Center for Quantitative Economics

King's law and food storage in Saxony, c. 1790-1830

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King's law and food storage in Saxony, c. 1790–1830*

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Abstract

This article presents new data on grain production, storage and prices in Saxony between 1789 and 1830. We contribute to three interrelated debates. First, we discuss whether monthly price increases were sufficient to cover storage costs, and how they relate to storage levels at the end of the harvest year. Second, we estimate price elasticity of demand, a test of "King's Law". Finally, we investigate the main determinants of grain storage in a framework that takes reverse causality into account. We find that price fluctuations within the harvest year were consistent with interest rates of about 5%. On the second subject, our findings are mainly consistent with "King's Law", according to which price elasticity of demand is relatively low with -0.4, and reject higher estimates of the recent literature. Finally, we show that storage quantity reacted in the predicted way to price shocks but way about as much driven by harvest variations. Between harvests, storage indeed smoothed food supply over time as theory predicts, however to a limited extent.

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1 Introduction

How much food did pre-modern societies store between harvests? How successful were they in smoothing food consumption? Were the rulers' paternalistic motive the main driver of storage or rather individual profit maximization? For Europe, these questions have so far been discussed mainly using price and quantity or even only price data (McCloskey & Nash 1984, Persson 1996, Persson 1999, Clark 2001). This article adds empirical substance to this debate. It uses data on rye and wheat production, storage, seeds sown and prices in Saxony between 1789 and 1830 fresh from the archives.

We contribute to three interrelated debates. First, we discuss whether monthly price increases were sufficient to cover storage costs, and how they relate to storage levels at the end of the harvest year (McCloskey & Nash 1984, Persson 1996, Clark 2001). Second, we estimate price elasticity of demand, a test of "King's Law" (Fogel 1989, Persson 1999). Finally, we investigate the main determinants of grain storage in a vector autoregression-framework that takes reverse causality into account, because every variable is trated as endogenous.

Our results are as follows: Contrary to medieval England, where price increases imply an interest rate of up to 30 percent according to McCloskey & Nash (1984), our late-18th/early-19th century prices produce average returns that are consistent with plausibly low interest rates of five percent. Returns are very dispersed right after harvest, probably reflecting substantial uncertainty about harvest outcomes. In contrast, price increases are quite stable and predictable in summer just before the next harvest, which is consistent with the observed small amounts of grain left between years.

The second topic is "King's Law". It postulates that demand for basic foodstuffs was largely unaffected by price – or that price elasticity was about -0.4. This was debated intensely but never with all the required data. Our findings allow for a reconciliation of the diverging viewpoints. First, Fogel's (1989) by all means implausibly low estimate of -0.2 can be clearly rejected, while Persson's (1999) claim that elasticity was rather in the vicinity of -0.6 can be reproduced by making the same simplifying assumptions as the remainder of the literature. However, making full use of our database, we confirm "King's Law". Finally, our results surprisingly do not show an increase of price elasticity of demand for rye and wheat after the turn of the 19th century, although given the increase in potato growing and more trade this would be plausible.

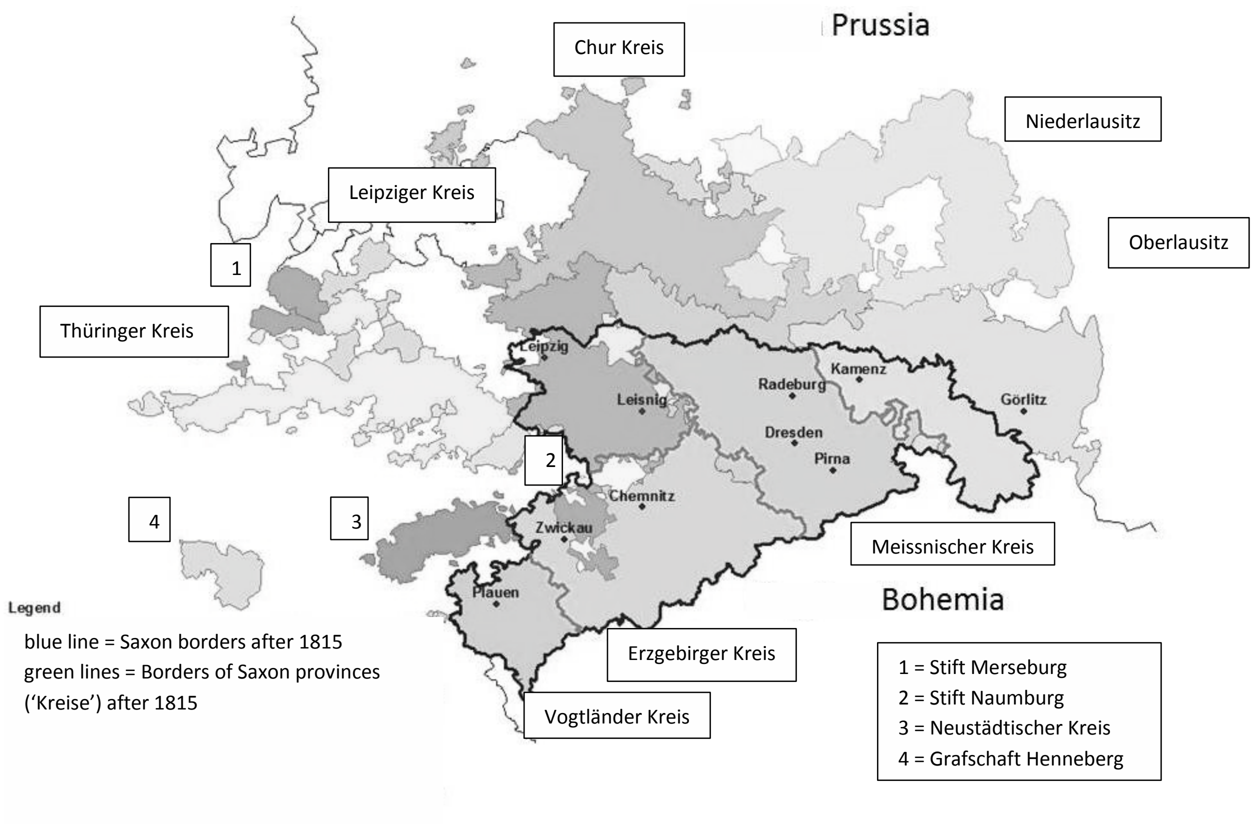
The final step in the analysis considers determinants of storage. With a simple linear regression we find that storage decisions were driven by both price signals and harvest variations. However, as this is likely to be plagued by autocorrelation, simultaneity and endogeneity bias, we conduct a vector autoregression analysis, which confirms our findings impressively. Thus, barns were regularly used to cushion bumper harvests as well as to store grain bought at low prices on the market.

The next section explains the data set shortly, and presents a descriptive overview of the main trends in production and consumption. Then, in section 3, we discuss intra-year price changes, in section 4 "King's Law", and in section 5 the determinants of storage before we finally wrap up in the conclusion.

2 Data and historical overview

2.1 Sources

The statistics we rely on were created with the purpose of garantueeing food security through the central government. In the 16th century, the Elector August von Sachsen established the first public granaries. But until the mid-18th century, such systems nearly disappeared (Franz 1960, pp. 56-57). As a consequence of the crop failures in 1754 and 1770/71, records of the subsequent harvests were create, which is why data of the harvest years 1755 and 1772 are available today. Furthermore, in 1791 a general duty to disclose harvest outputs was enacted by elector Friedrich August III, and registers for the years 1789 and 1790 were created in hindsight.



Sources: Blaschke, Jäschke (2009); Grünebaum (2012)

Figure 1: Saxony in the late 18th and early 19th century (dark outline).

Regarding data quality, the registers after the crises 1754 and 1770/71 are of dubious quality, especially the former one. Pfister & Kopsidis (2013, p. 11) estimate agricultural output using an alternative approach which is largely consistent with the output figures presented here from ca. 1790. However, the earlier years evidently failed to register about 40% of the harvested grain.

These registers were made for almost every agricultural product that potentially served as food in Saxony. They had to be collected by any kind of local authority and should be created by every individual. If grain was kept in secret, this was punished by a two Taler levy per Scheffel, and being late with the declaration resulted in a charge of ten Taler. One Scheffel of rye or wheat cost between two and four Taler in the late 18th century, so at least cost half of the concealed grain was at risk. Furthermore, the results were kept secret so tax evasion could not be an incentive to hold back information.[1]

After the Congress of Vienna, Saxony lost many of its northern and western territories to Prussia. The borders of the Electorate of Saxony and its counties in the late 18th century can be found in figure 1. The cities marked in figure 1 are those for which price data are available. The price series are taken from a weekly newspaper (*Gnädigst privilegiertes Leipziger Intelligenz-Blatt, in Frag- und Anzeigen, für Stadt- und Land-Wirthe, zum Besten des Nahrungsstandes* Intelligenzcomtoir), which was published since the 1760's and contains prices for several products from different Saxon cities. Figure 2 gives an overview about the availability of all prices.

The harvest, storage an seed data we use have been recorded at the *Kreise* (referred to as districts below) level of which 14 existed until 1812. From 1815 only four districts remained plus the area of Oberlausitz, which were divided in eleven *Amtshauptmannschaften* plus several other areas, which can be matched to the earlier districts such that the records can be used across the territorial change of Saxony.

