -.030223    .0137854
    dum_hr14 |  -.0192506   .0111134    -1.73   0.083    -.0410337    .0025325
    dum_hr15 |  -.0284803   .0110377    -2.58   0.010    -.0501149   -.0068457
    dum_hr16 |  -.0335619   .0110723    -3.03   0.002    -.0552645   -.0118593
    dum_hr17 |  -.0320523   .0110974    -2.89   0.004    -.0538041   -.0103005
    dum_hr18 |  -.0185793   .0111767    -1.66   0.096    -.0404864    .0033279
    dum_hr19 |  -.0127311   .0111151    -1.15   0.252    -.0345175    .0090554
    dum_hr20 |  -.0189219   .0109953    -1.72   0.085    -.0404734    .0026296
    dum_hr21 |  -.0119054   .0108172    -1.10   0.271    -.0331079    .0092972
    dum_hr22 |   .0008665   .0106102     0.08   0.935    -.0199304    .0216633
    dum_hr23 |   .0154359   .0103647     1.49   0.136    -.0048798    .0357515
     dum_sun |  -.0624129   .0055799   -11.19   0.000      -.07335   -.0514758
     dum_mon |  -.0351381   .0063084    -5.57   0.000    -.0475031   -.0227731
     dum_tue |  -.0523739   .0063577    -8.24   0.000    -.0648355   -.0399123
     dum_wed |  -.0491633   .0063494    -7.74   0.000    -.0616086   -.0367181
     dum_thu |   -.050337   .0063177    -7.97   0.000    -.0627202   -.0379538
     dum_fri |  -.0460011   .0060042    -7.66   0.000    -.0577698   -.0342325
     dum_jan |  -.0254807   .0075337    -3.38   0.001    -.0402474   -.0107141
     dum_feb |  -.0339339   .0076656    -4.43   0.000    -.0489591   -.0189087
     dum_mar |   .0889972   .0075455    11.79   0.000     .0742075    .1037869
     dum_apr |   .3099539   .0095245    32.54   0.000     .2912853    .3286226
     dum_may |   .3554057    .011675    30.44   0.000     .3325219    .3782896
     dum_jun |     .37421   .0141481    26.45   0.000     .3464787    .4019413
     dum_jul |   .4394642   .0159202    27.60   0.000     .4082593     .470669
     dum_aug |   .5101882   .0141546    36.04   0.000     .4824441    .5379323
     dum_sep |   .3709695   .0126271    29.38   0.000     .3462195    .3957195
     dum_oct |   .2562318    .009877    25.94   0.000     .2368722    .2755914
     dum_nov |   .0232052   .0083926     2.76   0.006     .0067551    .0396552
   wind_prod |  -.0000622   9.70e-06    -6.41   0.000    -.0000812   -.0000432
```

```
    cross_h_1 |    .000252   .0000574     4.39   0.000     .0001394    .0003646
      cross_1 |  -.0002304   .0000568    -4.06   0.000    -.0003417   -.0001192
    cross_h_2 |   .0000881   .0000215     4.09   0.000     .0000459    .0001303
      cross_2 |  -.0002217   .0000394    -5.63   0.000    -.0002989   -.0001446
    cross_h_3 |  -4.77e-06   .0000147    -0.32   0.745    -.0000335     .000024
      cross_3 |  -.0000264   .0000416    -0.63   0.527     -.000108    .0000553
    cross_h_4 |  -.0000539   .0000117    -4.61   0.000    -.0000769    -.000031
      cross_4 |  -.0000235   .0000284    -0.83   0.409    -.0000792    .0000323
flow_direc~n |  -.0676059   .0040031   -16.89   0.000    -.0754523   -.0597595
      SSNCLCG |   .0264511   .0148482     1.78   0.075    -.0026525    .0555547
        _cons |   4.334755   .0323777   133.88   0.000     4.271292    4.398217
------------------------------------------------------------------------------

     Variable |       Obs        Mean    Std. Dev.       Min        Max
-------------+--------------------------------------------------------
       effect |      1612    .0182288    .0296093          0   .1141725
```

Annex 4

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************************************************************
*         The Dynamic Regime-Shifting IV-Model            *
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/*Denmark*/

ivreg ln_price_cph_interpol cross* lag_price_cph* dum* wind_prod flow_direction
SSNCLCG (consumption central_prod
= cons_lag24 centrprod_lag24)

Instrumental variables (2SLS) regression

      Source |       SS       df       MS              Number of obs =   21816
-------------+------------------------------           F( 60, 21755) = 1390.38
       Model |  3250.13844    60  54.1689741           Prob > F      =  0.0000
    Residual |  847.244573 21755  .038944821           R-squared     =  0.7932
-------------+------------------------------           Adj R-squared =  0.7927
       Total |  4097.38302 21815  .187824113           Root MSE      =  .19734

------------------------------------------------------------------------------
ln_price_c~l |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
 consumption |   .0000167   .0000224     0.75   0.456    -.0000272    .0000606
central_prod |   .0001192   8.77e-06    13.59   0.000      .000102    .0001364
   cross_h_1 |    .000253   .0000521     4.86   0.000      .000151     .000355
     cross_1 |   .0002806   .0000515     5.45   0.000     .0001796    .0003817
   cross_h_2 |   .0002204   .0000197    11.20   0.000     .0001818    .0002589
     cross_2 |   .0002086   .0000355     5.87   0.000      .000139    .0002783
   cross_h_3 |   .0002345   .0000135    17.43   0.000     .0002081    .0002608
     cross_3 |   .0003031   .0000376     8.06   0.000     .0002294    .0003769
   cross_h_4 |   .0001782   .0000106    16.74   0.000     .0001573    .0001991
     cross_4 |   .0001198   .0000257     4.67   0.000     .0000695    .0001701
lag_price~h1 |   .7737004   .0068461   113.01   0.000     .7602815    .7871193
lag_price~h2 |   .0783196   .0085644     9.14   0.000     .0615327    .0951065
lag_price~h3 |  -.0607743   .0085703    -7.09   0.000    -.0775727   -.0439759
lag_price~h4 |  -.0174759   .0085783    -2.04   0.042      -.03429   -.0006618
lag_price~h5 |   .0211975     .00857     2.47   0.013     .0043996    .0379954
lag_price~h6 |  -.0453953   .0085546    -5.31   0.000     -.062163   -.0286276
lag_price~h7 |   .0458253     .00666     6.88   0.000     .0327712    .0588793
     dum_hr1 |   .0138438   .0095765     1.45   0.148    -.0049269    .0326145
     dum_hr2 |  -.0085678   .0100358    -0.85   0.393    -.0282386    .0111031
     dum_hr3 |  -.0069527   .0102496    -0.68   0.498    -.0270427    .0131373
     dum_hr4 |  -.0100222    .010275    -0.98   0.329    -.0301619    .0101174
     dum_hr5 |   .0243394   .0101803     2.39   0.017     .0043854    .0442935
     dum_hr6 |   .0766973   .0097632     7.86   0.000     .0575608    .0958338
     dum_hr7 |   .0770054   .0094214     8.17   0.000     .0585388    .0954721
     dum_hr8 |   .1313167   .0109849    11.95   0.000     .1097854     .152848
     dum_hr9 |   .0959203   .0126195     7.60   0.000     .0711851    .1206556
    dum_hr10 |   .0530439    .013486     3.93   0.000     .0266104    .0794774
    dum_hr11 |   .0569317   .0138868     4.10   0.000     .0297125    .0841509
    dum_hr12 |   .0539534   .0136914     3.94   0.000     .0271172    .0807896
    dum_hr13 |   .0193971   .0133714     1.45   0.147    -.0068119     .045606
    dum_hr14 |   .0296394   .0131497     2.25   0.024      .003865    .0554138
    dum_hr15 |   .0305772   .0127405     2.40   0.016     .0056049    .0555495
    dum_hr16 |   .0289894   .0122905     2.36   0.018     .0048992    .0530795
    dum_hr17 |   .0584307   .0127045     4.60   0.000      .033529    .0833324
    dum_hr18 |   .1118272   .0144865     7.72   0.000     .0834326    .1402218
    dum_hr19 |   .0571582   .0144062     3.97   0.000     .0289211    .0853953
    dum_hr20 |  -.0267722   .0128557    -2.08   0.037    -.0519704   -.0015741
    dum_hr21 |  -.0091208   .0115185    -0.79   0.428    -.0316978    .0134563
    dum_hr22 |   .0347896   .0106877     3.26   0.001     .0138408    .0557383
    dum_hr23 |   .0350333   .0097211     3.60   0.000     .0159793    .0540873
     dum_sun |  -.0214114   .0050763    -4.22   0.000    -.0313612   -.0114615
     dum_mon |  -.0038341   .0062286    -0.62   0.538    -.0160426    .0083744
     dum_tue |   -.010645   .0065803    -1.62   0.106     -.023543    .0022529
     dum_wed |  -.0101542   .0066611    -1.52   0.127    -.0232105    .0029021
     dum_thu |  -.0100883   .0065485    -1.54   0.123    -.0229238    .0027471
     dum_fri |  -.0172386   .0061167    -2.82   0.005    -.0292277   -.0052494
     dum_jan |   .0024847   .0069102     0.36   0.719    -.0110598    .0160292
     dum_feb |   .0069129    .006878     1.01   0.315    -.0065685    .0203943
     dum_mar |   .0196281    .006858     2.86   0.004     .0061859    .0330703
     dum_apr |   .0630123   .0082704     7.62   0.000     .0468017     .079223
```

```
     dum_may |   .0713564   .0097233     7.34   0.000     .0522981    .0904148
     dum_jun |   .0621786   .0102733     6.05   0.000     .0420422    .0823149
     dum_jul |   .0809565   .0122622     6.60   0.000     .0569218    .1049912
     dum_aug |   .0989072   .0106505     9.29   0.000     .0780314     .119783
     dum_sep |   .0726964   .0100599     7.23   0.000     .0529782    .0924146
     dum_oct |   .0585048   .0086224     6.79   0.000     .0416042    .0754054
     dum_nov |   .0207343   .0074172     2.80   0.005      .006196    .0352726
   wind_prod |  -.0000341   9.09e-06    -3.75   0.000     -.000052   -.0000163
flow_direc~n |  -.0189509   .0038792    -4.89   0.000    -.0265544   -.0113473
     SSNCLCG |   .0407427   .0134329     3.03   0.002     .0144132    .0670722
       _cons |   .8937805   .0335873    26.61   0.000     .8279468    .9596141
------------------------------------------------------------------------------


    Variable |       Obs        Mean    Std. Dev.       Min        Max
-------------+--------------------------------------------------------
      effect |      1612    1.093074    .5503521   .0041234   2.948765
```

```
/*Sweden*/

ivreg ln_price_swe_interpol cross* lag_price_swe* dum* wind_prod flow_direction
SSNCLCG (consumption central_prod
= cons_lag24 centrprod_lag24)

Instrumental variables (2SLS) regression

      Source |       SS       df       MS              Number of obs =   21816
-------------+------------------------------           F( 60, 21755) = 3845.43
       Model |  1607.05898    60  26.7843164           Prob > F      =  0.0000
    Residual |  151.512343 21755  .006964484           R-squared     =  0.9138
-------------+------------------------------           Adj R-squared =  0.9136
       Total |  1758.57133 21815  .080612942           Root MSE      =  .08345

------------------------------------------------------------------------------
ln_price_s~l |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
 consumption |  -5.99e-07   9.53e-06    -0.06   0.950    -.0000193    .0000181
central_prod |   .0000384   3.99e-06     9.63   0.000     .0000306    .0000463
   cross_h_1 |   8.99e-06    .000022     0.41   0.682    -.0000341    .0000521
     cross_1 |  -.0000311   .0000218    -1.43   0.154    -.0000739    .0000116
   cross_h_2 |  -3.70e-06   8.27e-06    -0.45   0.654    -.0000199    .0000125
     cross_2 |  -.0000238   .0000151    -1.58   0.113    -.0000534    5.67e-06
   cross_h_3 |  -.0000122   5.65e-06    -2.16   0.031    -.0000233   -1.13e-06
     cross_3 |  -4.66e-06   .0000159    -0.29   0.770    -.0000358    .0000265
   cross_h_4 |  -.0000127   4.49e-06    -2.82   0.005    -.0000215   -3.85e-06
     cross_4 |  -2.85e-06   .0000109    -0.26   0.793    -.0000241    .0000184
lag_price~e1 |   1.072273   .0068433   156.69   0.000     1.058859    1.085686
lag_price~e2 |    -.17092   .0099338   -17.21   0.000     -.190391    -.151449
lag_price~e3 |  -.0256099    .009999    -2.56   0.010    -.0452088   -.0060111
lag_price~e4 |  -.0270801   .0099991    -2.71   0.007    -.0466792   -.0074811
lag_price~e5 |   -.001303   .0099982    -0.13   0.896    -.0209002    .0182942
lag_price~e6 |  -.0194468   .0099308    -1.96   0.050    -.0389119    .0000183
lag_price~e7 |   .0965854   .0067647    14.28   0.000     .0833261    .1098448
     dum_hr1 |   .0252175   .0040393     6.24   0.000     .0173003    .0331348
     dum_hr2 |  -.0054723   .0042187    -1.30   0.195    -.0137413    .0027966
     dum_hr3 |  -.0042319   .0043125    -0.98   0.326    -.0126847     .004221
     dum_hr4 |  -.0065551   .0043282    -1.51   0.130    -.0150387    .0019285
     dum_hr5 |   .0269019   .0042887     6.27   0.000     .0184957     .035308
     dum_hr6 |   .0721179   .0041201    17.50   0.000     .0640422    .0801936
     dum_hr7 |   .0626223   .0039997    15.66   0.000     .0547826     .070462
     dum_hr8 |    .080021   .0046553    17.19   0.000     .0708963    .0891456
     dum_hr9 |   .0807473   .0053348    15.14   0.000     .0702906    .0912039
    dum_hr10 |   .0505027   .0056832     8.89   0.000     .0393633    .0616421
    dum_hr11 |   .0615107   .0058282    10.55   0.000      .050087    .0729344
    dum_hr12 |   .0579966   .0057405    10.10   0.000     .0467447    .0692485
    dum_hr13 |   .0449822   .0056255     8.00   0.000     .0339559    .0560085
    dum_hr14 |   .0424711   .0055477     7.66   0.000     .0315972    .0533451
    dum_hr15 |   .0375245   .0053919     6.96   0.000     .0269559    .0480931
    dum_hr16 |   .0396949   .0052193     7.61   0.000     .0294648     .049925
    dum_hr17 |   .0459059   .0053984     8.50   0.000     .0353247    .0564871
    dum_hr18 |   .0599357   .0061536     9.74   0.000     .0478743    .0719972
    dum_hr19 |   .0416814   .0061224     6.81   0.000     .0296811    .0536816
    dum_hr20 |   .0247903   .0054615     4.54   0.000     .0140852    .0354953
```

dum_hr21	.0320974	.004871	6.59	0.000	.0225499	.041645
dum_hr22	.042206	.0045047	9.37	0.000	.0333764	.0510355
dum_hr23	.0305307	.0041018	7.44	0.000	.022491	.0385705
dum_sun	-.0070644	.0021485	-3.29	0.001	-.0112755	-.0028532
dum_mon	.0048937	.0026413	1.85	0.064	-.0002835	.0100708
dum_tue	.0029335	.0027938	1.05	0.294	-.0025425	.0084096
dum_wed	.0027557	.0028269	0.97	0.330	-.0027852	.0082967
dum_thu	.0018691	.0027805	0.67	0.501	-.0035809	.0073191
dum_fri	-.0004389	.0025916	-0.17	0.866	-.0055187	.0046409
dum_jan	-.0010511	.0029241	-0.36	0.719	-.0067825	.0046804
dum_feb	-.0015967	.0029115	-0.55	0.583	-.0073034	.0041101
dum_mar	.0048294	.0029042	1.66	0.096	-.000863	.0105219
dum_apr	.0122031	.0035809	3.41	0.001	.0051843	.0192218
dum_may	.0130306	.004187	3.11	0.002	.0048239	.0212374
dum_jun	.0111853	.0044088	2.54	0.011	.0025437	.0198269
dum_jul	.0157343	.0052691	2.99	0.003	.0054065	.0260621
dum_aug	.0214924	.0046338	4.64	0.000	.0124099	.0305749
dum_sep	.0159602	.0043258	3.69	0.000	.0074813	.024439
dum_oct	.0117982	.0036797	3.21	0.001	.0045857	.0190107
dum_nov	-.0008882	.0031266	-0.28	0.776	-.0070165	.0052402
wind_prod	-.0000141	3.84e-06	-3.68	0.000	-.0000217	-6.61e-06
flow_direc~n	-.0150352	.0016514	-9.10	0.000	-.0182721	-.0117983
SSNCLCG	.0016542	.0056806	0.29	0.771	-.0094802	.0127885
_cons	.3335905	.0179513	18.58	0.000	.2984047	.3687763

Variable	Obs	Mean	Std. Dev.	Min	Max
effect	1612	.0036469	.0111796	0	.052436

Annex 5

```
*************************************************************
*        The simultaneous equation model for prices         *
*************************************************************
/*Frst-step 2SLS*/
regress consumption swesnit dum* wind_prod flow_direction SSNCLCG cons_lag24
centrprod_lag24

      Source |       SS       df       MS              Number of obs =   21816
-------------+------------------------------           F( 46, 21769) = 6626.14
       Model |  2.8969e+09    46  62976953.3           Prob > F      =  0.0000
    Residual |   206899670 21769  9504.32588           R-squared     =  0.9333
-------------+------------------------------           Adj R-squared =  0.9332
       Total |  3.1038e+09 21815  142280.061           Root MSE      =   97.49

------------------------------------------------------------------------------
 consumption |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
     swesnit |   57.38517    2.74831    20.88   0.000     51.99828    62.77206
     dum_hr1 |  -49.55142   4.615709   -10.74   0.000    -58.59854   -40.50429
     dum_hr2 |  -78.21548   4.683684   -16.70   0.000    -87.39584   -69.03512
     dum_hr3 |  -91.96805   4.723695   -19.47   0.000    -101.2268   -82.70926
     dum_hr4 |   -93.6522   4.739083   -19.76   0.000    -102.9412   -84.36325
     dum_hr5 |  -87.45354    4.72834   -18.50   0.000    -96.72143   -78.18565
     dum_hr6 |  -61.75967   4.650441   -13.28   0.000    -70.87487   -52.64446
     dum_hr7 |   18.39578   4.578851     4.02   0.000     9.420901    27.37067
     dum_hr8 |   115.6779   4.802109    24.09   0.000     106.2654    125.0904
     dum_hr9 |   176.4143   5.067928    34.81   0.000     166.4808    186.3478
    dum_hr10 |   204.0382   5.235477    38.97   0.000     193.7763    214.3002
    dum_hr11 |   216.2624   5.322534    40.63   0.000     205.8299     226.695
    dum_hr12 |   209.9156   5.307101    39.55   0.000     199.5133    220.3179
    dum_hr13 |   202.1481   5.252556    38.49   0.000     191.8527    212.4435
    dum_hr14 |   196.9551   5.206401    37.83   0.000     186.7501      207.16
    dum_hr15 |   185.1761   5.127054    36.12   0.000     175.1267    195.2255
    dum_hr16 |   171.6051   5.041544    34.04   0.000     161.7233    181.4869
    dum_hr17 |   184.1936   5.102973    36.10   0.000     174.1914    194.1958
    dum_hr18 |   234.1764   5.418556    43.22   0.000     223.5556    244.7971
    dum_hr19 |   232.4193   5.415672    42.92   0.000     221.8042    243.0344
    dum_hr20 |   188.7321   5.145809    36.68   0.000      178.646    198.8183
    dum_hr21 |   141.7517   4.922278    28.80   0.000     132.1037    151.3997
    dum_hr22 |    109.571   4.775701    22.94   0.000     100.2102    118.9317
    dum_hr23 |   59.02019    4.63873    12.72   0.000     49.92794    68.11244
     dum_sun |   68.47557    2.67058    25.64   0.000     63.24104     73.7101
     dum_mon |   324.5265   2.811244   115.44   0.000     319.0163    330.0367
     dum_tue |   214.3496   2.500176    85.73   0.000     209.4491    219.2501
     dum_wed |   201.2932   2.504467    80.37   0.000     196.3842    206.2021
     dum_thu |   187.2591   2.511732    74.55   0.000     182.3359    192.1822
     dum_fri |   156.5854   2.493241    62.80   0.000     151.6984    161.4723
     dum_jan |   49.25767    3.30017    14.93   0.000     42.78909    55.72624
     dum_feb |   27.25408   3.352925     8.13   0.000      20.6821    33.82606
     dum_mar |  -16.58732   3.313166    -5.01   0.000    -23.08137   -10.09327
     dum_apr |  -84.72959    3.56935   -23.74   0.000    -91.72577    -77.7334
     dum_may |  -130.5738   3.831832   -34.08   0.000    -138.0844   -123.0631
     dum_jun |   -150.619   3.919557   -38.43   0.000    -158.3016   -142.9363
     dum_jul |   -186.631   4.548506   -41.03   0.000    -195.5464   -177.7156
     dum_aug |  -125.6232   4.211153   -29.83   0.000    -133.8774    -117.369
     dum_sep |  -119.3268   4.106083   -29.06   0.000    -127.3751   -111.2786
     dum_oct |  -74.88091   3.827223   -19.57   0.000    -82.38255   -67.37927
     dum_nov |  -15.48637    3.62835    -4.27   0.000    -22.59821   -8.374543
   wind_prod |   .0380615   .0040919     9.30   0.000      .030041     .046082
flow_direc~n |   52.34013   1.692976    30.92   0.000     49.02177    55.65848
     SSNCLCG |   25.49458   6.590926     3.87   0.000     12.57588    38.41327
  cons_lag24 |   .5167418   .0056348    91.71   0.000     .5056972    .5277864
centrprod~24 |    .054779    .002596    21.10   0.000     .0496905    .0598674
       _cons |   492.6671   9.742495    50.57   0.000     473.5711    511.7631
------------------------------------------------------------------------------

. predict fit_cons_dk, xb
(24 missing values generated)

. regress cons_se swesnit dum* wind_prod flow_direction SSNCLCG cons_selag24
centrprod_lag24

      Source |       SS       df       MS              Number of obs =   21816
```

```
-------------+------------------------------           F( 46, 21769) = 5981.89
       Model |  2.8197e+11    46  6.1297e+09           Prob > F      =  0.0000
    Residual |  2.2307e+10 21769     1024706           R-squared     =  0.9267
-------------+------------------------------           Adj R-squared =  0.9265
       Total |  3.0427e+11 21815  13947842.8           Root MSE      =  1012.3

------------------------------------------------------------------------------
     cons_se |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
     swesnit |   444.5976   28.53411    15.58   0.000     388.6686    500.5265
     dum_hr1 |  -218.8019   47.61135    -4.60   0.000    -312.1236   -125.4801
     dum_hr2 |  -317.1415   47.79909    -6.63   0.000    -410.8312   -223.4518
     dum_hr3 |  -373.9646   47.90515    -7.81   0.000    -467.8622    -280.067
     dum_hr4 |  -352.7121   47.95041    -7.36   0.000    -446.6984   -258.7257
     dum_hr5 |  -319.2807   47.95134    -6.66   0.000    -413.2689   -225.2926
     dum_hr6 |  -162.5332   47.65515    -3.41   0.001    -255.9408   -69.12562
     dum_hr7 |   290.0131   47.65933     6.09   0.000     196.5974    383.4289
     dum_hr8 |   702.9398   48.65578    14.45   0.000     607.5709    798.3087
     dum_hr9 |   863.0638   49.22039    17.53   0.000     766.5882    959.5394
    dum_hr10 |   904.3681   49.50352    18.27   0.000     807.3376    1001.399
    dum_hr11 |   945.1947   49.76004    19.00   0.000     847.6614    1042.728
    dum_hr12 |   910.0358   49.77158    18.28   0.000     812.4799    1007.592
    dum_hr13 |   860.1629   49.50414    17.38   0.000     763.1312    957.1946
    dum_hr14 |   814.4958   49.22444    16.55   0.000     718.0123    910.9793
    dum_hr15 |   787.5583   49.01849    16.07   0.000     691.4785    883.6381
    dum_hr16 |   821.0368   48.99763    16.76   0.000     724.9979    917.0758
    dum_hr17 |   830.7723   49.03409    16.94   0.000     734.6619    926.8827
    dum_hr18 |   842.6327   49.34172    17.08   0.000     745.9193     939.346
    dum_hr19 |   802.7577   49.27304    16.29   0.000     706.1789    899.3364
    dum_hr20 |   751.0827   48.94494    15.35   0.000     655.1471    847.0184
    dum_hr21 |    639.251   48.60744    13.15   0.000     543.9769    734.5251
    dum_hr22 |   519.1014   48.14911    10.78   0.000     424.7256    613.4772
    dum_hr23 |    275.017   47.71632     5.76   0.000     181.4895    368.5445
     dum_sun |   833.3642   26.73531    31.17   0.000     780.9611    885.7674
     dum_mon |   2763.134   27.11965   101.89   0.000     2709.978    2816.291
     dum_tue |   1580.909    26.0029    60.80   0.000     1529.942    1631.877
     dum_wed |   1516.942   26.00525    58.33   0.000      1465.97    1567.914
     dum_thu |   1437.359   26.06489    55.15   0.000      1386.27    1488.448
     dum_fri |    1089.15   25.88718    42.07   0.000     1038.409    1139.891
     dum_jan |   376.5769   34.21956    11.00   0.000      309.504    443.6497
     dum_feb |   364.3456   34.91507    10.44   0.000     295.9095    432.7817
     dum_mar |  -146.5604   34.33584    -4.27   0.000    -213.8612   -79.25967
     dum_apr |  -1196.115   38.57193   -31.01   0.000    -1271.718   -1120.511
     dum_may |  -1858.285   43.12294   -43.09   0.000    -1942.809   -1773.761
     dum_jun |  -2408.722   48.01032   -50.17   0.000    -2502.826   -2314.619
     dum_jul |  -2846.581   54.59302   -52.14   0.000    -2953.587   -2739.575
     dum_aug |  -2331.348   50.74311   -45.94   0.000    -2430.808   -2231.888
     dum_sep |  -1932.148   47.21193   -40.92   0.000    -2024.686   -1839.609
     dum_oct |  -1112.133   41.20957   -26.99   0.000    -1192.907   -1031.359
     dum_nov |  -346.8944   38.09647    -9.11   0.000    -421.5663   -272.2226
   wind_prod |  -.5567211   .0424791   -13.11   0.000    -.6399832    -.473459
flow_direc~n |   297.4001   17.53469    16.96   0.000     263.0308    331.7694
     SSNCLCG |   80.45623   68.43213     1.18   0.240    -53.67575    214.5882
cons_selag24 |   .5992962   .0054796   109.37   0.000     .5885558    .6100367
centrprod~24 |   .4341278   .0275851    15.74   0.000     .3800589    .4881967
       _cons |   5457.901   105.2229    51.87   0.000     5251.657    5664.146
------------------------------------------------------------------------------

. predict fit_cons_se, xb
(24 missing values generated)
```

```
/*Denmark & Sweden*/
sureg (ln_price_cph_interpol swesnit dum* wind_prod flow_direction SSNCLCG
fit_cons_dk) (ln_price_swe_interpol swe
snit dum* wind_prod flow_direction SSNCLCG fit_cons_se), isure

Seemingly unrelated regression, iterated
----------------------------------------------------------------------
Equation          Obs  Parms        RMSE    "R-sq"       chi2        P
----------------------------------------------------------------------
ln_price_c~l    21816     45    .3628173    0.2991    9008.81   0.0000
ln_price_s~l    21816     45    .2376265    0.2995    8858.92   0.0000
----------------------------------------------------------------------

------------------------------------------------------------------------------
             |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
ln_price_c~l |
     swesnit |   .3916092   .0105308    37.19   0.000     .3709692    .4122491
     dum_hr1 |   .0597093   .0173327     3.44   0.001     .0257378    .0936807
     dum_hr2 |   .0639072   .0178083     3.59   0.000     .0290036    .0988109
     dum_hr3 |   .0539559   .0180905     2.98   0.003     .0184992    .0894126
     dum_hr4 |   .0226149   .0181713     1.24   0.213    -.0130002      .05823
     dum_hr5 |     .01916   .0180632     1.06   0.289    -.0162434    .0545633
     dum_hr6 |   .0358369    .017532     2.04   0.041     .0014749     .070199
     dum_hr7 |   -.063209   .0170636    -3.70   0.000     -.096653   -.0297651
     dum_hr8 |   -.157402   .0186892    -8.42   0.000    -.1940322   -.1207719
     dum_hr9 |  -.2131061   .0205904   -10.35   0.000    -.2534626   -.1727496
    dum_hr10 |  -.2490778   .0217001   -11.48   0.000    -.2916093   -.2065463
    dum_hr11 |  -.2658708   .0222504   -11.95   0.000    -.3094808   -.2222608
    dum_hr12 |  -.2547131    .022072   -11.54   0.000    -.2979734   -.2114529
    dum_hr13 |  -.2647922   .0217199   -12.19   0.000    -.3073625    -.222222
    dum_hr14 |  -.2693727   .0214466   -12.56   0.000    -.3114073   -.2273381
    dum_hr15 |  -.2597506   .0209395   -12.40   0.000    -.3007913     -.21871
    dum_hr16 |  -.2429519   .0203911   -11.91   0.000    -.2829177   -.2029862
    dum_hr17 |  -.2581969   .0208203   -12.40   0.000    -.2990039   -.2173898
    dum_hr18 |  -.3035476   .0228727   -13.27   0.000    -.3483774   -.2587179
    dum_hr19 |  -.2908293   .0228376   -12.73   0.000    -.3355901   -.2460684
    dum_hr20 |  -.2627631    .021058   -12.48   0.000     -.304036   -.2214903
    dum_hr21 |  -.2071845   .0194799   -10.64   0.000    -.2453644   -.1690046
    dum_hr22 |   -.142022   .0184907    -7.68   0.000    -.1782631    -.105781
    dum_hr23 |  -.0569515    .017485    -3.26   0.001    -.0912216   -.0226815
     dum_sun |  -.0813494   .0093028    -8.74   0.000    -.0995827   -.0631162
     dum_mon |  -.0566157   .0107855    -5.25   0.000     -.077755   -.0354765
     dum_tue |   -.077176   .0112745    -6.85   0.000    -.0992736   -.0550784
     dum_wed |  -.0777079   .0113768    -6.83   0.000    -.1000061   -.0554097
     dum_thu |  -.0768322   .0112334    -6.84   0.000    -.0988493    -.054815
     dum_fri |  -.0975684   .0106057    -9.20   0.000    -.1183553   -.0767816
     dum_jan |  -.0725901   .0124526    -5.83   0.000    -.0969968   -.0481835
     dum_feb |    .004936   .0125483     0.39   0.694    -.0196583    .0295303
     dum_mar |   .2148423   .0122153    17.59   0.000     .1909007    .2387839
     dum_apr |   .3060436   .0140244    21.82   0.000     .2785563    .3335308
     dum_may |   .3098546   .0158764    19.52   0.000     .2787373    .3409718
     dum_jun |   .4064575   .0164949    24.64   0.000      .374128     .438787
     dum_jul |   .3150267   .0196271    16.05   0.000     .2765582    .3534951
     dum_aug |   .3733832   .0170666    21.88   0.000     .3399333     .406833
     dum_sep |   .2596595   .0165404    15.70   0.000      .227241     .292078
     dum_oct |   .1950969   .0147854    13.20   0.000     .1661181    .2240756
     dum_nov |   .0992611   .0135324     7.34   0.000     .0727382    .1257841
   wind_prod |  -.0004385   .0000152   -28.90   0.000    -.0004683   -.0004088
flow_direc~n |  -.1421732   .0064544   -22.03   0.000    -.1548236   -.1295228
     SSNCLCG |  -.0305147   .0244851    -1.25   0.213    -.0785045    .0174751
 fit_cons_dk |   .0009118   .0000296    30.79   0.000     .0008538    .0009699
       _cons |    4.12088   .0451459    91.28   0.000     4.032396    4.209365
-------------+----------------------------------------------------------------
ln_price_s~l |
     swesnit |  -.0068144   .0067976    -1.00   0.316    -.0201374    .0065086
     dum_hr1 |   .0150605    .011193     1.35   0.178    -.0068774    .0369984
     dum_hr2 |   -.011684   .0112556    -1.04   0.299    -.0337445    .0103766
     dum_hr3 |  -.0397947   .0112931    -3.52   0.000    -.0619288   -.0176606
     dum_hr4 |  -.0805885   .0113002    -7.13   0.000    -.1027365   -.0584405
     dum_hr5 |  -.0834778   .0112924    -7.39   0.000    -.1056106    -.061345
     dum_hr6 |  -.0471203   .0111957    -4.21   0.000    -.0690635   -.0251772
     dum_hr7 |  -.0686324   .0112132    -6.12   0.000      -.09061   -.0466549
     dum_hr8 |  -.0701234   .0115821    -6.05   0.000     -.092824   -.0474229
     dum_hr9 |  -.0456863   .0117975    -3.87   0.000    -.0688091   -.0225636
```