There is an additional set of harvest data for five major crops at the lower *Ämter*-level, almost 100 areas in total, in the years 1792-1811. For our purposes, the extremely high spatial resolution is not necessary, and cannot be matched by price data. However,Uebele & Grünebaum (2013) analyse these data extensively.

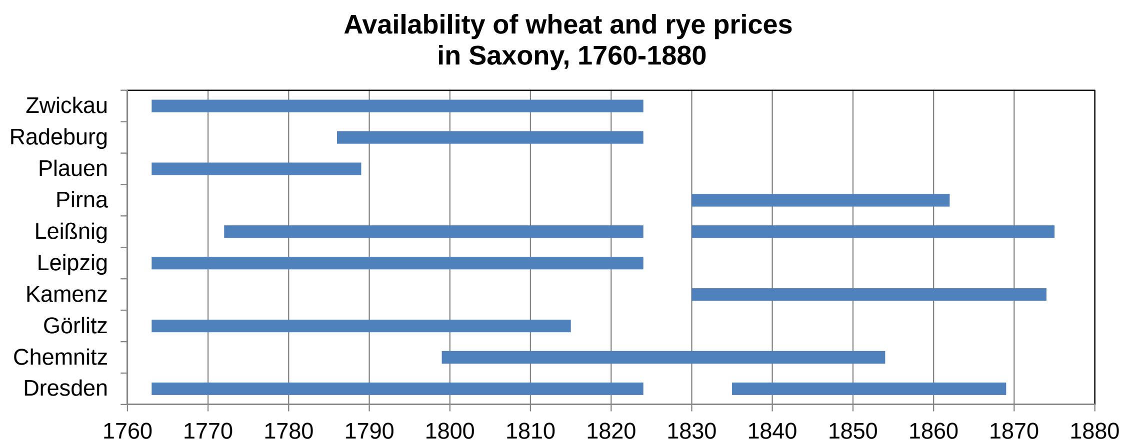


Figure 2: Available data on wheat and rye prices.

2.2 Overview

We continue with a graphical summary of the key characteristics of Saxony's statistics. If not stated otherwise, we make the nutritional values of the various crops comparable by expressing them in grain equivalent. Grain equivalents are measured per kilogram and expressed relative to the nutritional value of barley with rye = 1.01, wheat = 1.07, barley = 1, oats = 0.85, and potatoes = 0.22.[2] Following from this, 2.5 grain equivalents per year imply about 2200 calories per day, which is considered considered to be sufficient for survival in the relevant literature (Kopsidis & Pfister 2013, pp. 47).

[1]For more details see Kopsidis & Pfister (2013, pp. 14-16).

[2]See Kopsidis & Pfister (2013, p. 69) for details.

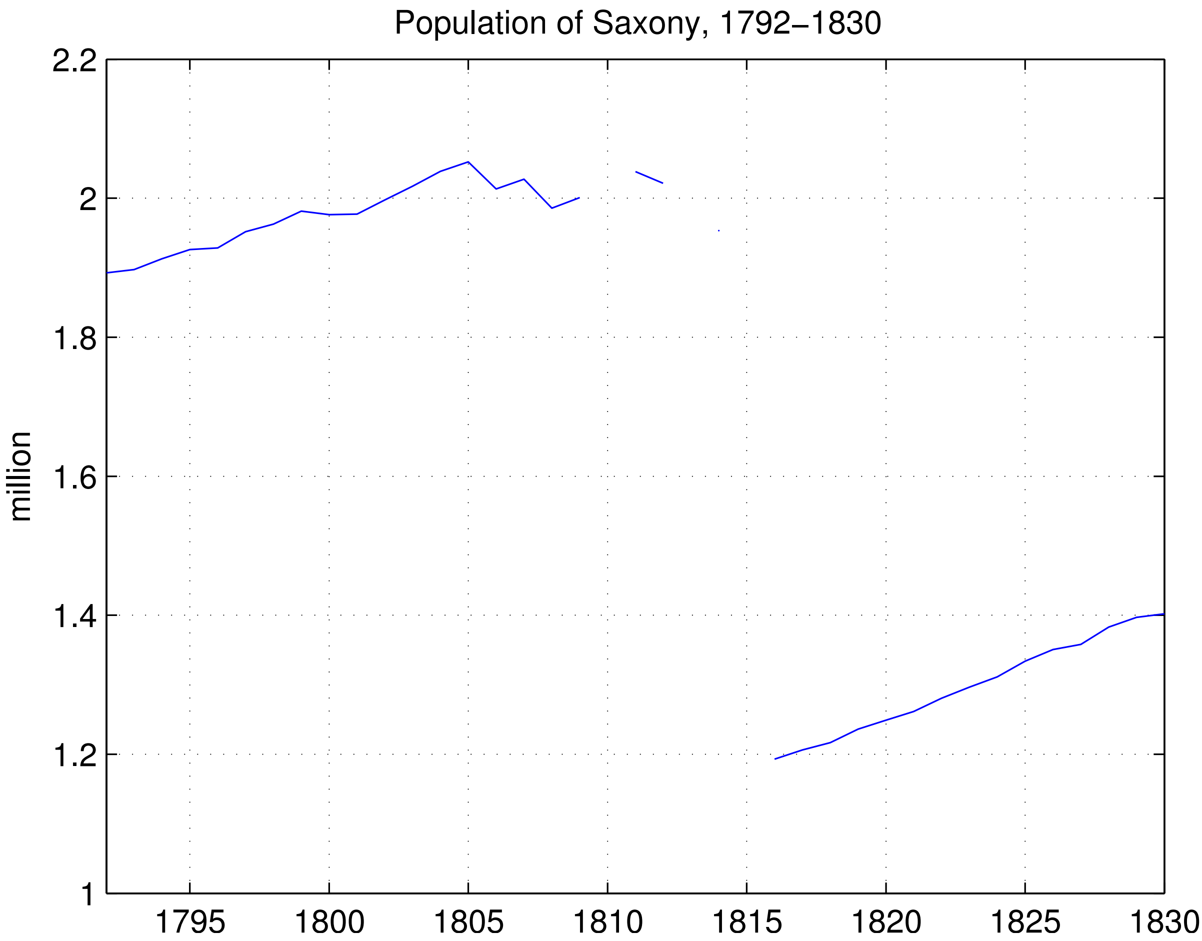


Figure 3: Population of Saxony (excl. Cottbusser Kreis), 1792-1830.

As Fig. 3 shows, the development of Saxony's population experienced a break due to the area change after 1815. The rising trend in the 18th century leveled off around 1805, but was continued even stronger after 1815. Kopsidis & Pfister (2013, pp. 47-57) give a detailed summary of the nutritional standard in Saxony, ca. 1790-1830 as judged from domestic harvest statistics. The main results can be found in Tab. 1. It presents net total crop production measured in grain equivalents and the respective amounts for human consumption, since not all net production was for human consumption.

When taking ca. 2200 calories or roughly 2.5 grain equivalents as a yardstick it can be seen that in the late 18th century per capita production was sufficient. However, in the early 19th century the situation deteriorated and per capita output fell well below subsistence level. The lowest point was in 1815/17 after the war when not even half of the necessary food was produced in Saxony's changed territory. Thereafter, production per capita improved quickly, but never to the level of the late 18th century.

This implies that at least after the war Saxony became a net food importer, while before we may assume that net trade was negligible. Pfister & Kopsidis (2013, p. 13) estimate per capita food consumption from real wage and price data, which implies that the level of consumption of the early 1790s had be restored by the 1820s.

Next, Fig. 4 illustrates the composition of Saxony's food production before and after 1812/1815

Table 1: Total net crop production, per capita. 1791-1829 in grain equivalents.

	1791/93	1803/05	1809/11	1815/17	1818/20	1827/29
Total prod.	3.55	3.36	3.07	1.76	2.22	2.20
Hum. cons.	2.39	2.07	2.04	1.12	1.57	1.57

Notes: 2.5 GE = 2233 calories per day. Total production consists of all recorded major and minor crops. Human consumption refers to rye, wheat, potatoes, and shares of oats and barley production for human consumption. Source: Kopsidis & Pfister (2013, Tab. 19a and 19b).