dum_hr10	-.0379992	.0118919	-3.20	0.001	-.0613068	-.0146916
dum_hr11	-.0385021	.011977	-3.21	0.001	-.0619766	-.0150275
dum_hr12	-.0332812	.0119599	-2.78	0.005	-.0567221	-.0098402
dum_hr13	-.039122	.0118685	-3.30	0.001	-.0623837	-.0158602
dum_hr14	-.0476573	.0117777	-4.05	0.000	-.0707412	-.0245734
dum_hr15	-.058457	.0117129	-4.99	0.000	-.0814139	-.0355
dum_hr16	-.0707981	.0117194	-6.04	0.000	-.0937677	-.0478285
dum_hr17	-.0707174	.0117323	-6.03	0.000	-.0937124	-.0477224
dum_hr18	-.0531249	.0118164	-4.50	0.000	-.0762846	-.0299652
dum_hr19	-.0426353	.0117834	-3.62	0.000	-.0657303	-.0195403
dum_hr20	-.0497036	.0116776	-4.26	0.000	-.0725913	-.0268158
dum_hr21	-.0385462	.0115471	-3.34	0.001	-.0611781	-.0159143
dum_hr22	-.0235888	.0113918	-2.07	0.038	-.0459164	-.0012613
dum_hr23	.0045915	.0112274	0.41	0.683	-.0174138	.0265968
dum_sun	-.0829416	.0060514	-13.71	0.000	-.0948021	-.0710811
dum_mon	-.0281628	.0066379	-4.24	0.000	-.0411729	-.0151527
dum_tue	-.0196169	.0067048	-2.93	0.003	-.0327581	-.0064757
dum_wed	-.0135236	.006697	-2.02	0.043	-.0266496	-.0003977
dum_thu	-.0192957	.0066722	-2.89	0.004	-.0323729	-.0062185
dum_fri	-.020199	.0064061	-3.15	0.002	-.0327547	-.0076433
dum_jan	-.0547993	.008081	-6.78	0.000	-.0706378	-.0389607
dum_feb	-.0301636	.0082587	-3.65	0.000	-.0463503	-.0139769
dum_mar	.1631672	.0079918	20.42	0.000	.1475035	.1788309
dum_apr	.3198176	.0096745	33.06	0.000	.3008559	.3387793
dum_may	.3298419	.0114955	28.69	0.000	.3073111	.3523727
dum_jun	.4914407	.0130097	37.77	0.000	.4659421	.5169394
dum_jul	.3971178	.0152846	25.98	0.000	.3671605	.4270751
dum_aug	.476983	.0137555	34.68	0.000	.4500227	.5039433
dum_sep	.3192612	.0124795	25.58	0.000	.2948018	.3437206
dum_oct	.197273	.0102335	19.28	0.000	.1772157	.2173304
dum_nov	.0457557	.0089948	5.09	0.000	.0281262	.0633851
wind_prod	-.0002402	.00001	-23.95	0.000	-.0002598	-.0002205
flow_direc~n	-.1282543	.0040905	-31.35	0.000	-.1362716	-.1202371
SSNCLCG	-.0684135	.0160345	-4.27	0.000	-.0998405	-.0369864
fit_cons_se	.0000681	1.58e-06	43.00	0.000	.000065	.0000712
_cons	4.264211	.0295537	144.29	0.000	4.206287	4.322135

Annex 6

```
**************************************************************
* The Regime-Shifting simultaneous equation model for prices *
**************************************************************

/*Frst-step 2SLS*/
regress  consumption  swesnit_low  swesnit_high  dum*  wind_prod  flow_direction
SSNCLCG cons_lag24 centrprod_lag24

      Source |       SS       df       MS              Number of obs =   21816
-------------+------------------------------           F( 47, 21768) = 6492.06
       Model |  2.8972e+09    47  61641578.8           Prob > F      =  0.0000
    Residual |   206685316 21768  9494.91528           R-squared     =  0.9334
-------------+------------------------------           Adj R-squared =  0.9333
       Total |  3.1038e+09 21815  142280.061           Root MSE      =  97.442

------------------------------------------------------------------------------
 consumption |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
 swesnit_low |   77.09198    4.97476    15.50   0.000     67.34108    86.84287
swesnit_high |   50.24839   3.130792    16.05   0.000     44.11181    56.38497
     dum_hr1 |  -49.49452   4.613439   -10.73   0.000     -58.5372   -40.45185
     dum_hr2 |  -78.12236   4.681405   -16.69   0.000    -87.29826   -68.94647
     dum_hr3 |  -91.86198   4.721409   -19.46   0.000    -101.1163   -82.60767
     dum_hr4 |  -93.53924   4.736796   -19.75   0.000    -102.8237   -84.25477
     dum_hr5 |   -87.3512   4.726048   -18.48   0.000     -96.6146    -78.0878
     dum_hr6 |  -61.70714   4.648152   -13.28   0.000    -70.81786   -52.59642
     dum_hr7 |   18.44322   4.576595     4.03   0.000     9.472765    27.41368
     dum_hr8 |   115.4581   4.799954    24.05   0.000     106.0498    124.8663
     dum_hr9 |   176.0769   5.065916    34.76   0.000     166.1473    186.0064
    dum_hr10 |   203.6011   5.233693    38.90   0.000     193.3427    213.8595
    dum_hr11 |   215.6163   5.321636    40.52   0.000     205.1855    226.0471
    dum_hr12 |   209.2446   5.306353    39.43   0.000     198.8437    219.6454
    dum_hr13 |   201.7541    5.25061    38.42   0.000     191.4626    212.0457
    dum_hr14 |   196.7838   5.203948    37.81   0.000     186.5837    206.9839
    dum_hr15 |    185.042   5.124593    36.11   0.000     174.9974    195.0866
    dum_hr16 |   171.4462   5.039158    34.02   0.000     161.5691    181.3233
    dum_hr17 |   184.1427   5.100458    36.10   0.000     174.1454    194.1399
    dum_hr18 |   233.9549   5.416074    43.20   0.000      223.339    244.5708
    dum_hr19 |   232.1014   5.413403    42.88   0.000     221.4908    242.7121
    dum_hr20 |   188.7907   5.143276    36.71   0.000     178.7095    198.8719
    dum_hr21 |   141.8212   4.919863    28.83   0.000     132.1779    151.4645
    dum_hr22 |   109.6394   4.773358    22.97   0.000     100.2833    118.9955
    dum_hr23 |   59.01549   4.636433    12.73   0.000     49.92774    68.10323
     dum_sun |   68.68262   2.669614    25.73   0.000     63.44998    73.91526
     dum_mon |      324.5   2.809857   115.49   0.000     318.9925    330.0076
     dum_tue |   214.3244   2.498943    85.77   0.000     209.4263    219.2225
     dum_wed |   201.2294   2.503263    80.39   0.000     196.3228     206.136
     dum_thu |   187.0142   2.511017    74.48   0.000     182.0924     191.936
     dum_fri |    156.506   2.492063    62.80   0.000     151.6213    161.3906
     dum_jan |   48.29193   3.304792    14.61   0.000      41.8143    54.76957
     dum_feb |   26.16471   3.359098     7.79   0.000     19.58063    32.74879
     dum_mar |  -16.76527   3.311737    -5.06   0.000    -23.25652   -10.27402
     dum_apr |  -85.17512   3.568815   -23.87   0.000    -92.17025   -78.17998
     dum_may |  -130.7599   3.830134   -34.14   0.000    -138.2672   -123.2525
     dum_jun |  -151.3757   3.920853   -38.61   0.000    -159.0609   -143.6906
     dum_jul |  -186.5224   4.546311   -41.03   0.000    -195.4335   -177.6113
     dum_aug |  -126.0447   4.210003   -29.94   0.000    -134.2966   -117.7928
     dum_sep |  -119.3096   4.104051   -29.07   0.000    -127.3538   -111.2653
     dum_oct |  -75.14007   3.825717   -19.64   0.000    -82.63875   -67.64138
     dum_nov |  -15.00521   3.627967    -4.14   0.000    -22.11629   -7.894127
   wind_prod |   .0378206   .0040902     9.25   0.000     .0298034    .0458377
flow_direc~n |   52.39809   1.692181    30.96   0.000     49.08129    55.71489
     SSNCLCG |   25.63918   6.587732     3.89   0.000     12.72674    38.55161
  cons_lag24 |   .5170788   .0056325    91.80   0.000     .5060388    .5281189
centrprod~24 |   .0557208   .0026023    21.41   0.000       .05062    .0608215
       _cons |   491.6089   9.740217    50.47   0.000     472.5173    510.7004
------------------------------------------------------------------------------

predict fit_cons_dk, xb
(24 missing values generated)

regress cons_se swesnit_low swesnit_high dum* wind_prod flow_direction SSNCLCG
cons_selag24 centrprod_lag24
```

Source	SS	df	MS
Model	2.8199e+11	47	5.9998e+09
Residual	2.2283e+10	21768	1023639.75
Total	3.0427e+11	21815	13947842.8

Number of obs	=	21816
F(47, 21768)	=	5861.22
Prob > F	=	0.0000
R-squared	=	0.9268
Adj R-squared	=	0.9266
Root MSE	=	1011.8

cons_se	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
swesnit_low	654.3639	51.69061	12.66	0.000	553.0466	755.6813
swesnit_high	368.9594	32.48076	11.36	0.000	305.2948	432.6241
dum_hr1	-218.608	47.58659	-4.59	0.000	-311.8812	-125.3348
dum_hr2	-316.8043	47.77427	-6.63	0.000	-410.4453	-223.1633
dum_hr3	-373.604	47.88028	-7.80	0.000	-467.4528	-279.7551
dum_hr4	-352.2988	47.92553	-7.35	0.000	-446.2363	-258.3612
dum_hr5	-318.9384	47.92644	-6.65	0.000	-412.8777	-224.9991
dum_hr6	-162.496	47.63035	-3.41	0.001	-255.855	-69.13703
dum_hr7	290.6705	47.63472	6.10	0.000	197.303	384.0381
dum_hr8	701.5889	48.63126	14.43	0.000	606.268	796.9097
dum_hr9	860.9386	49.19671	17.50	0.000	764.5094	957.3677
dum_hr10	901.4096	49.48149	18.22	0.000	804.4223	998.3969
dum_hr11	940.1219	49.74507	18.90	0.000	842.6179	1037.626
dum_hr12	904.6619	49.75794	18.18	0.000	807.1327	1002.191
dum_hr13	857.6656	49.48104	17.33	0.000	760.6791	954.652
dum_hr14	814.3102	49.19884	16.55	0.000	717.8769	910.7435
dum_hr15	787.665	48.99298	16.08	0.000	691.6352	883.6948
dum_hr16	820.7699	48.97216	16.76	0.000	724.7809	916.7589
dum_hr17	831.7469	49.00898	16.97	0.000	735.6858	927.8081
dum_hr18	842.1899	49.31613	17.08	0.000	745.5267	938.8531
dum_hr19	801.2773	49.24834	16.27	0.000	704.7469	897.8076
dum_hr20	753.2626	48.92152	15.40	0.000	657.3729	849.1524
dum_hr21	641.1864	48.58377	13.20	0.000	545.9586	736.4141
dum_hr22	520.746	48.12524	10.82	0.000	426.417	615.0749
dum_hr23	275.4698	47.69158	5.78	0.000	181.9909	368.9488
dum_sun	834.9373	26.72336	31.24	0.000	782.5576	887.317
dum_mon	2761.994	27.10655	101.89	0.000	2708.864	2815.125
dum_tue	1580.647	25.98942	60.82	0.000	1529.706	1631.588
dum_wed	1516.36	25.99199	58.34	0.000	1465.414	1567.306
dum_thu	1434.872	26.05634	55.07	0.000	1383.799	1485.944
dum_fri	1088.389	25.87418	42.06	0.000	1037.673	1139.104
dum_jan	366.5834	34.26336	10.70	0.000	299.4247	433.7421
dum_feb	352.9238	34.97577	10.09	0.000	284.3688	421.4789
dum_mar	-148.6612	34.32068	-4.33	0.000	-215.9322	-81.39011
dum_apr	-1201.693	38.5689	-31.16	0.000	-1277.291	-1126.095
dum_may	-1861.446	43.10539	-43.18	0.000	-1945.936	-1776.956
dum_jun	-2418.286	48.02558	-50.35	0.000	-2512.419	-2324.152
dum_jul	-2847.103	54.56471	-52.18	0.000	-2954.054	-2740.153
dum_aug	-2337.096	50.73046	-46.07	0.000	-2436.532	-2237.661
dum_sep	-1933.066	47.18773	-40.97	0.000	-2025.557	-1840.575
dum_oct	-1115.603	41.1943	-27.08	0.000	-1196.347	-1034.859
dum_nov	-342.041	38.08971	-8.98	0.000	-416.6996	-267.3824
wind_prod	-.5592157	.0424601	-13.17	0.000	-.6424405	-.4759908
flow_direc~n	298.2222	17.52638	17.02	0.000	263.8692	332.5752
SSNCLCG	82.08125	68.39734	1.20	0.230	-51.98252	216.145
cons_selag24	.5992439	.0054768	109.42	0.000	.588509	.6099787
centrprod~24	.444837	.0276585	16.08	0.000	.3906243	.4990496
_cons	5452.53	105.1739	51.84	0.000	5246.382	5658.679

```
. predict fit_cons_se, xb
(24 missing values generated)
```

```
/*Denmark & Sweden*/

sureg (ln_price_cph_interpol swesnit_low swesnit_high dum* wind_prod
flow_direction SSNCLCG fit_cons_dk) (ln_price
_swe_interpol swesnit_low swesnit_high dum* wind_prod flow_direction SSNCLCG
fit_cons_se), isure


Seemingly unrelated regression, iterated
----------------------------------------------------------------------
Equation          Obs  Parms        RMSE    "R-sq"       chi2        P
----------------------------------------------------------------------
ln_price_c~l    21816     46    .3604209    0.3083    9432.92   0.0000
ln_price_s~l    21816     46     .237043    0.3029    9013.40   0.0000
----------------------------------------------------------------------

------------------------------------------------------------------------------
             |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
ln_price_c~l |
 swesnit_low |   .1115567    .018547     6.01   0.000     .0752053    .1479081
swesnit_high |   .4943487   .0118209    41.82   0.000     .4711801    .5175173
     dum_hr1 |   .0574559   .0172184     3.34   0.001     .0237084    .0912034
     dum_hr2 |   .0602793   .0176912     3.41   0.001     .0256051    .0949534
     dum_hr3 |   .0496924   .0179717     2.77   0.006     .0144684    .0849163
     dum_hr4 |   .0182438   .0180521     1.01   0.312    -.0171376    .0536252
     dum_hr5 |   .0150815   .0179446     0.84   0.401    -.0200893    .0502524
     dum_hr6 |   .0330571   .0174165     1.90   0.058    -.0010786    .0671929
     dum_hr7 |  -.0635209    .016951    -3.75   0.000    -.0967442   -.0302976
     dum_hr8 |  -.1510699   .0185672    -8.14   0.000    -.1874609   -.1146789
     dum_hr9 |  -.2032583   .0204575    -9.94   0.000    -.2433543   -.1631624
    dum_hr10 |  -.2369903   .0215611   -10.99   0.000    -.2792492   -.1947313
    dum_hr11 |  -.2504555   .0221104   -11.33   0.000    -.2937911   -.2071199
    dum_hr12 |  -.2391191   .0219334   -10.90   0.000    -.2821079   -.1961303
    dum_hr13 |  -.2533276   .0215804   -11.74   0.000    -.2956244   -.2110309
    dum_hr14 |  -.2611819   .0213076   -12.26   0.000     -.302944   -.2194197
    dum_hr15 |   -.252405   .0208035   -12.13   0.000    -.2931791   -.2116308
    dum_hr16 |  -.2356558   .0202585   -11.63   0.000    -.2753618   -.1959499
    dum_hr17 |  -.2519945    .020685   -12.18   0.000    -.2925364   -.2114526
    dum_hr18 |  -.2932762   .0227252   -12.91   0.000    -.3378169   -.2487356
    dum_hr19 |  -.2792834   .0226908   -12.31   0.000    -.3237565   -.2348103
    dum_hr20 |  -.2579846   .0209215   -12.33   0.000    -.2989899   -.2169792
    dum_hr21 |  -.2040309    .019353   -10.54   0.000    -.2419621   -.1660998
    dum_hr22 |  -.1397728   .0183697    -7.61   0.000    -.1757767   -.1037689
    dum_hr23 |  -.0551904   .0173698    -3.18   0.001    -.0892347   -.0211462
     dum_sun |  -.0820167   .0092414    -8.87   0.000    -.1001296   -.0639038
     dum_mon |  -.0486576   .0107186    -4.54   0.000    -.0696657   -.0276495
     dum_tue |   -.072268   .0112015    -6.45   0.000    -.0942225   -.0503135
     dum_wed |  -.0728809   .0113031    -6.45   0.000    -.0950346   -.0507272
     dum_thu |  -.0698744   .0111621    -6.26   0.000    -.0917517   -.0479972
     dum_fri |  -.0934921   .0105367    -8.87   0.000    -.1141437   -.0728404
     dum_jan |  -.0573052   .0123937    -4.62   0.000    -.0815965    -.033014
     dum_feb |   .0204168   .0124907     1.63   0.102    -.0040645    .0448981
     dum_mar |   .2149138   .0121347    17.71   0.000     .1911303    .2386974
     dum_apr |   .3116723   .0139414    22.36   0.000     .2843476    .3389971
     dum_may |   .3130868   .0157806    19.84   0.000     .2821574    .3440161
     dum_jun |   .4147137   .0164062    25.28   0.000     .3825582    .4468693
     dum_jul |   .3147316    .019505    16.14   0.000     .2765025    .3529607
     dum_aug |   .3814652   .0169723    22.48   0.000     .3482002    .4147303
     dum_sep |   .2612816    .016437    15.90   0.000     .2290657    .2934976
     dum_oct |   .2005149   .0146965    13.64   0.000     .1717104    .2293195
     dum_nov |   .0924231    .013447     6.87   0.000     .0660675    .1187786
   wind_prod |  -.0004324   .0000151   -28.67   0.000    -.0004619   -.0004028
flow_direc~n |  -.1404927    .006412   -21.91   0.000    -.1530601   -.1279253
     SSNCLCG |  -.0300802   .0243233    -1.24   0.216    -.0777531    .0175926
 fit_cons_dk |   .0008898   .0000294    30.23   0.000     .0008321    .0009475
       _cons |   4.140711   .0448607    92.30   0.000     4.052785    4.228636
-------------+----------------------------------------------------------------
ln_price_s~l |
 swesnit_low |   -.122218   .0121537   -10.06   0.000    -.1460388   -.0983972
swesnit_high |   .0348671     .00768     4.54   0.000     .0198147    .0499196
     dum_hr1 |   .0148688   .0111656     1.33   0.183    -.0070153    .0367529
     dum_hr2 |  -.0119798   .0112281    -1.07   0.286    -.0339864    .0100268
     dum_hr3 |  -.0401457   .0112655    -3.56   0.000    -.0622257   -.0180657
     dum_hr4 |  -.0809148   .0112726    -7.18   0.000    -.1030086   -.0588209
```