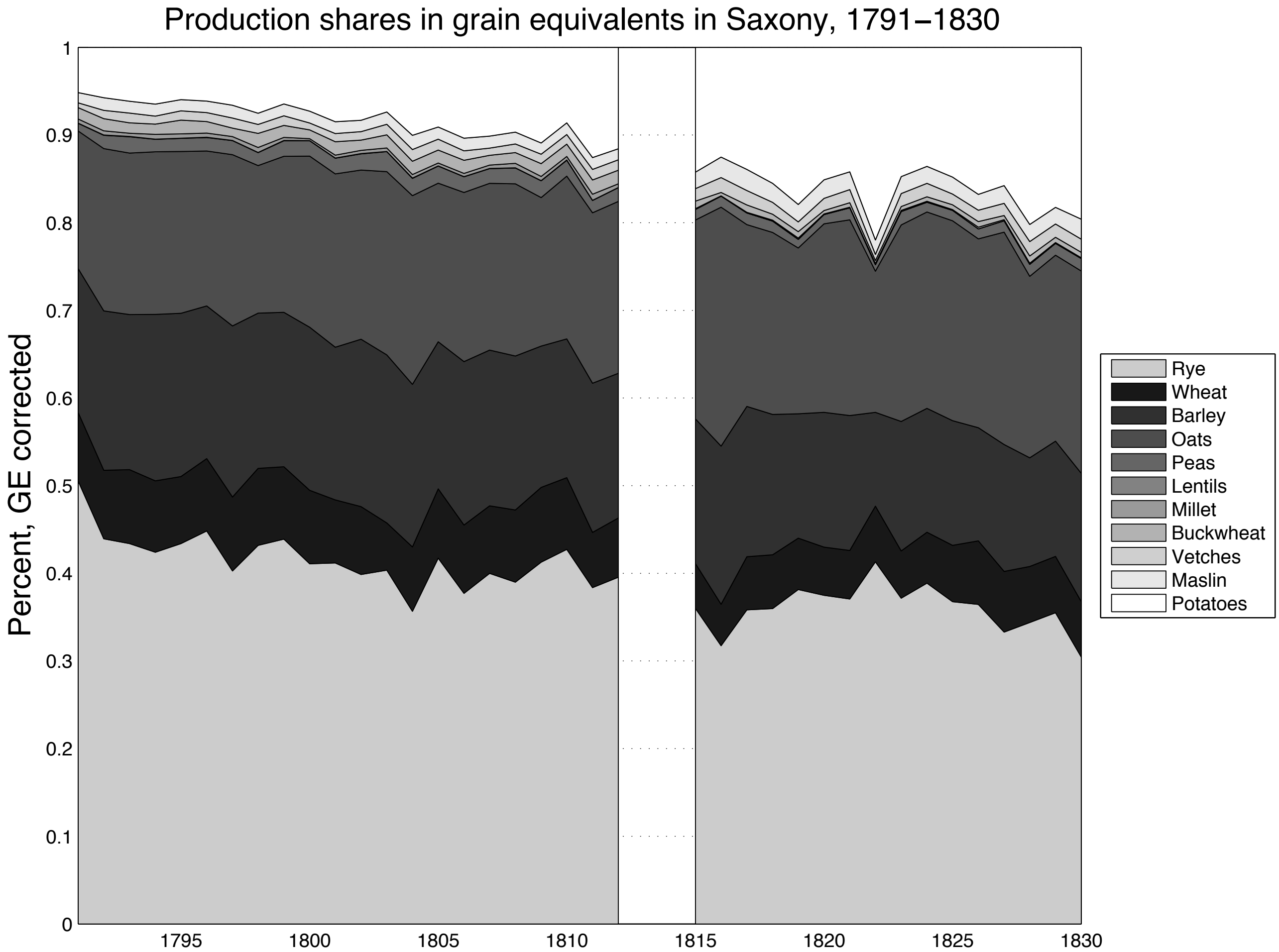


Figure 4: Shares of agricultural production in grain equivalents in Saxony, various areas, 1789-1830.

measured in grain equivalents. It shows first and for all the striking rise of the potato, and the relative decline of rye. As Uebele & Grünebaum (2013) show, the nutritional value and high yields of the potatoes was probably not the only reason for this relative increase of potato production. In many counties, potato harvests were usually good when rye harvests failed, and thus stabilized the average food intake.

Sections 3 to 5 contain the analytical parts of the paper. The next section is on within-year price movements. Then section 4 discusses “King’s Law”, and section 5 the determinants of storage.

3 Analysis of within-year storage

In this part we estimate the earnings of an investor who bought grain right after harvest and sold it throughout the ensuing year. Thus, for given cities, we calculate percentage price changes between the harvest month and all respective months thereafter. For each city, there will be a couple of dozen observations for which we report averages returns and their standard deviations. These are then contrasted with upper and lower storage cost boundaries. We especially discuss the implied level of interest rates under the assumption of risk-neutral investors. Furthermore, we make a methodological point by rejecting Clark's (2001) way of calculating monthly returns. The appendix explains the reasoning about the latter point in detail.

3.1 Theory

For a theoretical model of the dynamic optimization problem in a given market, please refer to Bauernfeind, Reutter & Woitek (2001) and Taub (1987). The central result is that under certainty, prices should rise continuously during the year depending on the discount rate, which consists of interest and storage costs. If there are costs for transporting the good to the market, prices will increase non-linearly throughout the year.

If information about harvests is uncertain, then the revealing of information and precautionary storage may cause prices to fall over the year. On average, however, when observing many years, intertemporal arbitrage should prevent prices to fall. Thus, should we observe falling prices, we must conclude that market participants did not behave rationally.

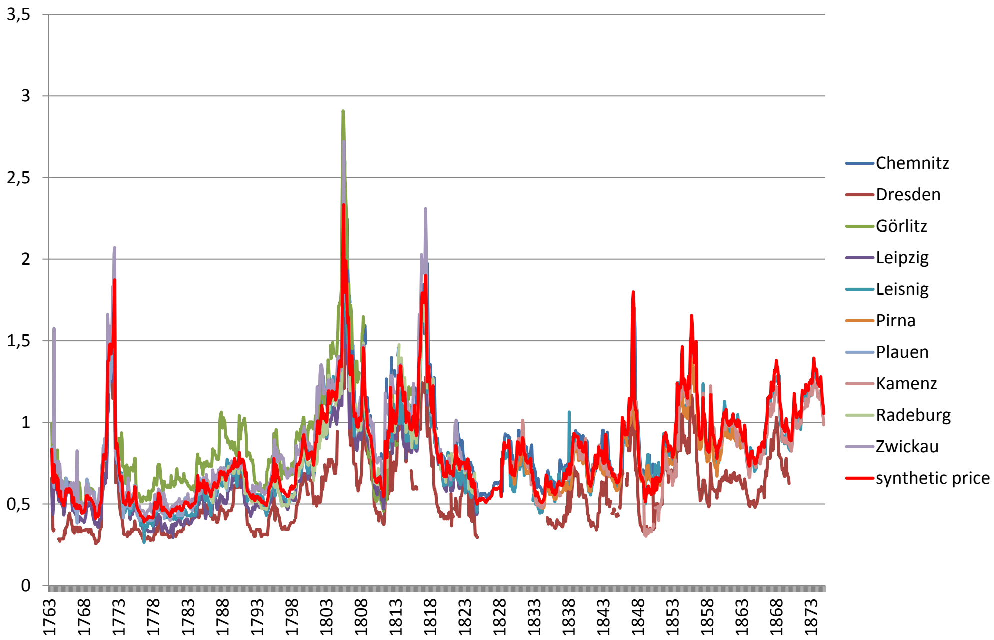


Figure 5: Monthly wheat prices in grams of silver per liter.

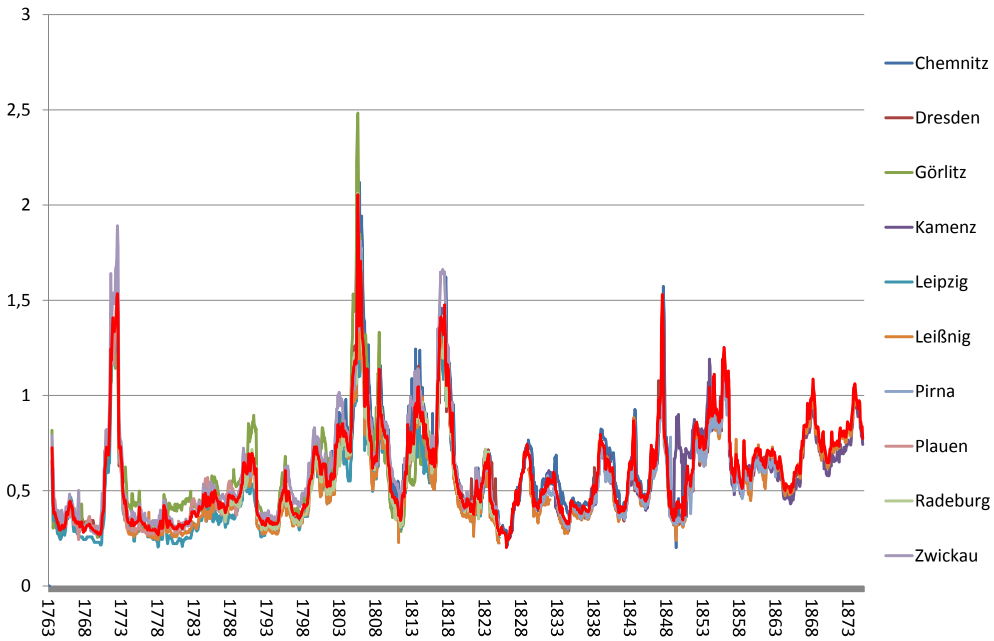


Figure 6: Monthly rye prices in grams of silver per liter.

3.2 Estimation

We observe prices for ten cities, and two grain types as shown in Fig. 5 and 6. Returns are the change of price relative to a base month $j = 0$, here August[3], and the number of observations for each city refers to all respective pairs of months over a maximum of 115 years (1763-1879):[4]

$$r_j^* = p_j/p_0 - 1 \tag{3.1}$$

r_j^* with an asterix refers to the return between the respective month pair. For reasons of comparability with the literature, the returns are annualized as follows to arrive at r_j:

$$r_j = (1 + r_j^*)^{\frac{1}{(j+k)/12}} - 1, \tag{3.2}$$

where k refers to the number of months passed after the base month.