dum_hr5	-.0837609	.0112648	-7.44	0.000	-.1058395	-.0616823
dum_hr6	-.0472199	.0111682	-4.23	0.000	-.0691093	-.0253306
dum_hr7	-.0687915	.0111858	-6.15	0.000	-.0907153	-.0468677
dum_hr8	-.0690373	.0115542	-5.98	0.000	-.0916831	-.0463915
dum_hr9	-.0441522	.0117694	-3.75	0.000	-.0672197	-.0210846
dum_hr10	-.036049	.0118638	-3.04	0.002	-.0593016	-.0127965
dum_hr11	-.0353912	.01195	-2.96	0.003	-.0588127	-.0119697
dum_hr12	-.0300288	.011933	-2.52	0.012	-.0534172	-.0066405
dum_hr13	-.0374626	.0118402	-3.16	0.002	-.060669	-.0142562
dum_hr14	-.0472773	.0117494	-4.02	0.000	-.0703057	-.0242488
dum_hr15	-.0582144	.0116848	-4.98	0.000	-.0811163	-.0353126
dum_hr16	-.070268	.0116912	-6.01	0.000	-.0931823	-.0473536
dum_hr17	-.0708588	.0117044	-6.05	0.000	-.0937989	-.0479186
dum_hr18	-.052547	.011788	-4.46	0.000	-.075651	-.0294429
dum_hr19	-.0415498	.011755	-3.53	0.000	-.0645893	-.0185104
dum_hr20	-.0506103	.0116503	-4.34	0.000	-.0734445	-.0277761
dum_hr21	-.0393475	.0115198	-3.42	0.001	-.0619259	-.0167691
dum_hr22	-.0242471	.0113645	-2.13	0.033	-.0465212	-.001973
dum_hr23	.0044454	.0111999	0.40	0.691	-.0175061	.0263969
dum_sun	-.0829109	.0060365	-13.73	0.000	-.0947423	-.0710796
dum_mon	-.0258629	.0066239	-3.90	0.000	-.0388455	-.0128802
dum_tue	-.0187977	.006689	-2.81	0.005	-.0319079	-.0056874
dum_wed	-.012798	.0066812	-1.92	0.055	-.025893	.000297
dum_thu	-.0176342	.006657	-2.65	0.008	-.0306818	-.0045867
dum_fri	-.0195521	.0063907	-3.06	0.002	-.0320777	-.0070265
dum_jan	-.0489652	.0080759	-6.06	0.000	-.0647936	-.0331367
dum_feb	-.0239582	.0082546	-2.90	0.004	-.0401369	-.0077795
dum_mar	.1633392	.0079722	20.49	0.000	.1477139	.1789645
dum_apr	.3226897	.0096586	33.41	0.000	.3037593	.3416202
dum_may	.3320184	.0114756	28.93	0.000	.3095265	.3545102
dum_jun	.4954042	.0129932	38.13	0.000	.4699379	.5208704
dum_jul	.3979945	.0152558	26.09	0.000	.3680936	.4278954
dum_aug	.480651	.0137359	34.99	0.000	.453729	.507573
dum_sep	.3204752	.0124553	25.73	0.000	.2960634	.3448871
dum_oct	.2000086	.0102155	19.58	0.000	.1799865	.2200307
dum_nov	.0429376	.0089754	4.78	0.000	.0253461	.060529
wind_prod	-.0002383	.00001	-23.81	0.000	-.0002579	-.0002187
flow_direc~n	-.127972	.0040805	-31.36	0.000	-.1359697	-.1199743
SSNCLCG	-.0683954	.0159951	-4.28	0.000	-.0997453	-.0370456
fit_cons_se	.0000676	1.58e-06	42.81	0.000	.0000645	.0000707
_cons	4.266908	.0294964	144.66	0.000	4.209096	4.32472

Variable	Obs	Mean	Std. Dev.	Min	Max
effect_dk	1612	.5061658	.2275049	.1180171	.6394302

Variable	Obs	Mean	Std. Dev.	Min	Max
effect_se	1612	.0264135	.0154817	0	.0354821

Annex 7

```
******** ARFIMA, DENMARK ************

---- Maximum likelihood estimation of ARFIMA(7,d,0) model ----
The estimation sample is:  1 - 21816
The dependent variable is: lp_dk  (arfimadata.in7)
(in deviation from sample mean)

                  Coefficient  Std.Error  t-value  t-prob
d parameter          0.302206    0.01509     20.0   0.000
AR-1                 0.461204    0.01643     28.1   0.000
AR-2                 0.139132   0.007459     18.7   0.000
AR-3               -0.0352077   0.007540    -4.67   0.000
AR-4               -0.0303022   0.007538    -4.02   0.000
AR-5               0.00941469   0.007562     1.24   0.213
AR-6               -0.0592871   0.007500    -7.90   0.000
AR-7               -0.0374103   0.007498    -4.99   0.000
wind            -8.08519e-005 3.028e-005    -2.67   0.008
swecl                0.246033   0.007830     31.4   0.000
central           0.000336354 1.781e-005     18.9   0.000
cons_dk           0.000440362 4.355e-005     10.1   0.000

log-likelihood     5202.51776
no. of observations     21816  no. of parameters          13
AIC.T             -10379.0355  AIC               -0.47575337
mean(lp_dk)     -7.43202e-016  var(lp_dk)           0.159556
sigma                0.190623  sigma^2             0.0363372

BFGS using numerical derivatives (eps1=0.0001; eps2=0.005):
Strong convergence
Used starting values:
      0.28335      0.47284      0.14315    -0.033415    -0.027640     0.012940
    -0.057516    -0.034313  -0.00022483      0.38194   0.00047646   0.00056537
```

```
******** ARFIMA, SWEDEN ************


---- Maximum likelihood estimation of ARFIMA(7,d,0) model ----
The estimation sample is:  1 - 21816
The dependent variable is: lp_se  (arfimadata.in7)
(in deviation from sample mean)

                  Coefficient  Std.Error  t-value  t-prob
d parameter          0.406497    0.01545     26.3   0.000
AR-1                 0.614668    0.01689     36.4   0.000
AR-2               -0.0158883   0.008153    -1.95   0.051
AR-3               -0.0278522   0.007961    -3.50   0.000
AR-4               -0.0519132   0.008010    -6.48   0.000
AR-5               -0.0301729   0.008098    -3.73   0.000
AR-6               -0.0422341   0.008092    -5.22   0.000
AR-7                0.0229074   0.007306     3.14   0.002
wind              0.000101562 1.581e-005     6.42   0.000
swecl              -0.0143009   0.003059    -4.67   0.000
central           0.000266203 8.393e-006     31.7   0.000
cons_se          8.05916e-006 1.482e-006     5.44   0.000

log-likelihood     23330.6335
no. of observations     21816  no. of parameters          13
AIC.T             -46635.2671  AIC               -2.13766351
mean(lp_se)     -1.17833e-015  var(lp_se)          0.0652697
sigma               0.0830388  sigma^2            0.00689545

BFGS using numerical derivatives (eps1=0.0001; eps2=0.005):
Strong convergence
Used starting values:
      0.43032      0.58017   -0.0020152    -0.025979    -0.048433    -0.030088
    -0.038599     0.014291 -9.9690e-005    -0.016707   0.00038514  4.0984e-005
```

Annex 8

```
******** RS-ARFIMA, DENMARK ************

---- Maximum likelihood estimation of ARFIMA(7,d,0) model ----
The estimation sample is:  1 - 21816
The dependent variable is: lp_dk  (arfimadata.in7)
(in deviation from sample mean)

                    Coefficient  Std.Error  t-value  t-prob
d parameter            0.302160    0.01515     19.9   0.000
AR-1                   0.460589    0.01649     27.9   0.000
AR-2                   0.139443   0.007458     18.7   0.000
AR-3                 -0.0353652   0.007539    -4.69   0.000
AR-4                 -0.0299711   0.007537    -3.98   0.000
AR-5                 0.00957494   0.007560     1.27   0.205
AR-6                 -0.0599446   0.007499    -7.99   0.000
AR-7                 -0.0373625   0.007509    -4.98   0.000
wind               -8.17860e-005 3.023e-005    -2.71   0.007
swecl_low              0.179218    0.01329     13.5   0.000
swecl_high             0.275703   0.009055     30.4   0.000
central             0.000334408 1.780e-005     18.8   0.000
cons_dk_rs          0.000438815 4.345e-005     10.1   0.000

log-likelihood       5218.0454
no. of observations      21816  no. of parameters          14
AIC.T               -10408.0908  AIC               -0.477085204
mean(lp_dk)       -7.43202e-016  var(lp_dk)            0.159556
sigma                  0.190488  sigma^2              0.0362855

BFGS using numerical derivatives (eps1=0.0001; eps2=0.005):
Strong convergence
Used starting values:
      0.29598      0.45794      0.14278    -0.032697    -0.026517     0.012111
    -0.059710    -0.036622  -0.00022357      0.15791      0.46486   0.00046802
   0.00055007


******** RS-ARFIMA, SWEDEN ************

Iterating:
it0    f=      2.488120 df=   0.01841 e1=  0.004043 e2=   0.07336 step=1
it1    f=      2.488293 df=  0.008724 e1=  0.005175 e2=   0.01853 step=0.25
it2    f=      2.488297 df=   0.01377 e1=  0.006248 e2=   0.01563 step=1
it3    f=      2.488353 df=  0.004410 e1=  0.002654 e2=   0.01325 step=1
it4    f=      2.488358 df=  0.006605 e1=  0.001743 e2=   0.01050 step=1
it5    f=      2.488386 df=  0.002305 e1=  0.001400 e2=  0.007914 step=1
it6    f=      2.488405 df=  0.001781 e1= 0.0009430 e2=  0.006178 step=1
it7    f=      2.488424 df=  0.002321 e1= 0.0006233 e2=  0.006054 step=1
it8    f=      2.488429 df= 0.0009659 e1= 0.0002035 e2=  0.001142 step=1
it9    f=      2.488429 df= 0.0001415 e1=1.856e-005 e2= 0.0009813 step=1
it10   f=      2.488430 df=7.635e-005 e1=1.092e-005 e2= 0.0005521 step=1
it11   f=      2.488430 df=4.149e-005 e1=6.854e-006 e2= 0.0002500 step=1
it12   f=      2.488430 df=7.614e-006 e1=1.335e-006 e2=5.336e-005 step=1
Strong convergence

---- Maximum likelihood estimation of ARFIMA(7,d,0) model ----
The estimation sample is:  1 - 21816
The dependent variable is: lp_se  (arfimadata.in7)
(in deviation from sample mean)

                    Coefficient  Std.Error  t-value  t-prob
d parameter            0.406551    0.01544     26.3   0.000
AR-1                   0.614489    0.01689     36.4   0.000
AR-2                 -0.0158173   0.008152    -1.94   0.052
AR-3                 -0.0278553   0.007960    -3.50   0.000
AR-4                 -0.0518942   0.008010    -6.48   0.000
AR-5                 -0.0303624   0.008099    -3.75   0.000
AR-6                 -0.0421102   0.008092    -5.20   0.000
AR-7                  0.0229231   0.007305     3.14   0.002
wind                0.000101634 1.581e-005     6.43   0.000
swecl_low           -0.00907401   0.005394    -1.68   0.093
swecl_high           -0.0168265   0.003614    -4.66   0.000
```

```
central           0.000266290 8.393e-006     31.7   0.000
cons_se_rs       8.10165e-006 1.482e-006     5.47   0.000

log-likelihood     23332.0153
no. of observations     21816  no. of parameters          14
AIC.T             -46636.0307  AIC               -2.13769851
mean(lp_se)     -1.17833e-015  var(lp_se)          0.0652697
sigma               0.0830336  sigma^2            0.00689458

BFGS using numerical derivatives (eps1=0.0001; eps2=0.005):
Strong convergence
Used starting values:
      0.43306       0.57594   -0.0014746    -0.025931    -0.048628    -0.029182
    -0.039866      0.013466 -9.9663e-005    -0.085632    0.0083533   0.00038223
  4.0885e-005
```

Annex 9

```
******** PL-ARFIMA, DENMARK ************


---- Maximum likelihood estimation of ARFIMA(7,d,0) model ----
The estimation sample is:  1 - 21816
The dependent variable is: p_dk  (arfimadata.in7)
(in deviation from sample mean)

                  Coefficient  Std.Error  t-value  t-prob
d parameter          0.240581    0.01473     16.3   0.000
AR-1                 0.495641    0.01623     30.5   0.000
AR-2                -0.243312   0.007563    -32.2   0.000
AR-3                0.0388189   0.009133     4.25   0.000
AR-4               -0.0157044   0.008111    -1.94   0.053
AR-5               -0.0108980   0.008052    -1.35   0.176
AR-6               0.00839470   0.007729     1.09   0.277
AR-7                0.0107390   0.006990     1.54   0.124
wind               -0.0278043    0.01164    -2.39   0.017
swecl                 109.260      4.130     26.5   0.000
central              0.115989   0.007942     14.6   0.000
cons_dk              0.172773    0.01983     8.71   0.000

log-likelihood     -132174.76
no. of observations     21816  no. of parameters          13
AIC.T              264375.521  AIC                12.1184232
mean(p_dk)      -3.82656e-014  var(p_dk)             24415.7
sigma                 103.508  sigma^2               10713.9

BFGS using numerical derivatives (eps1=0.0001; eps2=0.005):
Strong convergence
Used starting values:
      0.31243      0.41118     -0.23757    0.0066154    -0.027016    -0.018941
   -0.0015944    0.0064596    -0.042605       177.43      0.14221      0.19522



******** PL-ARFIMA, SWEDEN ************

Iterating:
---- Maximum likelihood estimation of ARFIMA(7,d,0) model ----
The estimation sample is:  1 - 21816
The dependent variable is: p_se  (arfimadata.in7)
(in deviation from sample mean)

                  Coefficient  Std.Error  t-value  t-prob
d parameter          0.449767    0.01370     32.8   0.000
AR-1                 0.536846    0.01527     35.1   0.000
AR-2               -0.0746472   0.007714    -9.68   0.000
AR-3              -0.00589873   0.007912   -0.746   0.456
AR-4               -0.0302602   0.007829    -3.86   0.000
AR-5               -0.0494433   0.007849    -6.30   0.000
AR-6              -0.00449055   0.007882   -0.570   0.569
AR-7              -0.00569652   0.007095   -0.803   0.422
wind                0.0221772   0.003035     7.31   0.000
swecl                -4.53124     0.6198    -7.31   0.000
central             0.0650905   0.001670     39.0   0.000
cons_se            0.00234206  0.0002959     7.91   0.000

log-likelihood    -92256.5775
no. of observations     21816  no. of parameters          13
AIC.T              184539.155  AIC                8.45889049
mean(p_se)      -2.57875e-014  var(p_se)             3445.11
sigma                 16.6069  sigma^2               275.788

BFGS using numerical derivatives (eps1=0.0001; eps2=0.005):
Strong convergence
Used starting values:
      0.40000      0.57577    -0.055397    0.0045864    -0.016691    -0.037586
    0.0094310    0.0036653    -0.013084      -4.5988      0.10169     0.010128
```

Annex 10

```
******** PLRS-ARFIMA, DENMARK ************

Iterating:
it0    f=     -4.638199 df=   0.01599 e1=  0.007005 e2=   0.02745 step=1
it1    f=     -4.638189 df=   0.02207 e1=  0.006954 e2=  0.008990 step=1
it2    f=     -4.638010 df=  0.004570 e1=  0.001398 e2=  0.009878 step=1
it3    f=     -4.637940 df=  0.005931 e1=  0.002731 e2=   0.02615 step=1
it4    f=     -4.637836 df=  0.007566 e1=  0.003617 e2=   0.02154 step=1
it5    f=     -4.637753 df=  0.003730 e1=  0.001411 e2=   0.01622 step=1
it6    f=     -4.637734 df=  0.001002 e1= 0.0002150 e2=  0.007845 step=1
it7    f=     -4.637731 df= 0.0002647 e1= 0.0001349 e2=  0.005727 step=1
it8    f=     -4.637731 df=8.099e-005 e1=1.007e-005 e2= 0.0007474 step=1
it9    f=     -4.637731 df=3.879e-005 e1=2.886e-006 e2= 0.0001839 step=1
it10   f=     -4.637731 df=2.578e-005 e1=8.347e-006 e2= 0.0001796 step=1
it11   f=     -4.637731 df=6.086e-006 e1=2.091e-006 e2= 0.0001197 step=1
it12   f=     -4.637731 df=6.277e-007 e1=1.706e-007 e2=1.866e-005 step=1
Strong convergence

---- Maximum likelihood estimation of ARFIMA(7,d,0) model ----
The estimation sample is:  1 - 21816
The dependent variable is: p_dk  (arfimadata.in7)
(in deviation from sample mean)

                  Coefficient  Std.Error  t-value  t-prob
d parameter          0.238932    0.01487     16.1   0.000
AR-1                 0.493429    0.01636     30.2   0.000
AR-2                -0.243521   0.007558    -32.2   0.000
AR-3                0.0369263   0.009167     4.03   0.000
AR-4               -0.0155670   0.008125    -1.92   0.055
AR-5               -0.0104480   0.008059    -1.30   0.195
AR-6               0.00766571   0.007728    0.992   0.321
AR-7                0.0115157   0.007000     1.65   0.100
wind               -0.0281731    0.01153    -2.44   0.015
swecl_low             54.0526      7.077     7.64   0.000
swecl_high            134.095      4.781     28.0   0.000
central              0.114730   0.007883     14.6   0.000
cons_dk_rs           0.169298    0.01968     8.60   0.000

log-likelihood    -132132.305
no. of observations     21816  no. of parameters          14
AIC.T              264292.609  AIC                12.1146227
mean(p_dk)      -3.82656e-014  var(p_dk)             24415.7
sigma                 103.307  sigma^2               10672.3

BFGS using numerical derivatives (eps1=0.0001; eps2=0.005):
Strong convergence
Used starting values:
      0.29315      0.42244     -0.23552    0.0080906    -0.023019    -0.015749
  -0.00054669    0.0094779    -0.041883       51.652       224.01      0.13749
      0.18634


******** PLRS-ARFIMA, SWEDEN ************

---- Maximum likelihood estimation of ARFIMA(7,d,0) model ----
The estimation sample is:  1 - 21816
The dependent variable is: p_se  (arfimadata.in7)
(in deviation from sample mean)

                  Coefficient  Std.Error  t-value  t-prob
d parameter          0.449805    0.01369     32.9   0.000
AR-1                 0.536770    0.01527     35.2   0.000
AR-2               -0.0748266   0.007714    -9.70   0.000
AR-3              -0.00574995   0.007912   -0.727   0.467
AR-4               -0.0301075   0.007829    -3.85   0.000
AR-5               -0.0499325   0.007851    -6.36   0.000
AR-6              -0.00419718   0.007883   -0.532   0.594
AR-7              -0.00573175   0.007094   -0.808   0.419
wind                0.0222033   0.003034     7.32   0.000
swecl_low            -2.81164      1.092    -2.58   0.010
swecl_high           -5.35552     0.7322    -7.31   0.000
central             0.0651187   0.001670     39.0   0.000
cons_se_rs         0.00235272  0.0002958     7.95   0.000

log-likelihood    -92253.2463
```

```
no. of observations     21816  no. of parameters          14
AIC.T              184534.493  AIC                8.45867677
mean(p_se)      -2.57875e-014  var(p_se)             3445.11
sigma                 16.6043  sigma^2               275.704

BFGS using numerical derivatives (eps1=0.0001; eps2=0.005):
Strong convergence
Used starting values:
      0.40000      0.57206    -0.052753    0.0033750    -0.017600    -0.034463
    0.0069061    0.0040255    -0.013077      -22.540       1.9240      0.10092
     0.010102
```

Chapter 4 The effect of congestion on price volatility in east Denmark

In this note we investigate the effect of limiting the capacity in the westbound direction on the Oresund-interconnection on the volatility of the electricity spot prices in eastern Denmark.

The main conclusion is that congestion significantly increases the volatility of the electricity spot prices. Our estimations indicate that the electricity prices in east Denmark are about 250 percent more volatile on days with congestion caused by internal bottlenecks at Cuts1-4 in Sweden, than on a day without congestion.

4.1. Data description

We use the same dataset as we use to estimate the effect on the electricity spot price in east Denmark. The dataset is described in note B.

4.2. The estimation method

Our aim is to obtain an estimate of the effect of congestion on the volatility of the electricity spot price volatility. We do that by regressing a measure of intra-day realized volatility in prices on a number of explanatory variables which capture the day-of-the-week and seasonal variation in price volatility.

The estimation model

We use a model where we capture the effect of congestion by a so-called congestion variable which we calculate from our data. We calculate the overall effect of congestion as the increase in the average realized volatility of the daily electricity spot price prices in east Denmark during the estimation period.

Our model is based on the model applied in Hadsell and Shawky (2006) where the focus was at congestion in the New-York area, using the NYISO data. In Hadsell and Shawky (2006), the authors employed the standard GARCH (1,1) specification of Bollerslev (1986), estimated with daily log returns calculated as $\ln(p_t/p_{t-1})$, where p_t is the average price in 17 peak demand hours of the day. The authors included the marginal cost of congestion as a continuous variable accounting for the effect of congestion on price volatility.

While we also wish to retain the daily frequency to be able to obtain an estimate of the increase in the day-ahead premium, we believe the choice of returns calculated at a daily frequency is not appropriate. Constructing the returns by using daily average prices washes out a number of intra-day volatility phenomena we wish to retain in our estimations. Therefore, our approach is to retain information on the intra-day development of volatility[25], which we call 'realized daily volatility' and construct it as shown below (see: *Dependent variable*).

We construct the daily dataset from the underlying hourly dataset, by constructing the intra-day sums of the squared returns, amount of capacity limitation due to common and Swedish-only causes, and the number of congested hours due bottlenecks at Cut 1-4 or all causes of congestion. Thereafter, dummies allowing for the identification of the days in the week and months are added. Finally, we calculate the natural logarithm of the intra-day sum of log gross return (which becomes the dependent variable, as shown below) and calculate the congestion variable.

The dependent variable in our regression is the conditional variance of the daily electricity spot prices in east Denmark which is equivalent to realized volatility (RV). The realized daily volatility can be interpreted as a measure of variance in the hourly prices within a given day. We calculate the realized volatility as the natural logarithm of the sum of intra-day squared log gross returns generated using the hourly price series for east Denmark.[26]

We use a number of independent variables in the regression.

Firstly, we include time dummies in order to capture any predictable changes in electricity prices due to the daily, weekly and seasonal demand cycles. A time dummy is inserted to capture deterministic effects, as in the price-level estimation.

Secondly, we used a continuous congestion variable measuring the intensity of congestion in the given day. It is constructed as the intra-day sum of limited capacity giving raise to congestion divided by the number of congested hours in the day[27]. This specification is chosen to ensure consistency with the definition of congestion used in estimating the effects on the price level.[28]The variable, therefore, measures how much capacity was limited on average in each congested hour for a given day. Its coefficient is to be interpreted as the increase in the daily realized volatility due to an extra 1MWh/h of limited (unavailable) westbound transmission capacity during an additional hour of congestion.

Thirdly, we included lags of the independent variables to correct for serial correlation in the residuals. Serial correlation is a standard feature in electricity price data, and therefore it is necessary to correct for it in order to fulfil assumptions of the OLS estimator to ensure that estimated coefficients remain unbiased. The lag optimal lag length is found to be 6 using the Schwartz criterion.

We state our model in the following way:

$$RV_n = \ln \sum_{t=1}^{24} \left(\frac{P_t}{P_{t+1}} \right)^2 = \beta_1 congestion_n + \sum_{l=1}^{6} \beta_{l+1} RV_{n-l} + \beta_8 time_n + \beta_{9-26} dum_{d,n}, \forall n \in \{1,...,2097\}$$

where:

- *RV* – is the daily realized volatility measure, defined as the natural logarithm of the intraday sum of squared gross returns.
- *congestion* is the average hourly limited capacity over *m* congested hours, *tc,* per day *n*, or formally:

---

[25] In other words, we 1) retain information contained in hourly prices and 2) work with all hourly prices not just peak hours.

[26] This method of computing realized volatility is standard in the financial literature.

[27] Alternatively, a binary dummy could have been adopted, to distinguish between days with and without capacity limitations. However, this would assume that daily volatility increases by the same amount during a day with only 1 hour of congestion, as during a day with 15 congested hours.

[28] Note that congestion at hourly frequency was the amount of limited (unavailable) capacity in a given hour.

$$congestion_n = \sum_{tc=1}^{m} (withdrawn\_capacity_{tc})/m, \forall n \in \{1,..,2097\}$$

- *time* is a continuous time variable uniquely identifying each day in the dataset, time $\in$ {1, …, 2097}
- $dum_{d,m}$ denotes 6 dummies identifying the day of the week and 11 dummies identifying the month of the year

In the estimation, we used the Newey-West standard errors to ensure that standard errors are not affected by the presence of serial correlation. Presence of serial correlation in residuals may diminish the magnitudes of standard errors, rendering certain coefficients erroneously significant at the chosen significance level (type I error). The optimal truncation parameter is calculated as the nearest integer.[29]

4.3. The effect on realized volatility in east Denmark

In this section we report our result for the daily realized volatility of the electricity spot price in east Denmark. We have estimated which effect congestion on the Oresund-interconnection in westbound direction has on the daily realized volatility of prices in east Denmark.

We conclude that volatility of the electricity spot prices in east Denmark is about 250 percent higher on days where bottlenecks at Cut 1-4 causes reduced capacity and congestion on the Oresund-interconnection than on day without congestion, cf. Table 11.

Table 11: Marginal and average effect on realized price volatility due to capacity limitation and congestion on the Oresund-interconnection, October 2000 to June 2006

	2000-2004	2004-2006
Marginal effect		
- Bottlenecks at Cut 1-4	0.20* percent	0.23 percent
- All causes	0.22 percent	0.25 percent
Average reduction in capacity		
- Bottlenecks at Cut 1-4	765* MWh/h	681 MWh/h
- All causes	784 MWh/h	698 MWh/h
Average effect		
- Bottlenecks at Cut 1-4	253* percent	254 percent
- All causes	270 percent	271 percent

Note: Number marked by * is inferred from the output of the other estimations.
Source: Copenhagen Economics.

We are interested in the effect on the price volatility of reduced capacity and congestion on the Oresund-interconnection due to bottleneck problems at Cut 1-4 during our whole estimation period, i.e. the period beginning in October 2000 and ending in June 2006.

For the period after 1 January 2004, i.e. from 1 January 2004 to June 2006, it is relatively easy to obtain this estimate. For this period, our data contains information about both the price levels and the reason why the capacity on the Oresund-interconnection was reduced and congestion occurred. As a result, we can estimate the effect on the realized price volatility for this period directly from our estimation model. The model shows that the realized price volatility in east Denmark increased by 0.00226 percent when the capacity is reduced by 1 MW/h due to bottlenecks at Cut 1-4. As the average limited capacity in the congested hours was 681 MWh/h in the period following 1 January 2004, we find that the average realized volatility was 154

[29] The results are not very sensitive to the chosen truncation lag. An alternative rule (4*(n/100)^(2/9)) can be implemented (results not reported).

percent higher on days where bottlenecks at Cut 1-4 caused congestion compared to days without congestion, cf. Table 11.

Before January 2004 where we only know when capacity was reduced and when congestion occurred on the Oresund-interconnection but we do not the reason why the capacity was reduced, the estimation is at little more uncertain. Here we apply a three-step procedure where we combine the more detailed information and results for the period after 1 January 2004 with the less detailed information and results for the period before 1 January 2004.

In the first step, we examine whether capacity limitation and congestion has had a different effect on the realized price volatility in east Denmark when the reason is not bottlenecks at Cut 1-4 after 1 January 2004. Our estimation show that the marginal effect on realized price volatility was 0.00245 and thus slightly lower when we focus at all sources of capacity limitations and congestion. The average limited capacity in the congested hours was with 698 MWh/h thus slightly higher when we focus at all sources of capacity limitation and congestion, cf. Table 11.

In the second step, we estimate to what extend reduced capacity and congestion resulted in higher realized price volatility in east Denmark before January 2004, i.e. in the period where we do not know the reason why the capacity was reduced. We find that the realized price volatility was 0.002174 percent higher before 1 January 2004 if the capacity on the Oresund-interconnection was reduced by 1 MW/h. As the average limited capacity was 784 MWh/h in the period before 1 January 2004, we obtain an average increase in the realized price volatility of 170 percent, cf. Table 11.

In the third step, we combine the results from the two previous steps to obtain our estimate of the price effects from capacity limitation and congestion due to bottlenecks at Cut 1-4 before January 2004. We make two assumptions. First, we assume that ratio of the marginal effects on the realized price volatility from bottlenecks at Cut 1-4 and from all causes of congestion (0.00226/0.00245) was the same before and after January 2004. Second, we assume that the ration of the average capacity reduction due to bottlenecks at Cut 1-4 and due to all causes of congestion (680/698) is also the same before and after 1 January 2004. With these two assumptions, we calculate effect on the realized price volatility of capacity limitation and congestion due to bottlenecks at Cut 1-4 before January 2004 to 153 percent, cf. Table 11.