We then report average returns for each month relative to August, thus twelve estimates per each of the ten cities. Additionally, we show p-values. The number of observations ranges from ca. 30 to 115, depending on availability of prices. Because of this relatively small number of observations, the p-values are often quite high.

[3]Depending on the region, September may have been the more appropriate month. Results are available on request.

[4]With this method I stay close to the bulk of the literature which ensures comparability of the results (Persson 1996, Persson 1999, McCloskey & Nash 1984). However, Bauernfeind et al. (2001) analyse the seasonal pattern of the logs and the first monthly differences of the prices. For this, they detrend the series with a Hodrick-Prescott filter adjusted for monthly observations.

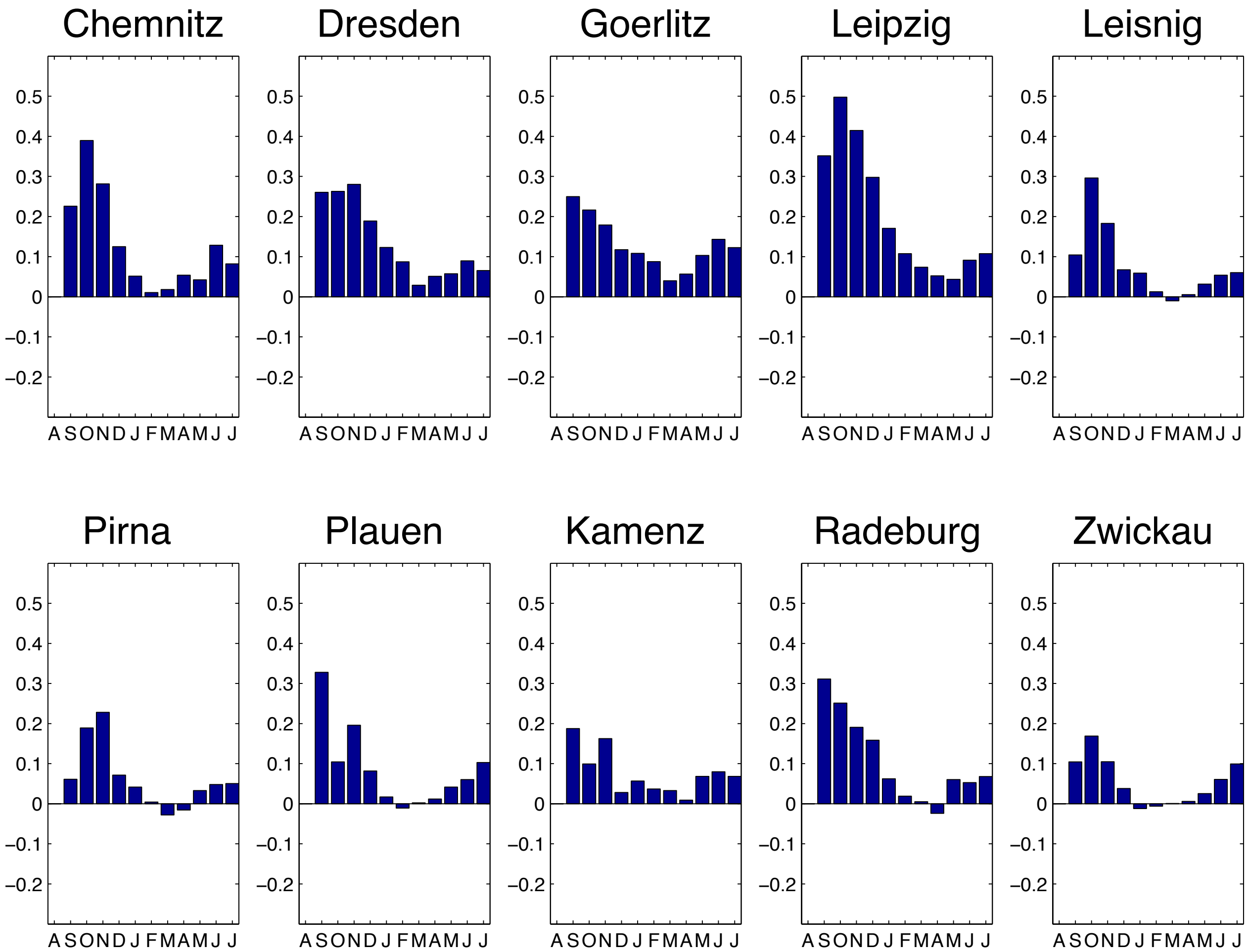


Figure 7: Annualized returns of monthly rye prices relative to August in ten cities in Saxony, 1763-1874.

Fig. 7-10 present results for price observations ranging from 1763 to 1879.[5] Each sub-graph reports monthly returns (blue) and p-values (red) for one city.

As a benchmark for the returns presented here we refer mainly to Persson (1996), who presents comparable estimates for Pisa, Siena, and Cologne, 1550-1700. We also refer to the results given in McCloskey & Nash (1984, p. 179).

3.3 Discussion

What is most striking in Fig. 7 and 9 on the average returns is that for rye a pattern emerges for all cities, while for wheat this is not the case to the same extent. Also, average returns are much higher in the case of rye than in the case of wheat. Similarly, there a big differences between the accompanying p-values, which are much lower for rye than for wheat.

The pattern observed for rye consists of high price increases in the first months after harvest. In most cities, rye prices increase on average by more than 20% (annualized) during October and November, and are still significantly positive in December and January applying a significance level of 10%. For wheat, the returns in October and November are much lower around 10%, and more

[5]Results for subperiods before and after 1815 can be obtained on request.

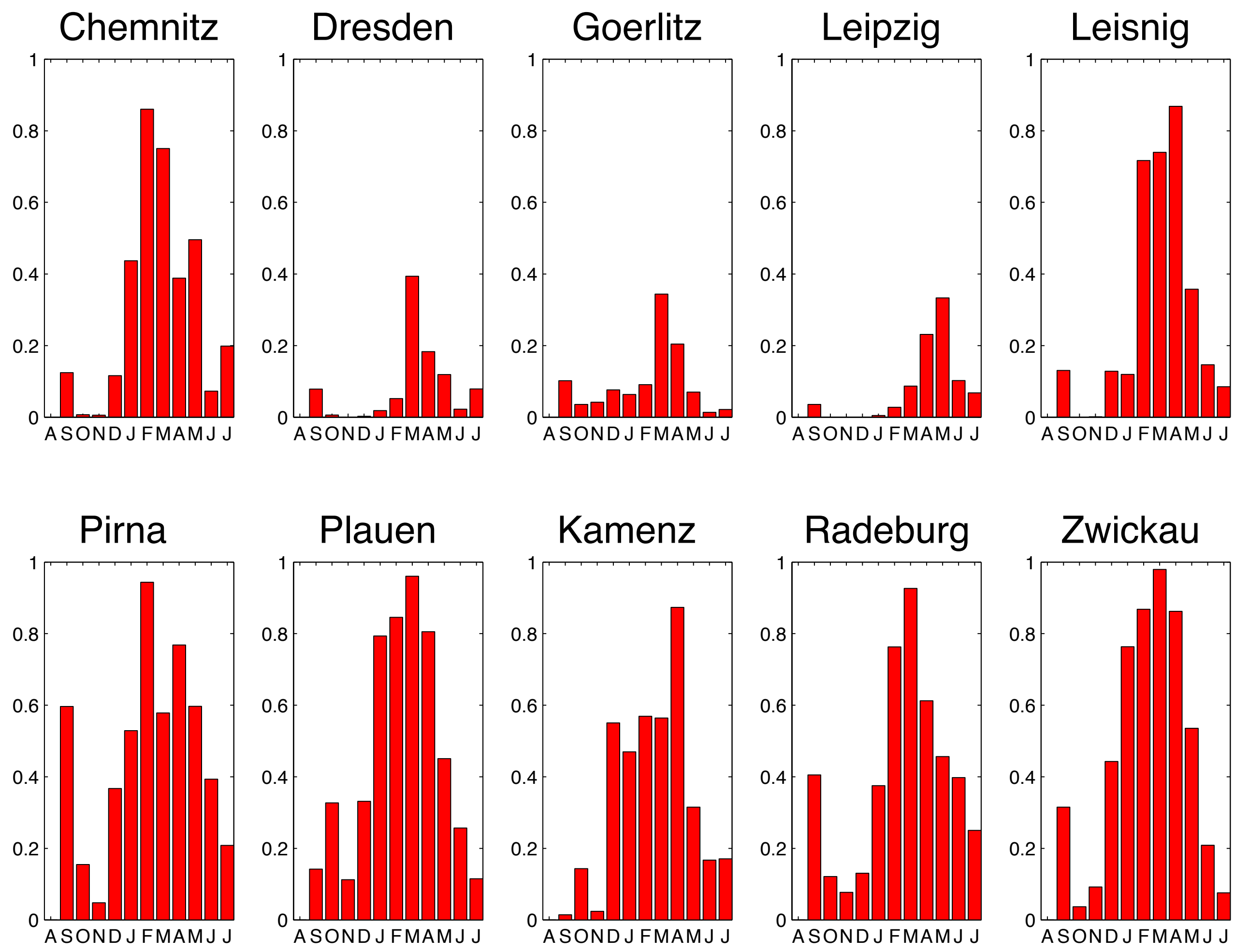


Figure 8: P-values for rye returns, Saxony, 63-1874.

often insignificant.

For rye, returns become indistinguishable from zero during late winter and spring as indicated by the high p-values in Fig. 8. In late spring and early summer, returns begin to rise again, but not to the levels achieved after harvest. Since the standard deviations do not rise again, though, these returns are often significantly positive again. This pattern emerges on a lower level for wheat as well, but apart from June and July, these returns become seldom significant.

Lastly, negative returns cannot be observed in the case of rye, but for wheat we find this in Plauen in Octobers, in Leisnig in the late winter and early spring months, and in Pirna in May on average. As Bauernfeind et al. (2001) and Taub (1987) point out, this implies that not opportunities for profit were exploited. One possible explanation for this could be a shortage of liquidities in the markets for wheat, which is surprising given wheats high value to weight ratio, but consistent with the fact that rye was by far the most important grain in Germany in this period (Kopsidis & Pfister 2013). The argument of liquidity would also be consistent with the fact that larger cities such as Dresden, and Leipzig seem to exhibit lower p-values than smaller cities, and never negative returns.

Most of this evidence is comparable to results obtained by Persson (1996, p. 700) for Siena, Cologne and Pisa in the 16th and 17th centuries. It is important to note, however, that prices from Siena and Cologne are averages for each month, whereas prices from Pisa are single day observations and therefore should exhibit higher variation. Since we use monthly averages of price observations at

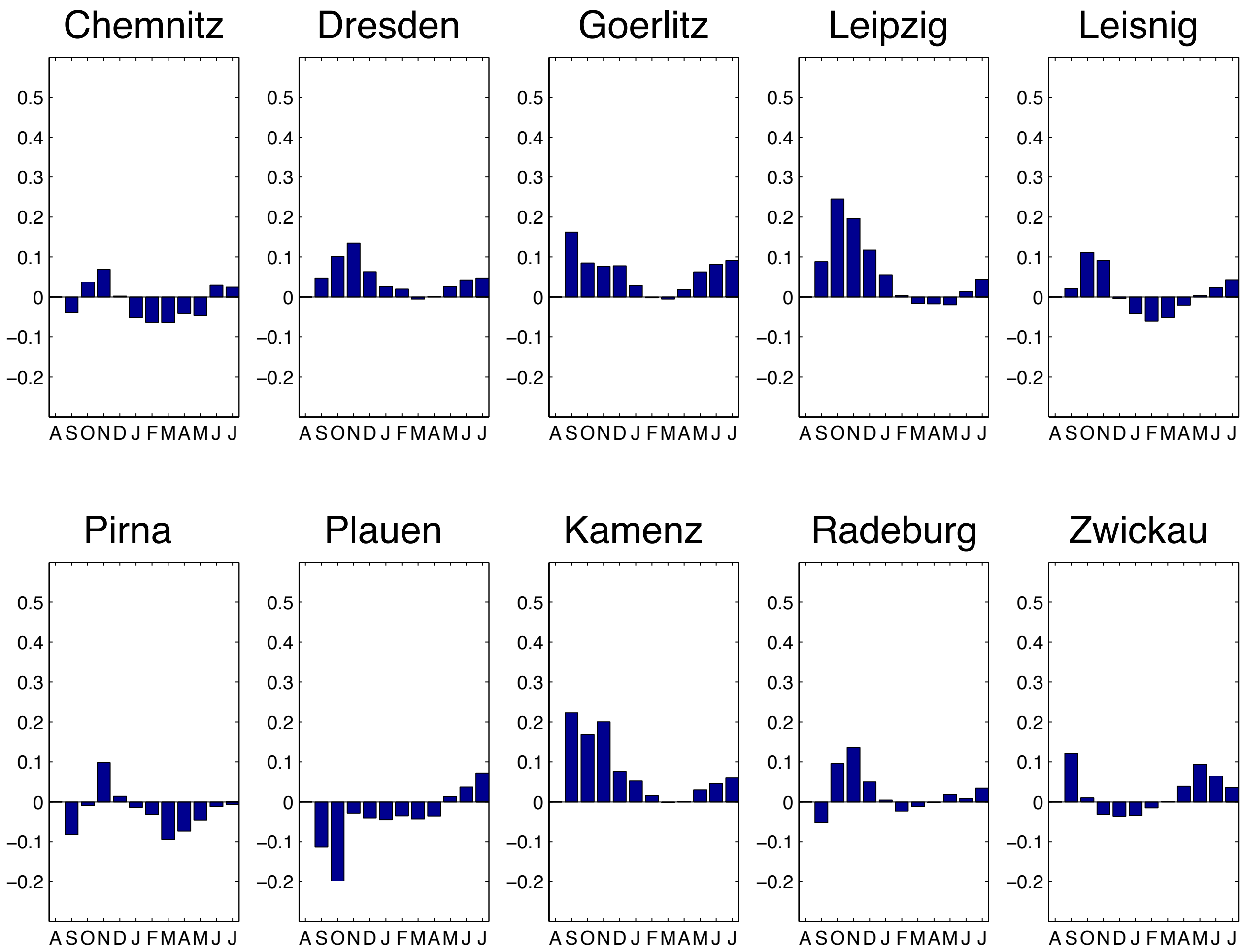


Figure 9: Annualized returns of monthly wheat prices relative to August in ten cities in Saxony, 1763-1874.

weekly held markets, we compare our results only to Siena and Cologne, and not to Pisa.

For Siena, Persson (1996) reports September returns to be about 50%, and October returns close to 40%, declining to below 20% only in December without any significant rise in the rest of the year. The same pattern holds for Cologne, however, at a lower level.

We do not report standard deviations due to space restrictions. They range between ca. 0.20 and 0.75 for wheat and ca. 0.30 and 2.00 for rye. The standard deviations given by Persson (1996, p. 700) are mostly higher than in Saxony, starting at ca. 2.00 for Siena in September, declining to ca. 1.00 in October, further declining to just below 0.40 from January on and remaining at about this level. Cologne standard deviations again follow a similar course at lower levels until December and at very comparable sizes throughout the rest of the year.

The estimates in McCloskey & Nash (1984, p. 179) for medieval England are calculated in a slightly different way, and are therefore only roughly comparable. They show on average 52% annualized returns in October, falling to around 25% by December with standard deviations at the same order of magnitude.[6]

Compared to medieval England and early modern Siena and Cologne our prices show similar patterns. The closest similarity is found after harvest time for rye, when very high returns are ac-

[6]The annualized returns are calculated from the averages of Table 2 in McCloskey & Nash (1984) with $r = (1+r^*)^{12}$.

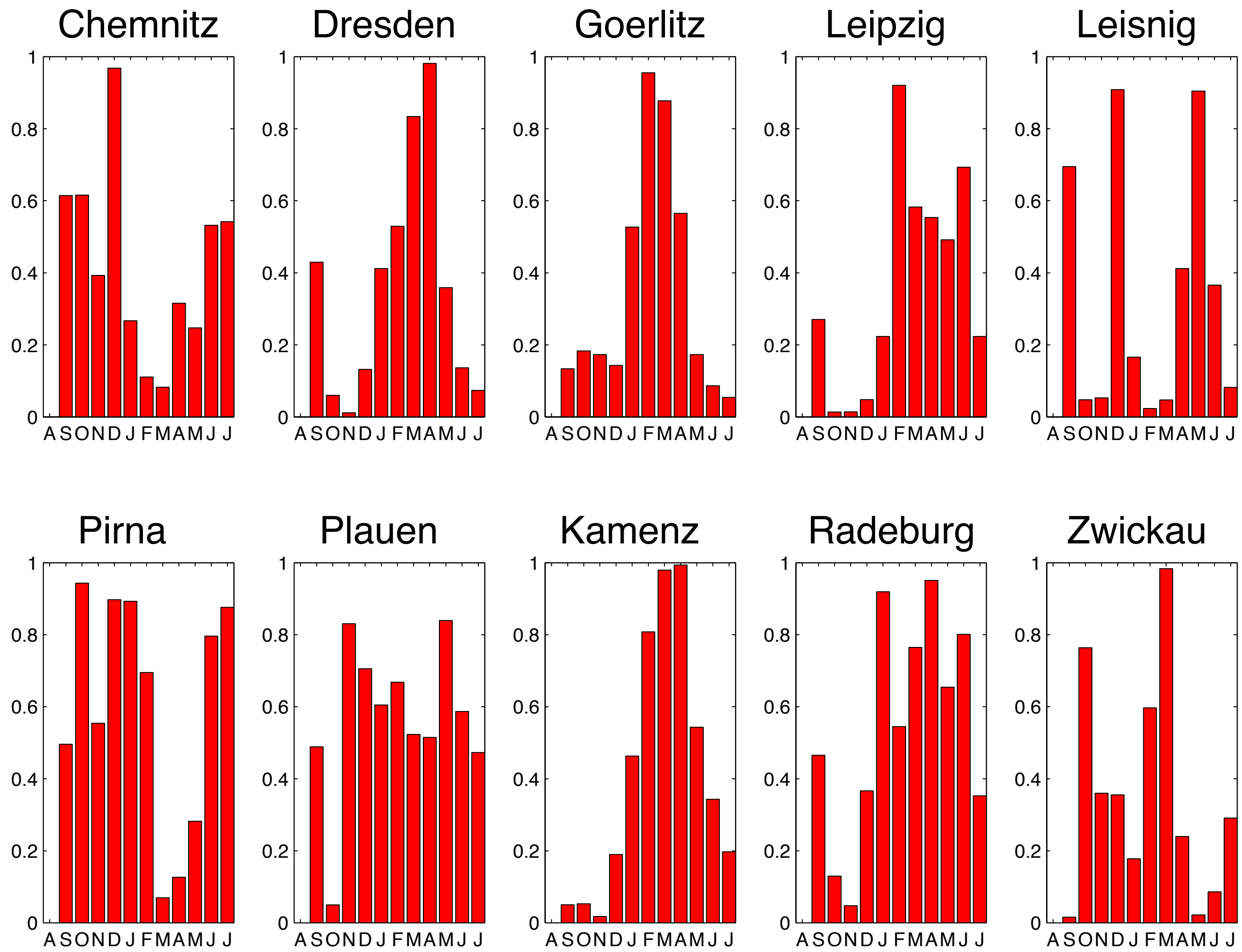


Figure 10: P-values for wheat returns, Saxony, 1763-1874.