The detailed results from our estimations are shown in Annexes 1-3 at the end of this note.

Post-estimation diagnostics
We applied a number of post-estimation diagnostic tests to examine the performance of our model with respect to the assumptions.

Firstly, we tested the residuals for normality with both graphical and numerical techniques. The graphical techniques showed close-to-normal distribution. However, the normality of the residual was not confirmed by our numerical techniques.

Secondly, we tested for autocorrelations. We found that the AC function still displayed significant autocorrelations at small lags.

Annex 1: Estimation of the effect on realized price volatility in east Denmark with continuous congestion variable, bottlenecks at Cut 1-4, January 2004 to June 2006

```
. newey log_ds_ret dum* time L(1/6).log_ds_ret congdumcaphr if time >=1188, la
> g(10)

Regression with Newey-West standard errors          Number of obs  =       910
maximum lag: 10                                     F( 25,   884)  =     28.62
                                                    Prob > F       =    0.0000

------------------------------------------------------------------------------
             |             Newey-West
  log_ds_ret |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
dum_sun      |   .9438605   .2095361     4.50   0.000     .5326142    1.355107
dum_mon      |   .6789205   .1985384     3.42   0.001      .289259    1.068582
dum_tue      |   .4110941   .1915743     2.15   0.032     .0351006    .7870875
dum_wed      |   .5467701    .201766     2.71   0.007     .1507737    .9427664
dum_thu      |   .4145361   .1985152     2.09   0.037       .02492    .8041522
dum_fri      |   .4695769   .1811751     2.59   0.010     .1139934    .8251605
dum_jan      |   .1010806   .2426651     0.42   0.677    -.3751864    .5773476
dum_feb      |   -.054719   .2726419    -0.20   0.841      -.58982     .480382
dum_mar      |  -.1195307   .2982475    -0.40   0.689    -.7048865    .4658251
dum_apr      |   .3245014   .3020017     1.07   0.283    -.2682225    .9172253
dum_may      |   .4894268   .3396929     1.44   0.150    -.1772718    1.156125
dum_jun      |    .055118   .2766693     0.20   0.842    -.4878873    .5981233
dum_jul      |   .5506371   .3805156     1.45   0.148    -.1961824    1.297457
dum_aug      |  -.4916362   .3807191    -1.29   0.197    -1.238855    .2555826
dum_sep      |   .2662532   .3285803     0.81   0.418    -.3786354    .9111417
dum_oct      |   .5071201   .2849038     1.78   0.075    -.0520467    1.066287
dum_nov      |   .4879588   .3142746     1.55   0.121    -.1288526     1.10477
time         |   .0000264   .0002889     0.09   0.927    -.0005406    .0005935
log_ds_ret   |
          L1 |   .2743917   .0516579     5.31   0.000     .1730052    .3757781
          L2 |   .0905463   .0404735     2.24   0.026      .011111    .1699817
          L3 |   .0217058   .0343577     0.63   0.528    -.0457264    .0891379
          L4 |   .0471257   .0380555     1.24   0.216     -.027564    .1218153
          L5 |   .0440196   .0326746     1.35   0.178    -.0201093    .1081485
          L6 |   .0613974   .0268602     2.29   0.023     .0086802    .1141147
congdumcaphr |   .0022583    .000245     9.22   0.000     .0017775    .0027391
_cons        |  -2.250248   .6146732    -3.66   0.000    -3.456637   -1.043859
------------------------------------------------------------------------------
```

Annex 2: Estimation of the effect on realized price volatility in east Denmark with continuous congestion variable, bottlenecks at Cut 1-4, January 2004 to June 2006

```
newey log_ds_ret dum* time L(1/6).log_ds_ret congdumcaphr_swe if time >=1188,
la
> g(10)

Regression with Newey-West standard errors          Number of obs  =       910
maximum lag: 10                                     F( 25,   884)  =     31.56
                                                    Prob > F       =    0.0000
```

log_ds_ret	Coef.	Newey-West Std. Err.	t	P>|t|	[95% Conf.	Interval]
dum_sun	.9180364	.2094915	4.38	0.000	.5068777	1.329195
dum_mon	.6973547	.1997592	3.49	0.001	.3052971	1.089412
dum_tue	.4419348	.1950174	2.27	0.024	.0591837	.8246859
dum_wed	.5618045	.2030967	2.77	0.006	.1631965	.9604126
dum_thu	.4342148	.2015582	2.15	0.031	.0386263	.8298033
dum_fri	.4701065	.183741	2.56	0.011	.109487	.8307259
dum_jan	.0862639	.255563	0.34	0.736	-.4153171	.587845
dum_feb	-.0938052	.2857399	-0.33	0.743	-.6546129	.4670026
dum_mar	-.2023107	.3127097	-0.65	0.518	-.8160507	.4114293
dum_apr	.5063414	.3029971	1.67	0.095	-.0883363	1.101019
dum_may	.5417363	.3452959	1.57	0.117	-.1359591	1.219432
dum_jun	.2166985	.2923389	0.74	0.459	-.3570607	.7904577
dum_jul	.5893285	.3693191	1.60	0.111	-.1355162	1.314173
dum_aug	.016838	.3518341	0.05	0.962	-.6736896	.7073656
dum_sep	.3447781	.3215286	1.07	0.284	-.2862705	.9758267
dum_oct	.5110308	.2945851	1.73	0.083	-.067137	1.089199
dum_nov	.5270395	.3099274	1.70	0.089	-.0812398	1.135319
time	-.0001369	.0002757	-0.50	0.620	-.0006779	.0004042
log_ds_ret						
L1.	.2773375	.0515265	5.38	0.000	.176209	.378466
L2.	.1006125	.0404267	2.49	0.013	.0212691	.179956
L3.	.0225711	.0339688	0.66	0.507	-.0440978	.0892401
L4.	.0541576	.0389293	1.39	0.165	-.022247	.1305622
L5.	.052806	.0327158	1.61	0.107	-.0114037	.1170156
L6.	.0650768	.0271189	2.40	0.017	.011852	.1183017
congdumcap~e	.0024524	.0002583	9.49	0.000	.0019455	.0029594
_cons	-1.955002	.5887172	-3.32	0.001	-3.110448	-.7995554

Annex 3: Estimation of the effect on realized price volatility in east Denmark with continuous congestion variable, all causes of congestion, October 2000 to December 2003

```
newey log_ds_ret dum* time L(1/6).log_ds_ret congdumcaphr if time <1188,
lag(10)

Regression with Newey-West standard errors          Number of obs  =      1181
maximum lag: 10                                     F( 25,  1155)  =     41.81
                                                    Prob > F       =    0.0000

------------------------------------------------------------------------------
             |             Newey-West
  log_ds_ret |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
     dum_sun |     .57728   .1220176     4.73   0.000     .3378789     .816681
     dum_mon |   1.134881   .1711849     6.63   0.000     .7990131    1.470749
     dum_tue |   .8556568   .1452833     5.89   0.000     .5706081    1.140706
     dum_wed |   .8747089    .147703     5.92   0.000     .5849127    1.164505
     dum_thu |   .9749819   .1398316     6.97   0.000     .7006295    1.249334
     dum_fri |   .7024975   .1526919     4.60   0.000     .4029129    1.002082
     dum_jan |  -.5031075   .2206026    -2.28   0.023    -.9359341   -.0702809
     dum_feb |  -.3180322   .2261616    -1.41   0.160    -.7617657    .1257013
     dum_mar |  -.4708347   .1996133    -2.36   0.019      -.86248   -.0791894
     dum_apr |  -.4658614   .2225755    -2.09   0.037    -.9025589   -.0291638
     dum_may |    .209448   .2163269     0.97   0.333    -.2149897    .6338858
     dum_jun |   .2204144   .2308202     0.95   0.340    -.2324594    .6732882
     dum_jul |   .3001649   .1918455     1.56   0.118    -.0762398    .6765695
     dum_aug |   .0242571    .166874     0.15   0.884     -.303153    .3516671
     dum_sep |   -.189038   .2613111    -0.72   0.470    -.7017356    .3236596
     dum_oct |  -.3271282   .1924422    -1.70   0.089    -.7047035    .0504472
     dum_nov |  -.4370684   .1927089    -2.27   0.024    -.8151672   -.0589695
        time |  -.0003078   .0001504    -2.05   0.041    -.0006029   -.0000128
  log_ds_ret |
         L1. |   .4279862    .032059    13.35   0.000     .3650858    .4908865
         L2. |   .0169368   .0325887     0.52   0.603    -.0470028    .0808764
         L3. |   .0115491   .0284228     0.41   0.685     -.044217    .0673152
         L4. |   .0527079   .0301244     1.75   0.080    -.0063967    .1118126
         L5. |   .0463052   .0290202     1.60   0.111     -.010633    .1032435
         L6. |   .0505148   .0257609     1.96   0.050    -.0000285    .1010582
 congdumcaphr|   .0021735   .0002221     9.79   0.000     .0017378    .0026093
       _cons |  -1.581491   .1894545    -8.35   0.000    -1.953205   -1.209777
------------------------------------------------------------------------------
```

Chapter 5 The incidence of congestion in the absence of capacity limitations

We want to determine the number of hours with congestion that would remain if Svenska Kraftnät lifted capacity limitations on the Oresund connection due to internal bottlenecks (Cut 1-4) in hours where the overall and Oresund electricity flows are both in southerly direction.

We first study the period between 1 January 2004 and 28 June 2006 for which we have detailed information about the origins of capacity limitation. The number of hours in this period constitute 5,210 hours of which 1,612 (31 percent) were congested. If Svenska Kräftnat had not limited export capacity in these hours, congestion would nevertheless remain in some hours. We estimate that about only 45 of the 1,612 hours (3 percent) would remain congested.

We then study the period between 1 October 2000 and 1 January 2004 for which we have more limited information and only know whether capacity limitation had Danish or Swedish origin. However, assuming the same pattern of capacity limitation as in the more recent period, we estimate that 43 hours would remain congested. This is about 6 percent of all congested hours in that period (741 hours).

Accordingly, we conclude that 88 hours would remain congested following a hypothetical lifting of capacity limitations on the Oresund-connection between October 2000 and June 2006 corresponding to about 4 percent of all 2,353 congested hours.

5.1. The probabilities of congestion

Our approach is to calculate the probabilities of observing a congested hour in the absence of capacity limitations, and use these estimates to calculate how many of the congested hours would remain congested assuming capacity limitations are lifted. Since the probability of observing a congested hour in the absence of capacity limitations (corresponding to the SSNCLCG outcome) is likely to be affected by intra-day and weekly cyclicality, as well as seasonal (quarterly) effects, we calculate separate probabilities for each the hour, day of the week and quarter, cf. Equation 8.

Equation 8

$$n_{s,SSNCL'CG} = p_s(h = SSNCLCG) \times n_{s,SSCLCG}$$

where:

- $n_{s,SSNCL'CG}$ is the amount of hours remaining congested given a hypothetical withdrawal of capacity limitations in the southbound direction.[30]

- $p_s(h = SSNCLCG) = \dfrac{n_{s,SSNCLCG}}{n_{s,SSNCLCG} + n_{s,SSNCLNCG}}$ is the probability of observing congestion in the absence of capacity limitations. It is calculated as the amount of congested hours in the absence of capacity limits divided by the total amount of hours without capacity limits in the southbound direction.

- $n_{s,SSCLCG}$ is the number congested hours in the presence of capacity limits in the southbound direction.

- The '*s*' subscript denotes a sub-period defined to capture intra-day, weekly and seasonal effects.

When we apply the approach outlined in Equation 8 to the sub-sample of the dataset where an exact identification of the origin of the capacity limitation is possible (after January 2004), we find that about 45 hours would have remained when capacity limitations. About 40 of these hours would have been a peak hour on a week day, cf. Table 12.

Table 12: Hours remaining congested in a hypothetical absence of capacity limitations on the Oresund-connection, October 2004 -- June 2006

	Weekday		Weekend	
	Peak hours	Off-peak hours	Peak hours	Off-peak hours
Quarter 1	$\frac{13}{694} \times 607 = 11.4$	$\frac{3}{390} \times 38 = 0.3$	$\frac{4}{221} \times 90 = 1.6$	$\frac{1}{170} \times 8 = 0.0$
Quarter 2	$\frac{73}{1187} \times 118 = 7.3$	$\frac{11}{555} \times 5 = 0.1$	$\frac{5}{349} \times 0 = 0.0$	$\frac{3}{188} \times 0 = 0.0$
Quarter 3	$\frac{62}{1121} \times 102 = 5.6$	$\frac{3}{573} \times 8 = 0.0$	$\frac{12}{402} \times 0 = 0.0$	$\frac{7}{211} \times 0 = 0.0$
Quarter 4	$\frac{21}{688} \times 500 = 15.3$	$\frac{3}{355} \times 57 = 0.5$	$\frac{8}{231} \times 71 = 2.5$	$\frac{1}{131} \times 8 = 0.1$
Sum	39.5 hrs	0.9 hrs	4.1 hrs	0.1 hrs
			Total	**44.6 hrs**

Note: The numerators contain the number of hours congested in the absence of southbound capacity limitations, making up the total of 227 hours of the "SSNCLCG" outcome. The denominators contain the number of hours without capacity limitations, which is the sum of the "SSNCLCG" and "SSNCLNCG" outcomes (total of 7466 hrs). The number following the fraction is the amount of congested hours in the "SSCLCG" outcome (total of 1612 hrs). The result of the expression is the amount of hours remaining congested in the hypothetical absence of capacity limitations.
Source: Copenhagen Economics

We use the same approach to calculate the number of hours remaining congested in the period before January 2004. We note that in that period 882 hours were congested due to common causes. Assuming that the percentage of hours congested due to Swedish causes is the same as in the period for which its identification is possible; we derive the number of hours congested due to Swedish causes in the period prior to January 2004 as follows: $\frac{1612}{1926} \times 882 \approx 0.84 \times 882 = 741$ hours. We use the same approach to break this figure down by quarter, type of day in the week and type of hour.

[30] *SSNCLCG*=South-South- No Capacity Limitation-Congestion where the *NCL'* indicates a hypothetical No Capacity Limitation

When we apply Equation 8 we find that 43 hours would have remained congested following a hypothetical lifting of capacity limitations in the 882 hours congested due to Swedish causes in the period October 2000 – December 2003. All congestion would have occurred in a peak hour on a week day, cf.
Table 13.

Table 13: Hours remaining congested in a hypothetical absence of capacity limitations on the Oresund-connection, Oct 2004 – Dec 2003

	Weekday		Weekend	
	Peak hours	Off-peak hours	Peak hours	Off-peak hours
Quarter 1	$\frac{1}{665}\times 173 = 0.3$	$\frac{0}{136}\times 9 = 0$	$\frac{0}{121}\times 7 = 0$	$\frac{0}{44}\times 1 = 0.0$
Quarter 2	$\frac{71}{1145}\times 124 = 7.7$	$\frac{0}{274}\times 43 = 0.0$	$\frac{0}{237}\times 13 = 0.0$	$\frac{0}{97}\times 5 = 0.0$
Quarter 3	$\frac{247}{1371}\times 143 = 25.7$	$\frac{3}{361}\times 10 = 0.1$	$\frac{0}{200}\times 3 = 0.0$	$\frac{0}{76}\times 0 = 0.0$
Quarter 4	$\frac{40}{860}\times 202 = 9.4$	$\frac{0}{336}\times 5 = 0.0$	$\frac{0}{252}\times 3 = 0.0$	$\frac{0}{152}\times 0 = 0.0$
Sum	43.1 hrs	0.1 hrs	0.0 hrs	0.0 hrs
			Total	**43.2 hrs**

Note: The numerators contain the number of hours congested in the absence of southbound capacity limitations, making up the total of 227 hours of the "SSNCLCG" outcome. The denominators contain the number of hours without capacity limitations, which is the sum of the "SSNCLCG" and "SSNCLNCG" outcomes (total of 7466 hrs). The number following the fraction is the amount of congested hours in the "SSCLCG" outcome (total of 1612 hrs). The result of the expression is the amount of hours remaining congested in the hypothetical absence of capacity limitations.
Source: Copenhagen Economics

Chapter 6 The origin of capacity limitations on the Konti-Skan-connection

This note documents the origin of capacity limitations on the Konti-Skan-connection between west Denmark and Sweden in the period between 15 January 2003 and 28 June 2006.

Overall, we conclude that capacity limitations were much more frequent on the Konti-Skan-connection than on the Oresund-connection, in particular in the direction to Denmark. Capacity was limited in more than one third of all hours in the direction to Denmark and in almost one fifth of all hours in the direction to Sweden. However, the frequency of capacity limitations in the direction to Denmark has declined radically over time – from beyond 4000 hours per year to now below 200 hours per year.

On the Konti-Skan-connection, limitations of transmission capacity are significantly more likely to be associated with the recipient country's system operator rather than the dispatching country's system operator. In cases where capacity is limited in the direction to Denmark, Eltra, is mostly to blame and in cases where capacity is limited in the direction to Sweden, Svenska Kraftnät is mostly to blame. We suspect that the reasons for these patterns has been Eltras desire to limit imports in hours with excess supply of wind power and Svenska Kraftnäts desire to limit import in hours with northbound capacity problems on the West Coast transmission network.

As prices have a tendency to increase in the receiving area when capacity is limited, most of the consequences of the actions of each system operator are born by its own population rather than the population in the neighbouring country. This is very different from the situation on the Oresund-connection, where most of the capacity limitations have costly consequences in the neighbouring country.

6.1. Identification of relevant hours

We start by identifying congested hours using the same step-wise procedure as that applied for identifying congested hours on the Oresund-connection. We first define what is meant by maximum capacity, cf. Table 14 .

Table 14: Maximum physical transmission capacities on Konti-Skan, 2000-2006

Date	Southbound physical capacity (MWh/h)	Northbound physical capacity (MWh/h)
2000	580	610
2001	580	610
2002	580	610
2003*	490	460
2004	490	460
2005	490	460
2006	490	460

Note: The maximum physical and trading transmission capacities on Konti-Skan declined on October 4, 2003, following a transformer fire on line 1.
Source: Copenhagen Economics

We now split all hours in 16 different types, cf. Figure 2, identified in terms of:

- Direction of the overall flow between Germany and Sweden
- Direction of the flow on Konti-Skan
- Presence of capacity limitations (limitations)
- Occurrence of a price differential between west-Denmark and Sweden (congestion)

We find that transmission in the southbound direction was limited in 10,868 hours in the period between 15 January 2003 and 28 June 2006. The corresponding figure for northbound capacity limitations is 5,294 hours, cf. Figure 2.

Figure 7: Identification of congested hours, Konti-Skan-connection, 15 January 2003 – 28 June 2006

Overall	Occurrence (hrs)	Percent of whole period 2003-2006	Kontiskan		Percent of whole period 2000-2006	Capacity	Occurrence (hrs)	Percent of whole period 2000-2006	Congestion	Occurrence (hrs)	Percent of whole period 2003-2006
Overall flow north if P(Sweden)≥P(EEX)	12200	40,31	**Kontiskan - flow north If net transaction is <0**	9268	30,62	**No capacity limit north** If capacity≤ -600 (-480 after Oct 3, 2003)	7308	24,15	Congestion If P(Vdk)≠ P(Sweden)	3601	12,54
									No congestion If P(Vdk)=P(Sweden)	3707	12,91
						Capacity limit north If capacity> -590 (-480 after Oct 3, 2003)	1960	6,48	Congestion If P(Vdk)≠ P(Sweden)	1155	4,02
									No congestion If P(Vdk)=P(Sweden)	805	2,80
			Kontiskan - flow south If net transaction is >0	2932	9,69	**No capacity limit south** If capacity≥ 570 (450 after Oct 3, 2003)	2198	7,26	Congestion If P(Vdk)≠ P(Sweden)	805	2,80
									No congestion If P(Vdk)=P(Sweden)	1393	4,85
						Capacity limit south If capacity< 570 (450 after Oct 3, 2003)	734	2,43	Congestion If P(Vdk)≠ P(Sweden)	293	1,02
									No congestion If P(Vdk)=P(Sweden)	441	1,54
Overall flow south If P(Sweden)<P(EEX)	16509	54,55	**Kontiskan - flow north If net transaction is <0**	6095	20,14	**No capacity limit north** If capacity≤ -600 (-480 after Oct 3, 2003)	4885	16,14	Congestion If P(Vdk)≠ P(Sweden)	1005	3,50
									No congestion If P(Vdk)=P(Sweden)	3880	13,51
						Capacity limit north If capacity> -590 (-480 after Oct 3, 2003)	1210	4,00	Congestion If P(Vdk)≠ P(Sweden)	381	1,33
									No congestion If P(Vdk)=P(Sweden)	829	2,89
			Kontiskan - flow south If net transaction is >0	10414	34,41	**No capacity limit south** If capacity≥ 570 (450 after Oct 3, 2003)	8321	27,49	Congestion If P(Vdk)≠ P(Sweden)	5029	17,52
									No congestion If P(Vdk)=P(Sweden)	3292	11,47
						Capacity limit south If capacity< 570 (450 after Oct 3, 2003)	2093	6,92	Congestion If P(Vdk)≠ P(Sweden)	1287	4,48
									No congestion If P(Vdk)=P(Sweden)	806	2,81

Source: Copenhagen Economics

6.2. Identification of the origins of capacity limitations

To identify the origin of capacity limitations, we use the daily declarations filed by Eltra and Svenska Kraftnät to specify the amount of available transmission capacity in both directions on the Konti-Skan-conncetion. We attribute the origin of a capacity limitation to the system operator that declares the lowest amount of transmission capacity. Thus, if Energinet.dk declares the lowest capacity, this is marked "Limitation by Eltra", otherwise if Svenska Kraftnät declares the lowest capacity, this is marked "Limitation by SVK". We distinguish between hours with complete outages, capacity limitations of more than 10 MW below the maximum transmission capacity, instances where both system operators limit capacity by equal amounts due to technical reasons, and the lack of capacity limitations, cf. Table 15.

Table 15: Criteria to identify causes of capacity limitations on the Konti-Skan-connection

Cause	Condition
Outage by Eltra	If the capacity declared by Eltra is zero
Outage by SVK	If the capacity declared by SvK is zero
Limitation by Eltra	If the capacity declared by Eltra is 10 MW or more lower than declared capacity by SvK
Limitation by SVK	If the capacity declared by SvK is 10 MW or more lower than declared capacity by Eltra
Common limitation	If the absolute value of the difference between SVK and ENDK-declared capacities is less than 10 MW and the individual capacities both are lower than the maximum possible physical capacity less 10 MW
No limitation	If SvK and Eltra-declared capacities are more than the maximum available capacity less 10 MW

Note: SVK – Svenska Kraftnät,
Source: Copenhagen Economics

To eliminate trivial limitations, we define capacity as limited if the available capacity falls 10 MWh/h below the physical maximum, cf. Table 16.

Table 16: Causes of capacity limitations on the Konti-Skan-connection, January 2003 – June 2006

Direction / Occurrence	To west-Denmark		To Sweden	
	no. of hours	percent	no. of hours	percent
Outage by Eltra	772	2.7	351	1.2
Outage by SVK	119	0.4	9	0.0
Limitation by Eltra	8,054	28.1	1,349	4.7
Limitation by SVK	808	2.8	2,533	8.8
Bilateral limitation	1,174	4.1	1,057	3.6
No limitation	17,782	61.9	23,410	81.5
Total	28,709	100.0	28,709	100.0

Note: The table tracks the origin of 10868 hours when southbound transmission capacity has been congested (direction: To west-Denmark) and 5294 hours northbound transmission capacity limitations (direction: To Sweden).
Source: Copenhagen Economics and Energinet.dk.

We find that when imports are limited, the causes are significantly more likely to be associated with the recipient country's system operator than the dispatching country's system operator. Thus, when imports to west Denmark are limited, Eltra is nearly 10 times more likely to be responsible for introducing the limitation than Svenska Kraftnät. Similarly, in the case of imports to Sweden, Svenska Kraftnät is about 2 times more likely to have introduced the import capacity limitation than Eltra.

The frequency of capacity limitations on imports to west Denmark introduced by Energinet.dk has declining over time, except for the recent increase in Q2, 2006. The incidence of capacity limitations introduced by Svenska Kraftnät has remained unchanged, cf. Table 17 and Figure 8.

Eltra and Svenska Kraftnät were both imposing limits on imports to Sweden in an interchangeable fashion until Q1, 2005. Thereafter, their capacity limitations had been concerted, with both of them applying essentially the same capacity limits in the northbound direction, cf. Table 17 and Figure 9.

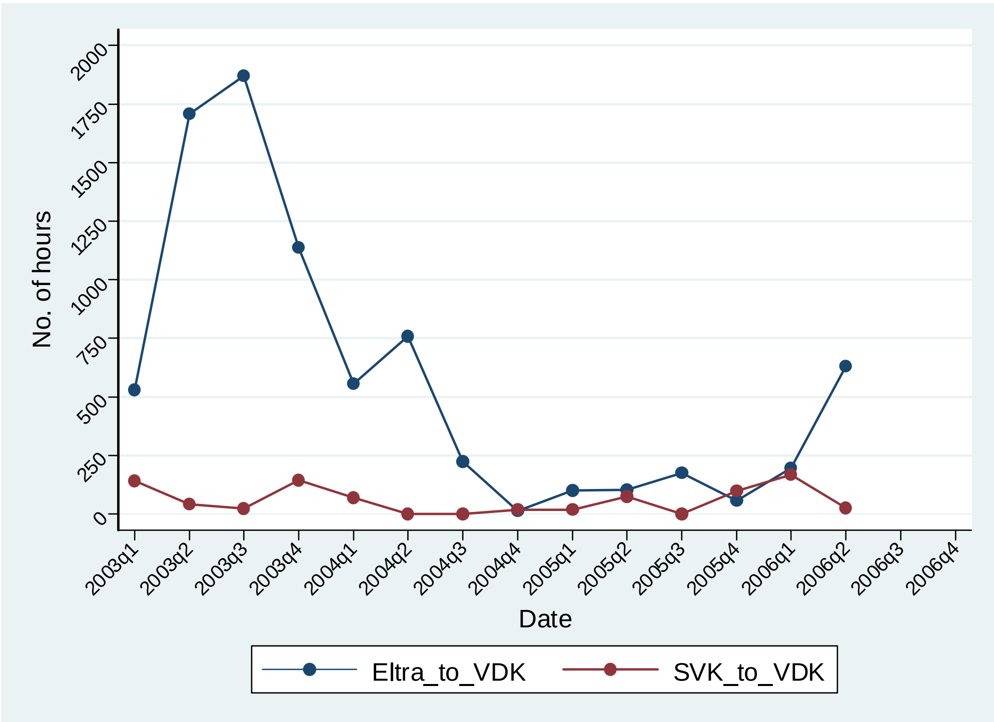
Table 17: Seasonal patters in capacity limitations caused by Eltra and SVK, Jan 2003 – Jun 2006

Quarter		Q1		Q2		Q3		Q4	
Year	Origin	Eltra	SVK	Eltra	SVK	Eltra	SVK	Eltra	SVK
2003	To WDK	529	141	1709	41	1869	23	1136	145
2004	To WDK	557	71	758	1	223	1	12	18
2005	To WDK	100	18	103	76	175	0	57	99
2006	To WDK	195	167	631	25	n/a	n/a	n/a	n/a
2003	To S	22	170	10	129	145	6	12	339
2004	To S	18	445	87	251	330	40	8	291
2005	To S	115	111	50	30	48	53	58	184
2006	To S	121	124	325	360	n/a	n/a	n/a	n/a

Note: The table tracks the seasonal occurrence of 'Limitation by Eltra' and 'Limitation by SVK' (Svenska Kraftnät) in the southbound and northbound directions on the Konti-Skan, Jan 2003 – Jun 2006

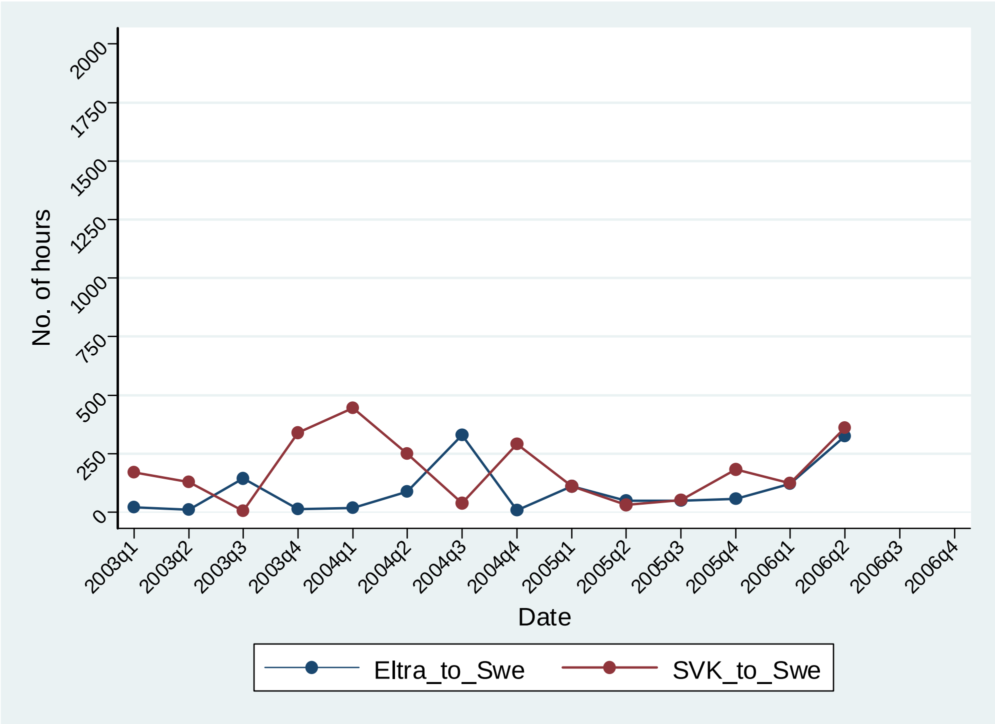
Source: Copenhagen Economics

Figure 8: Import capacity limitations to west Denmark via the Konti-Skan-connection, January 2003 – June 2006



Source: Copenhagen Economics

Figure 9: Import capacity limitations to Sweden via the Konti-Skan-connection, January 2003 – June 2006



Source: Copenhagen Economics

Chapter 7 Economic losses and gains to Danish and Swedish electricity consumers

When Svenska Kraftnät reduces transmission capacity on the Oresund connection in the direction towards east Denmark, it has economic implication for both Swedish and Danish consumers. In east Denmark, less import from low cost power plants in Sweden makes prices go up and become more volatile and unpredictable. In Sweden, less export means that Svenska Kraftnät does not need to finance the costly alternative of counter trade and prices may even go down.

In this chapter, we quantify these economic losses and gains for east Danish and Swedish consumers. The analysis covers the period between October 2000 and June 2006.

Our conclusion is that the total economic loss for Danish consumers amounts to at least 725 million DKK in the relevant period, three fourths of it after January 2004. This is a conservative estimate ignoring among others the costs of increased volatility. We also conclude that Swedish consumers gain 215-265 million DKK compared to a situation where Svenska Kraftnät - instead of capacity limitations - relied completely on counter trade to solve internal bottlenecks. Swedish producers and distributors may have gained a similar sum.

7.1. The economic losses for consumers in east Denmark

Electricity consumers in east Denmark are likely to experience a *direct* economic loss when Svenska Kraftnät limits the export of electricity from Sweden to east Denmark in periods with ample supply of low cost hydro power. In this situation, less export from Sweden implies a lower supply of electricity in east Denmark. Assuming realistically that the demand is price insensitive in the short run, electricity in east Denmark becomes more expensive in all hours where capacity has been limited by Svenska Kraftnät due to internal bottlenecks and where it has given rise to congestion. This holds for 1,612 hours between January 2004 and June 2006 and for 2,808 hours in the entire period between October 2000 and June 2006.

If Svenska Kraftnät abstains from using capacity limitations, there are two possible outcomes. Either there will still be congestion and still two price areas in east Denmark and Sweden. Or there will be no congestion as the capacity limitation ceases to be binding and the two price areas melt into a single price area with a common spot price.

In an econometric model, we have shown that the number of hours where congestion still occurs is very limited if capacity limitations are completely abolished and in what follows we will ignore these hours; cf. Chapter 5.