companied by high standard deviations. What distinguishes our results somewhat, however, are the increasing returns before the next harvest. Instead, McCloskey & Nash (1984) reports on average higher returns throughout the whole year, while Persson (1996) finds ever declining returns until August.

There is no accepted explanation for the high returns after harvest found here and elsewhere. McCloskey & Nash (1984, p. 179) comment only on the decline of returns in spring when new information about the next harvest becomes available. Persson (1996, p. 701) attributes high short-term profits paired with high risk to uncertainty about the current harvest outcome. Finally, Clark (2001, pp. 17) denies the factual existence of high returns at the beginning of the harvest year althogether. However, we believe his way of calculating average price changes may bias returns downward, and is therefore not informative for our question.[7]

Another argument is made by Poynder (1999, pp. 17). He disagrees with the model of the rational investor and the idea that returns should equal storage costs. He argues that there may have been an incentive to store more than warranted by expected price changes because of the monetary function of grain, which according to him (and citing Adam Smith) fulfilled short term value conservation better than silver.

[7] A detailed explanation is available on request.

We think that Persson's (1996) explanation about the uncertain harvest outcome leads in the right direction. It is consistent with the fact that it is not clear in our results if the lowest price was regularly found in August or September. Also, the custom of fixing tax payments after harvest around the holiday of St. Martin (11 November) may have added to that uncertainty. Tenants who needed to pay in kind but without sufficient harvest may have tried to buy grain on the market. Elaborating on Persson's (1996) idea, the period after harvest may be regarded as a market with high transaction (especially information) costs. During this time, price volatility may have slowly decreased as the stream of new information became bigger, e.g. from threshing outcomes at different estates in the region, and the respective outcomes of tax fixing. This may have interacted strongly with liquidity, see our remarks above.

With regard to the increased returns at the end of the harvest year, we conjecture that the same reasoning may apply. At the end of every crop year, there will be a number of households running out of stocks, which increases demand for grains on the market. The fact that the dispersion of prices does not rise may be due markets being able to predict this demand induced behaviour better.

The returns we discuss are gross returns, i.e. without reference to costs. The main elements of expenditure for storing grain are spoilage, rental cost of a barn, and opportunity cost of capital, i.e. interest. Spoilage caused by rot, mice, fungi, or loss is usually estimated at 10 to 20% per year (McCloskey & Nash (1984, p. 182);Persson (1996, p. 701)). This seems to be stable over time, as for example in 2011 the United Nations Food and Agriculture Organization called for improved grain storage because of annual pre-process losses of grains in Africa at exactly the rate of 10 to 20% XXXCITEFood2011.

The cost of storing was calculated by Claridge & Langdon (2011, p. 1265) for medieval England from purveyance accounts at about 10% of the value of wheat, while McCloskey & Nash (1984, p. 183), having no direct evidence, doubt that barn costs were "much of a factor in storage costs to begin with." For Saxony, we have no data on the cost of storage, thus we take Claridge and Langdon's (2011) estimate as an upper bound.

Evidence on interest is similarly difficult to come up with. Implicitly, McCloskey & Nash (1984) presumes annual interest may have been as high as 30% in medieval England, which was heavily critized in Clark (2001, pp. 17), advocating a smaller rate of interest. However, Clark (2001) simply interpretes the same data differently. We may come closer to the issue by referring to the situation on German capital markets. Generally, interest rates were subject to customs or even directly government by law. Thus, in 19th century Prussia, 5% was the interest rate to be applied in most cases (Bracht 2009, p. 150).

Summing up, the annual cost of storing grain must have been in the range of 15% (10% spoilage, no barn costs, 5% interest) to 35% (20% spoilage, 10% barn costs, 5% interest) with a median of 25% or just under 2% per month (ca. 1% and 3%, respectively).

Comparing 25% to the annualized month-to-month returns found in our price data, there is no evidence for excess returns, i.e. returns exceeding costs. Of course the span of our cost estimate is very wide. But even at the lower bound of 15% annually (ca. 1% monthly) only the immediate period after harvest exhibits abnormal returns. Cashing in on them was however a very risky endeavour. At the end of the harvest year, the observed returns of below 10% even mean substantial losses for investors holding grain so long. This may hint at shrinking storage costs as stocks declined, because inefficient barns would be emptied first during the year (Taub 1987, p. 1051).

As we saw in section 2.2, the level of grain stored from on harvest to the next was around 2% of an annual harvest for most of the time. The one conclusion that can be drawn from this about storage levels *between* harvests is probably that if carryover was small, the risk of running out of food at the end of the harvest year was perceived as small. Therefore, stocks were almost fully used up at the end of the year, and waste was minimized. This seems to be consistent with small but certain price increases in summer as found here for wheat and rye. If there had been frequent food shortages in Saxony shortly before the new harvest, returns should have been clearly above storage costs for most of the year, accompanied by large standard deviations. Neither of it is found here.

Finally, it should be noted that the assumed rate of interest of 5% seems not too low. Even at this rate, the observed returns do usually not cover the assumed storage costs. A higher rate would have driven annual storage costs way beyond reason. Thus, interest rates of 30% as advocated by McCloskey & Nash (1984) for 12th and 13th century England are clearly not applicaple to 18th and 19th century Saxony.

4 King's Law of Demand

In this section we estimate price elasticity of demand for wheat and rye, and compare the periods before and after the geographical reshaping of Saxony. Before explaining the data and estimation issues, we shortly summarize the debate in the literature.

4.1 King's Law of Demand in the literature

In early modern Europe, when parts of the market for agricultural products where already commercialized but transport and transaction costs were high, the question of smoothing food prices between years was a matter of public policy. Persson (1999, 1996) studies food market regulation in early modern Europe and shows that market power and positive externalities lead to failure in the intertemporal market for food. He thus aims at solving a puzzle: Given the erratic character of weather shocks and the detrimental impact they had on food security, combined with high transport and transaction costs, the amount of storage was surprisingly low. Allegedly below 5% of an annual harvest was carried over into the next harvest year. Subsistence crises were prevalent until well into the 18th century, and partly until the first half of the 19th century in Germany (Post 1977, Bass 1991).

Most of the studies dealing with the question of early modern food crises and public responses, however, have only limited quantitative evidence on the actual amount of storage. Even for England, usually more data abundant than other countries, actual amounts of storage are not available. McCloskey & Nash (1984), Persson (1999), Persson (1996), Clark (2001) and Campbell & Ó Gráda (2011) derive their conclusions mainly from price and yield data. An exception is the body of work by Carol Shiue, which rests among others on storage data from 18th century Chinese provinces (Shiue 2002, Shiue 2004). The political economy background of agricultural market regulation is however very different from the European case and therefore of limited interest for students of early modern Europe. Thus, Shiue (2004, 2002) does not directly connect to the storage puzzle presented here.

Claridge & Langdon (2011, p. 1245) try to fill the gap of storage volume data by presenting evidence of the size and frequency of barns in medieval England prior to the Black Death. They introduce the important distinction between urban and rural granaries with the former being the more interesting ones to students of historical grain markets. From the description of the storage places they conclude that the system of storage in medieval England was predominantly privately organized (p. 1256), and served rather within-year storage than year-to-year carryover (pp. 1257).

Traditional societies can be assumed to have very inelastic demand for staple food stuffs, since if the harvest fell short of the usual level, people where willing to spend all their income on it and prices would increase accordingly. The reaction of price to a supply shock can measure the price elasticity of demand if we assume local supply to be equal to local consumption. [8]

One of the earliest instances of price elasticity of demand is the so-called King's law of demand. [9] It relates to observations from the British grain market in the late 17th century about wheat output and prices. A table of price-reactions to supply shocks was first published by Davenant. From this a price elasticity of demand of -0.41 can be derived (Fogel 1989, p. 10). Consequently, a decrease in the wheat supply of 1% in comparison to what Davenant called a normal harvest would result in an increase in price compared to the normal by about 2.5%. Several historians and economists have referred to these observations as some kind of a rule or law, which applied for every medieval society (Schirmer (2000, p. 153), Wehler (1996, pp. 78-79), Abel (1974, pp. 272-273)).

The first attempt to estimate price elasticity of demand for wheat goes back to Fogel (1989). He estimated a similar elasticity using Davenant's data following the demand function $Q = P^{(-0.403)}$. Using price series by Hoskins (1968, 1964) about medieval England, he argued that given this specific demand curve, the implied harvest fluctuations were implausibly high.

However, most authors were not actually interested in price elasticity of demand but just took the law as evidence for a disproportionately high price reaction to harvest shocks. This indeed is not only characteristic for medieval but also for modern economies, as demand is usually inelastic for basic foodstuffs.

Barquin Gil (2005, p. 246) shows that calculating elasticity of demand depends heavily on the assumptions made about the underlying data. Davenant did not define "harvest". Was it equal to gross production or output net of seeds? Applying one or the other assumption the implied elasticities vary from -0.41 to -0.84. In addition, Persson (1999) shows that depending on the assumptions about trade and storage the estimates vary strongly. Our results below may help to reconcile these diverging views since with our data we can substantiate many of the claims made in the debate.

[8] This is a necessary but realistic simplification for pre-modern societies. Von Hippel (1995, p. 8) guesses that in early modern times the majority of people had to spend 70-80% of their income on food. This was witnessed in Bamberg in 1772, when the high food prices forced the citizens to renounce other industrial products (Schneider 2008, p. 284). Persson (1999, pp. 48-52) and Persson (1996, p. 693) discuss this approach of estimating the elasticity using local supply and consider it to be appropriate.

[9] Since there still is a discussion if it really comes down to Gregory King, his colleague Charles Davenant or both. See further Taylor (2005), Stone (1996), and Evans (1967).

4.2 Supply volatility

In the discussion above assumptions about storage an trade is prominent among the arguments about estimation of King's Law. In this section, we can directly use our storage data to quantify these effects. However, the effect of trade is more difficult to assess, since trade data are not available. Kopsidis & Pfister (2013, pp. 13-14) summarize the scarce evidence and conclude that in the 18th century net trade was probably negligible in normal years, while after 1815 the remaining territory of Saxony must have relied on food imports of the surplus regions formerly being part of Saxony. This is also consistent with preliminary evidence on price comovement in Saxony produced by the authors.

Another piece of evidence is presented in Uebele & Grünebaum (2013). They exploit the highly disaggregated harvest data set for the years 1792-1811 and show that trade within Saxony had the potential to reduce harvest volatility by 25-30% if transport costs had been zero. Bearing in mind that transport costs were not zero but most likely substantial, the effect of trade on our estimates below should therefore have been very limited for the 18th century. For the period after 1815, comparable estimates are missing so far, but putting an upper bound of 20% volatility reduction may be a plausible guesstimate.

4.3 Data preparation

Missing data: There are several price observations missing: 1825-1828 for the district of Meissner Kreis, and 1825-1827 for Leipziger Kreis[10]. We replaced the missing observations with interpolations based on "synthetic" price, a method originally proposed by Clark (2001, p. 4):

To obtain an average grain price for Saxony we regressed prices on a full set of time and city fixed effects:

$$ln(P_{it}) = c + \sum_{i=1}^{k-1} \alpha_i C_i + \sum_{t=1}^{T-1} \beta_t M_t + \epsilon_{it} \tag{4.1}$$

with P_{it} being the price series of *i* cities and *t* periods (months), C_i being the city dummies, M_t the time dummies, and ϵ_{it} an i.i.d. error term. To avoid perfect multicollinearity problems, one set of dummies (*i* and *t*) were omitted, in this case the ones for Plauen and the last month. To obtain a general price level for Saxony, we took the exponential of the sum of the constant and each period-specific β_t. This results in an index P^*. Each price is then regressed on this synthetic price:

$$P_{it} = c_i + \alpha_i P_j^* + \epsilon_{it}. \tag{4.2}$$

Here, P_{it} is the price of city i in month t and P_j^* the synthetic price from equation 4.1. So each series gets its own constant c_i and coefficient α_i, which take account of every series-specific relation to the synthetic price in Saxony. All missing observations are then replaced with forecasts using the estimated parameters and the synthetic price as predictive model.

[10]With alternative sources it should be possible to close this gap, though.

Detrending: Looking at the monthly price series for wheat and rye in Fig. 5 and 6 of which we use annual averages, we cannot rule out long run trends. They are likely to reflect population growth or monetary devaluation, which bear no information for short run decisions. Therefore, we use the Hodrick-Prescott filter with a smoothing parameter of $\lambda = 100$ to exclude the trend.[11]

Matching prices and volumes: Our grain prices relate to single cities as shown in Fig. 1. Thus, we cannot match each production series automatically with a price series. Although we have rye and wheat prices for important cities in the counties of Meissen, Leipzig and Erzgebirge, Görlitz, for which we do have prices, was handed over to Prussia after 1815. Therefore, the Saxon part of the Oberlausitz can not be included in the analysis. Nor do we have data for any city in the Vogtland. Table 2 shows which price series has been matched with which volume series. If there were two price series per district, we simply took their mean as the combined price information.

Table 2: Matching districts (harvest, seed and storage data) with cities (price data).

District	**City**
Meissner Kreis	Dresden, Radeburg
Leipziger Kreis	Leipzig, Leisnig
Erzgebirger Kreis	Chemnitz, Zwickau
Oberlausitz	Görlitz

Note: In the case of two cities per district we averaged the price series.

Supply and demand: The data we gathered tell us about supply, however, we are actually interested in demand. The difference between production and can be derived from the macroeconomic identity:

$$Y_t = C_t + I_t + (X - Z)_t, \tag{4.3}$$

where Y_t is total expenditure, C_t public and private consumption, I_t investment, and $(X - Z)_t$ net trade. This identity assumes that all returns to investment of the previous period are captured by higher Y_t in the present period, but we could also introduce a non-interest bearing asset S_t, which has to be subtracted on the left hand side of the equation, since it can not be used for consumption. However, previous expenditure on this asset may be consumed this year, and thus S_{t-1} is added on the left-hand-side:

$$Y_t + S_{t-1} - S_t = C_t + I_t + (X - Z)_t, \tag{4.4}$$

In the context of grain production in county i, we can now relabel Y_t into $y_{i,t}$, agricultural production from the recent harvest, C_t into $q_{i,t}$, which is consumption in district i, I_t into $z_{i,t}$, the amount of seed sown for the next year's harvest, S_t into $s_{i,t}$, the grain stored, and finally $(X - Z)_t$, into $(exp - imp)_{i,t}$, the net amount of grain imported from bordering states. The difference between supply and demand $y_{i,t} - q_{i,t}$ then amounts to:

[11] In the case of stochastic trends, the Hodrick-Prescott is known to create spurious cycles (A'Hearn & Woitek 2001). Robustness tests with alternative filters, however, did not affect the results.

$$y_{i,t} - q_{i,t} = z_{i,t} + s_{i,t} - s_{i,t-1} + (exp - imp)_{i,t}. \tag{4.5}$$

The economic history literature mostly assumes the right-hand-side of this equation to be zero because of the lack of data. In our case, however, we possess information for all right-hand side terms except the trade balance.

Thus, $q_{i,t}$ is assumed to equal harvest corrected for storage and seed quantity under the assumption of negligible foreign trade. This assumption may bias price elasticity estimates downward: If grain flows from abundant to deficient areas, then trade smoothes consumption.[12] Therefore, since our consumption proxy does not include trade, volatility is biased upward. Combining this with given volatilities of prices, our elasticity estimates are biased downward.

4.4 Estimation

We use two complementary procedures to estimate price elasticity of demand following Campbell and Ó Gráda (2011, p. 876). Method 1 (equation 4.6) was suggested by Fogel (1989). He estimates price elasticity of demand for the period 1540-1840 using price data from Schofield, Wrigley & Anthony (1981) and yield data from 1884-1913 for England using the equation

$$\epsilon_r = \frac{\sigma_q}{\sigma_p} \; r_{pq}. \tag{4.6}$$

Here, ϵ_r is price elasticity of demand, σ_p volatility of price, σ_q volatility of quantity, and r_{pq} the correlation coefficient between price and quantity. Fogel (1989) assumes price and quantity to be perfectly negatively correlated, and thus $r_{pq} = -1$. A smaller correlation coefficient in absolute value makes elasticity even smaller and thus would have strengthened Fogel's argument for a very low price elasticity. Since we have continuous data on prices and output for the two periods, we are able to estimate the correlation coefficient, and check the relevance of this assumption.

For Method 2 we estimate the following regression:

$$q_{it} = \alpha + \beta p_{it} + u_{it} \tag{4.7}$$

Here, q_{it} is output in district i in period t relative to trend supply in district i, and p_{it} is the respective price relative to trend. u_{it} is an error term with the usual distribution assumptions. The trend estimation was discussed above.[13] Since our variables are expressed in percentage deviations, β in equation 4.7 can be interpreted as price elasticity of demand.[14]

We will use both Methods 1 and 2 to estimate price elasticity of demand in equations 4.6 and 4.7.

[12] See Uebele & Grünebaum (2013) for a discussion of consumption smoothing through diversification of local subsistence food production when trade costs are high.

[13] In contrast to this procedure, Campbell and Ó Gráda (2011, p. 876-877) take first differences of natural logarithms.