In a range of econometric models, we have also concluded that in those hours where congestion ceases to arise, the east Danish price drops by 70-80 percent; cf. Chapter 3.[31] The lower bound results come from direct estimations of the change in the east Danish price. The upper bound result comes indirectly from estimations of the change in Swedish prices.[32]

We can obtain the hourly cost of congestion by multiplying the estimated price change in east Denmark by the amount of electricity consumed in every hour. Finally, taking the sum of all hourly costs we obtain the total economic loss in east Denmark caused by capacity limitations due to Svenska Kraftnät. Formally, we can write the loss to the consumers in east Denmark due to congestion, L_{EDK} , expressed in nominal DKK as:

$$L_{EDK} = \sum_{t=1}^{50328} \left[C_{EDK,t} \times \Delta P_{EDK,t} \right] \qquad (1)$$

where[33]:

- $C_{EDK,t}$ is the observed consumption of electricity in east Denmark at time t.
- $\Delta P_{EDK,t}$ is the price increase due to congestion caused by capacity limitations initiated by Svenska Kraftnät and is equal to the price actually observed minus the price that would have prevailed in the absence of congestion as inferred from the econometric models. The price difference is positive in hours with congestion, zero otherwise
- *50,328* is the number of hours in the period between October 2000 and June 2006.

We calculate the total loss for east Danish consumers to 799 million DKK, cf. Table 18. The loss before January 2004 is found on the assumption that capacity limitations due to internal Swedish bottlenecks are equally frequent before and after 2004. The figure is the ordinary sum of losses in each individual year and ignores discounting.

Table 18: Loss to the electricity consumers in east Denmark due to congestion caused by internal Swedish bottlenecks, October 2000 to June 2006

Year	Congested hours	Average price difference	Average consumption	Loss in eastern Denmark
	Hours	DKK/MWh	MWh/h	Million DKK
2000-2003	695	124.5	2,108	164
2004	139	96.7	2,166	26
2005	1,058	212.9	2,064	419
2006	371	265.0	2,258	200
Total	**2,263**	**187.1**	**2,123**	**799**

Note: The exact number of congested hours due to internal Swedish bottlenecks is only known for the period 2004-2006. We assume that congested hours are equally frequent before and after 2004. All values are nominal.
Source: Copenhagen Economics.

When capacity limitations give rise to bottlenecks, the Danish system operator receives an additional income from bottleneck taxes. This income is paid back to the distribution companies through lower transmission tariffs. As the transmission tariff is a variable cost in Denmark, it is very likely that these cost savings are passed-on fully to Danish consumers, even in the short run. We calculate the bottleneck tax accrued to Energinet.dk (or its predecessors) for the entire

[31] Currently, the Swedish price is 81 percent lower than the east Danish price in hours with capacity limitations and congestion initiated by Svenska Kraftnät.

[32] The strong econometric evidence of a stable Swedish price implies that the latter result is stronger, but to be conservative we use the former result.

[33] Note that $\Delta P_{EDK,t} > 0$ in congested hours only.

period and we assume that the tax has been passed-on in full. Since 2000, we estimate[34] the total bottleneck tax and, thus, the overall *indirect* gain for Danish consumers arising from lower transmission tariffs to be approximately 75 million DKK.

Accordingly, we estimate conservatively the total economic loss for Danish consumers to be at least 725 million DKK.

7.2. The economic gains for consumers in Sweden

Electricity consumers in Sweden are also likely to experience two different types of economic gain.

First, there may be a *direct* price effect in Sweden. Less export to east Denmark means that the supply of electricity in Sweden increases; most likely leading to a downwards pressure on prices in Sweden.

Second, there might an *indirect* effect through avoided costs of counter trade and lower transmissions tariffs. If Svenska Kraftnät did not limit capacity on Oresund it would have to handle the internal bottlenecks in Sweden by other means, for example by counter trade. Counter trade is costly and the costs would have to be born by Svenska Kraftnät. Thus, when Svenska Kraftnät uses capacity limitations instead of counter trade to solve the internal bottlenecks, Swedish consumers may experience an economic gain by avoiding costs of counter trade, but only to the degree that lower transmission tariffs is passed-on from producers and distributors of electricity (who benefit directly from lower transmission tariffs) to Swedish consumers.

We can write the total gain to the Swedish consumers, $\Delta W_{s,}$ as follows:

$$\Delta W_s = \sum_{t=1}^{50328} (\Delta P_{s,t} \times X_{S,t}) + C_{c,t}$$

where:

- $\Delta P_{S,t}$ is the price decrease in Sweden due to congestion caused by capacity limitations initiated by Svenska Kraftnät and is equal to the price actually observed minus the price that would have prevailed in the absence of congestion as inferred from the econometric models.
- $X_{S,t}$ is the actual consumption of electricity in Sweden at time t
- $C_{c,t}$ is the (avoided) cost of counter trade *passed on to Swedish consumers*
- *50,328* is the number of hours in the period between October 2000 and June 2006.

Our estimations show that capacity limitations on the Oresund-connection have no significant price effect in Sweden; cf. Chapter 3.[35] This implies that $\Delta P_{S,t}$ in the above equation is zero.

We can calculate the total (avoided) costs of counter trade, $Cm_{c,t}$, *as*:

$$Cm_{c,t} = f_{Q_{fe}} \sum_{t=1}^{50328} Q_{fe,t} \times P_{C,t}$$

where:

[34] Based on *Bilaga til flaskhalsavtal 1.1-28.2 2005*; *Avtal om fördeling av flaskhalsintäkter* mellan Affärsverket svenska kraftnät (SvK), Eltra a.m.b.a. (Eltra), Elkraft System a.m.b.a. (Elkraft), Fingid Oyj (FG), och Statnett SF (SN); Svenska Kraftnät, *Den svenska elmarknaden och Svenska Kraftnäts roll*, November 2004 samt Energinet.dk, *El-tariffer for 4. kvartal 2006.*

[35] See Appendix A.

- $Q_{fe,t}$ is the observed capacity limitation on the Oresund-connection in westbound direction at time *t*
- $P_{c,t}$ is the unit price of counter trade at time *t*
- f_{Qfe} is a ratio indicating how much counter trade is needed as a percentage of the observed capacity limitation at time *t*

We distinguish between two types of hours with capacity limitations, hours where capacity limitation has lead to congestion and hours where capacity limitation has not lead to congestion. In the latter, we assume that there is no need for counter trade because counter trade only takes place after it has been observed whether congestion arises or not. In the former we assume that the need for counter trade (expressed in MWh) is smaller than the need for capacity limitations again because counter trade only takes place after the actual need for transmission has been observed. This assumption is captured by the parameter $f_{Qfe} < 1$.

We calculate the gains in a situation where Svenska Kraftnät completely stops using capacity limitation as a tool to solve internal Swedish bottlenecks. An alternative scenario could be a situation where Svenska Kraftnät in all hours guarantees a minimum transmission capacity at 850 MWh in each and every hour and only uses counter trade in those hours where internal Swedish bottlenecks are extraordinarily severe.

The size of the parameter f_{Qfe} is crucial. We assume that $f_{Qfe} = 0.5$ implying that if we in a specific hour observe a capacity limitation on Oresund at 750 MW the substitute amount of counter trade will be 375 MW, on average. The assumption is empirically based on a (limited) number of counterfactual simulations. In 22 simulated hours, the observed ratio f_{Qfe} on average is equal to about *0.3*; cf. Chapter 8.

We calculate the price of counter trade by exploiting information about the price level in Sweden and the marginal cost in southern Sweden and east Denmark. Our calculations are based on the following formula:

$$P_{C,t} = \underbrace{m \times P_{S,t}}_{A} + \underbrace{\left((1-d) \times MC_{SS} + d \times MC_{EDK}\right) \times (1+m)}_{B}$$

where:

- $P_{C,t}$ is Svenska Kraftnät's price of counter trade at time *t*
- $P_{S,t}$ is the electricity spot price in Sweden at time *t*
- *m* is the average profit margin of electricity producers in Sweden
- *d* is the share of counter trade purchased in east Denmark
- MC_{SS} is the marginal cost at the marginal plant in southern Sweden
- MC_{EDK} is the marginal cost at the marginal plant in east Denmark

The first term, *A*, is the required compensation to producers north of the internal bottleneck in northern Sweden to reduce their production. Reducing output producers save variable production costs, but they loose the profits for which they need compensation. The second term, *B*, is the required compensation to producers south of the internal bottleneck to increase their production by the same amount. The compensation includes the variable cost of producing extra output plus profits.

According to Energinet.dk, the marginal cost of the marginal plant in southern Sweden is 533 DKK MWH and 320 DKK MWH in east Denmark. We assume that the average profit rate in Sweden is 5-10 percent and that Svenska Kraftnät would buy between one third and two thirds of the required counter trade in east Denmark. With an average spot price in Sweden of 221 DDK, these assumptions give us an average price of counter trade between 425 and 500 DKK pr. MWh/h, cf. Table 19.

Table 19: Average price of counter trade in Sweden, bottom-up approach, October 2000 to June 2006

DKK per MWh/h	Share of counter trade production in east Denmark	
Average profit margin Sweden	**33%**	**66%**
5%	497	423
10%	509	454

Note: Values in million nominal DKK.
Source: Copenhagen Economics.

The price level from our calculations is in line with the price level which can be inferred from the information contained in a letter from the general director of Svenska Kraftnät to his Danish colleague at Energinet.dk dated in March 2006. The letter concerns the extreme price spike occurring in east Denmark on 28 November 2005. The general director discusses the potential role of counter trade and indicates that the required amount of counter trade would not be higher than 500 MWh/h and that the total cost would not exceed a few hundred thousand SEK.[36] With a conservative interpretation, a few hundred thousand means 300,000 SEK which gives us an average price of counter trade of 600 SEK or about 475 DKK per MWh/h.

We can now calculate the total costs of counter trade to 350-450 million DKK in the period between October 2000 and June 2006, cf. Table 20.

Table 20: Costs of counter trade, bottom-up approach, October 2000 to June 2006

	Share of counter trade production in east Denmark	
Average profit margin Sweden	**33%**	**66%**
5%	424	361
10%	454	388

Note: Values in million nominal DKK.
Source: Copenhagen Economics.

The results are not much different when we use the price of counter trade from the letter from the general director of Svenska Kraftnät, i.e. an average price of 475 DKK. Here we find that the costs of counter trade would have been 400 million DKK in the period between October 2000 and June 2006.

The Swedish system operator also receives an additional income from bottleneck taxes, when capacity limitations give rise to bottlenecks. Since 2000, we estimate[37] the total bottleneck tax accrued to Svenska Kraftnät to approximately 75 million DKK.

The key question is to which degree the cost savings from avoided counter trade and from bottleneck taxes are passed-on to Swedish consumers via lower transmission tariffs paid by distributors and producers of electricity. We don't know whether Svenska Kraftnät actually has

[36] The Swedish text was the following: *"De simmuleringar, som har gjorts av överföringssituationen den 28 november, visar att det under det mest ansträngda timmen skulle ha räckt med en mothandelsindsats som var mindre än 500 MW för att helt utjämma priset mellan Själland och Sverige. Kostnaden bedöms til högst några hundrattusen kroner."* Source: Letter from Magnusson, J., Svenska Kraftnät, to Andreasen, P. Ø., Energinet.dk, January 3, 2006.

[37] Based on *Bilaga til flaskhalsavtal 1.1-28.2 2005*; *Avtal om fördeling av flaskhalsintäkter* mellan Affärsverket svenska kraftnät (SvK), Eltra a.m.b.a. (Eltra), Elkraft System a.m.b.a. (Elkraft), Fingid Oyj (FG), och Statnett SF (SN); Svenska Kraftnät, *Den svenska elmarknaden och Svenska Kraftnäts roll*, November 2004 samt Energinet.dk, *El-tariffer for 4. kvartal 2006.*

lowered transmission tariffs in the period in question, but we assume that this is what they have actually done, *krone-for-krone*.

Swedish transmission tariffs are structured in a way that is much less favourable to pass-on than in Denmark. The tariff has two parts: effect and energy. The effect part is a subscription-like tariff that does not change with production. For pricing decisions it is to be considered as a fixed cost that is unlikely to be passed-on to consumers in the short term we are considering. In contrast, the energy part is a variable tariff that is more readily passed-on to Swedish consumers, even in the short run.

We assume that both parts of the tariffs are reduced proportionally. As each of the two parts of the tariff account for 50 percent of the transmission tariff revenue[38], we estimate that Swedish consumers since 2000 may have saved 215-265 million DKK from the practice of Svenska Kraftnät.

[38] Svenska Kraftnät, *Årsredovisning 2005*, p13-14.

Chapter 8 Counterfactual simulations of prices in east Denmark and Sweden in the absence of capacity limitations

We have asked Nord Pool to simulate the market outcome in the absence of capacity limitations on the Oresund-connection in the direction from Sweden to Denmark in 22 carefully selected congested hours in 2005 and 2006, cf. Table 21. We stress that the sample of congested hours is not necessarily representative, but has been set up to represent many different combinations of levels of demand, prices, and price differences between Sweden and east Denmark.

If capacity limitations were lifted there would be congestion in only one hour and no congestion in the remaining 20 hours. One hour is missing due to data problems. This supports the conclusion that congestion rarely occurs in the absence of capacity limitations; cf. Chapter 5.

The average transmitted capacity increases from 434 MWh in the congested hours to only 690 MWh in the hypothetical non-congested hours, far below the maximum physical capacity. In only four hours the hypothetical transmitted capacity surpasses 1000 MWh. This support a conclusion that managing bottlenecks much closer to real time very easily would be economically beneficial, cf. Chapter 7..

In the congested hours the Danish price is far above the Swedish price, on average almost 60 percent higher. In the hypothetical non-congested hours the average Danish price is only about 2 percent higher than the Swedish price which is almost identical to the Swedish price in the congested hours. This supports the conclusion that if capacity limitations were lifted the observed price gab between east Denmark and Sweden would essentially be eliminated; cf. Chapter 3.

Table 21 Hypothetical prices in Sweden and east Denmark and transmission in the absence of capacity limitations in 22 selected hours in 2005 and 2006

					Actual prices		Actual prices and consumption				Actual transmission		Hypothetic		
	date	hour	month	year	PEDK	PS	Central prod	Decentra Prod	Wind prod	consumption	Kapasitet Öresund	Flyt Öresund	Flyt Öresund	Pris Sjælland	Pris Sverige
sø	27-02-2005	10	2	2005	186	181	930	451	457	1837	1177	223	216	186,27	181,36
on	05-10-2005	15	10	2005	560	217	1018	269	54	1862	941	941	1147	217,84	217,84
ma	07-11-2005	19	11	2005	700	229	1328	460	73	2228	839	546	909	229,87	229,87
on	09-11-2005	18	11	2005	799	219	1543	469	134	2307	1291	439	966	223,81	223,81
on	09-11-2005	20	11	2005	420	213	1481	422	125	2069	923	482	1027	217,22	217,22
lø	12-11-2005	18	11	2005	635	203	632	364	194	2036	937	937	1300	479,59	206,22
on	16-11-2005	19	11	2005	1864	255	1512	497	122	2342	813	813	1230	262,98	262,98
ma	21-11-2005	17	11	2005	992	492	2173	515	34	2288	577	577	585	294,81	294,81
on	23-11-2005	11	11	2005	924	249	1835	498	12	2223	384	384	950	257,94	257,94
ma	28-11-2005	18	11	2005	13460	319	1836	489	1	2531	368	368	872	479,72	479,72
ma	28-11-2005	19	11	2005	8992	290	1834	489	2	2454	414	414	788	315,06	352,73
ma	28-11-2005	11	11	2005	1643	269	1750	482	9	2270	491	491	761	283,55	310,58
on	30-11-2005	18	11	2005	1883	510	1617	480	126	2493	110	110	304	539,48	539,48
to	29-12-2005	18	12	2005	928	465	1418	499	59	2382	No data available				
on	18-01-2006	10	1	2006	571	359	1784	477	158	2389	573	573	597	359,59	359,59
to	19-01-2006	8	1	2006	557	519	1890	446	80	2260	412	412	456	519,29	519,29
to	16-03-2006	19	3	2006	445	404	1918	488	241	2350	257	257	262	404,19	404,19
ti	21-03-2006	20	3	2006	1008	444	1938	447	22	2228	23	23	298	460,00	460,00
on	22-03-2006	20	3	2006	1077	444	1919	442	44	2224	140	140	452	448,37	448,37
on	22-03-2006	12	3	2006	899	435	1912	446	102	2180	152	152	348	436,58	436,58
to	23-03-2006	20	3	2006	680	443	1913	449	19	2208	433	433	505	444,25	444,25
to	23-03-2006	11	3	2006	653	449	1917	439	31	2198	393	393	501	451,56	451,56

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