[14] Correlation between price and quantity is usually estimated with price being influenced by supply. We might also – as done many times by other authors – estimate equation: $p_{it} = c + dq_{it} +_{it}$ Obviously, $\frac{1}{d} \neq b$. The results out of this approach will be presented later in this chapter.

Results: The results for Method 1 can be found in table 3. σ_q and σ_p are the standard deviations of quantity and price, and while ϵ is price elasticity of demand assuming $r_{pq} = -1$, ϵ_r is the result with the estimated r_{pq}.[15] "Saxony" represents average results of all four districts. As Uebele & Grünebaum (2013) demonstrate, increasing the level of aggregation decreases the volatility of quantity, and lower price elasticity of demand.

Table 3: Price elasticity of demand, calculated using Method 1. Saxony, 1789-1830.

			Meiss. Kreis	Leipz. Kreis	Erzgeb. Kreis	Oberl.	Saxony incl. s	Saxony excl. s
rye	1789 -1812	σ_q	0.18	0.16	0.16	0.19	0.171	0.178
		σ_p	0.26	0.24	0.22	0.32	0.263	0.263
		ϵ	**-0.70**	**-0.66**	**-0.70**	**-0.58**	**-0.651**	**-0.676**
		r_{pq}	-0.60	-0.69	-0.66	-0.70	-0.664	-0.628
		ϵ_r	**-0.42**	**-0.45**	**-0.47**	**-0.41**	**-0.432**	**-0.425**
	1815 -1830	σ_q	0.14	0.16	0.21	0.18	0.174	0.175
		σ_p	0.30	0.33	0.34	-	0.320	0.320
		ϵ	**-0.48**	**-0.49**	**-0.63**	**-**	**-0.544**	**-0.547**
		r_{pq}	-0.61	-0.86	-0.77	-	-0.751	-0.735
		ϵ_r	**-0.30**	**-0.42**	**-0.49**	-	**-0.409**	**-0.402**
wheat	1789 -1812	σ_q	0.17	0.15	0.13	0.18	0.160	0.164
		σ_p	0.18	0.17	0.15	0.23	0.187	0.187
		ϵ	**-0.92**	**-0.91**	**-0.87**	**-0.78**	**-0.855**	**-0.881**
		r_{pq}	-0.66	-0.77	-0.72	-0.53	-0.645	-0.629
		ϵ_r	**-0.61**	**-0.70**	**-0.62**	**-0.41**	**-0.551**	**-0.554**
	1815 -1830	σ_q	0.13	0.12	0.18	0.14	0.145	0.146
		σ_p	0.24	0.22	0.22	-	0.225	0.225
		ϵ	**-0.56**	**-0.55**	**-0.79**	**-**	**-0.644**	**-0.647**
		r_{pq}	-0.45	-0.83	-0.60	-	-0.606	-0.599
		ϵ_r	**-0.25**	**-0.46**	**-0.48**	**-**	**-0.390**	**-0.387**

Notes: $\epsilon_r = (\sigma_q/\sigma_p)$ The parameters refer to equation 4.6. ϵ denotes price elasticity of demand with $r_{pq} = -1$. s denotes storage left from the previous year.

Prices for Oberlausitz are missing in the second period, so no elasticities can be calculated for this region. However, in the first period the average across all districts is not very different when Oberlausitz is included or not. For rye, the maximium difference is 0.036 and for wheat 0.094. Thus, the averages between periods are roughly comparable .

The estimates reveal some remarkable characteristics of the Saxon grain market and the role of storage. First, the standard deviation of demand is always below that of price. This indicates price inelastic demand.

[15]Small deviations due to rounding.

If we take a look at ϵ, that is, elasticity with assumed $r_{pq} = -1$, we can compare the results with Fogel (1989) and Persson (1999). Note, however, that there is a fundamental difference in the calculation of σ_q. Persson (1999, p. 64) uses yields, i.e. output per seed corn or per hectare crop land as q. This procedure is inclusive of seed sown assuming the whole harvest output having an impact on price in contrast to equation 4.5. Remembering that the absolute quantity of seeds is very stable this should drive supply variations down relative to q net of seeds. Since $\epsilon = -\sigma_q/\sigma_p$, our elasticity estimates in table 3 are therefore likely to be higher than Persson's.

Fogel (1989) uses yields in levels and then calculates the deviations from trend. His estimated standard deviation is 0.04, which is extremely low. This can be attributed to his data, which is far from being representative for early modern and especially medieval Europe. Furthermore, his production data represents England as a whole. As discussed above, increasing the level of aggregation should drive standard deviation down. However, Fogel's aim was mainly to discuss a new procedure for estimating price elasticity of demand and not the adequacy of his results. We should therefore expect values considerably above Fogel's.

The most important finding is that demand for grain is inelastic, but not as inelastic as found by Fogel, and the results appear to be at the order of magnitude of Persson's, which means a higher elasticity as the Kind-Davenant Law of Demand of around -0.4 postulates. Barquin Gil (2005) finds the same for western European countries.

Using our additional knowledge on the actual correlation coefficients, of course the elasticity decreases. The correlation coefficients vary much, but are all negative and quite high with values between -0.45 and -0.83, with Meissner Kreis at the low and Leipziger Kreis at the high end.[16]

Interestingly, the elasticities with estimated coefficients produce a strong confirmation of King's Law in the first period for rye, as in all counties the elasticity is only slightly above -0.4 in absolute terms. On average, the result is -0.432 when storage is included. Thus, we still do not get any way near Fogel's estimate of -0.04, but Persson's rejection of King's Law suddenly appears weaker than before: Taking estimated correlation of price and quantity into account, the values of about -0.6 are corrected to such an extent that King's Law of -0.4 again becomes the more likely value of demand elasticity for grain even in the mid- and late 18th century.

Comparing the results to those obtained by Barquin Gil (2005, p. 264) for wheat, our elasticities for Saxony are much lower than his results for late medieval Europe, which reach from -0.68 to -0.90. He discusses the role of aggregation in detail and as he used data on cities – thus a quite low level of aggregation – this could not explain the difference. So price elasticity of demand in Saxony around 1800 was lower than for many other European cities in a period reaching from 1316 to 1800.

Furthermore, Brandenberger (2004, p. 161) estimates an elasticity of demand of -0.83 for late 18th century Switzerland, not accounting for storage and trade, and assuming a correlation coefficient between price and quantity of -1. This is in the range of the results for ϵ in table 3.

This comparison is done under the assumption that rye was the staple food grain in Germany, while wheat played that role in France and England, to which Fogel and Persson refer. Taking wheat itself, which was the much less frequently consumed product compared to rye (see fig. 4), the picture in period 1 (1789-1812) is somewhat different. The elasticities are much higher with the standardized

[16]Note that the correlations refer to the detrended series. The correlations of the series in levels are of course spuriously high which justifies our procedure.

correlation of -1, and range between -0.78 and -0.93. This might be caused by the fact that wheat was not a staple crop. The estimated correlation coefficients are only slighty higher than those for rye, and thus the elasticities with estimated correlation lie between -0.6 and -0.7. An exception is the Oberlausitz, for which both elasticity and correlation are considerably lower, and the final result is the exact same as for rye, namely -0.41. These results may come as a rescue to Persson, since his claim of generally higher elasticities than King's Law can not be rejected here. If wheat or rye is the correct comparison in the case of Germany must remain open, though.

When considering the second period in comparison, 1815-1830, the elasticity of demand for rye decreases a little after 1815, especially in Meissner Kreis, even though the correlation coefficients increase. For wheat, the decrease is even stronger, and drops to an average of just below -0.4 in absolute value when estimated correlation is used. Thus, the elasticity gap between rye and wheat from the end of the 18th century disappears in the beginning of the 19th century because wheat is less elastically demanded.

This is a somewhat surprising result as one would rather expect higher elasticity for food products as more interregional trade and the rise of the potato provide more consumption alternatives. One explanation, however, may be that products made from wheat such as white bread and cake where not substitutable by other grains, and that slowly rising incomes provided people with the means to afford a more constant share of these food items. Pfister & Kopsidis (2013, pp. 3-4) report indead rising real wages, however only slowly catching up with the peak after the Thirty Years War (ca. 1650).[17]

The results for Method 2 are shown in table 4. We estimated the price elasticity of demand for all available districts, just as the last two columns in table 3; again with and without storage. Furthermore, to account for outliers in 1805, we inserted a dummy variable for that year in all counties. The dummy is highly significant and goodness of fit prefers the model including the dummy.[18]

Table 4: Price elasticity of demand, calculated using Method 2. Saxony, 1789-1830.

		rye		wheat	
		incl. s	excl. s	incl. s	excl. s
1789	obs.	96	96	96	96
-1812	b	**-0.423**	**-0.416**	**-0.522**	**-0.524**
	S.E.	(0.038)	(0.037)	(0.068)	(0.069)
	R^2	0.487	0.448	0.457	0.442
1815	obs.	48	48	48	48
-1830	b	**-0.409**	**-0.402**	**-0.390**	**-0.387**
	S.E.	(0.046)	(0.046)	(0.073)	(0.073)
	R^2	0.564	0.540	0.367	0.359

It is remarkable that results from both methods are almost exactly the same. Comparing results for the second period, there are no discrepancies at all. The differences in the first period are due to the omission of the year 1805 in Method 1. So we can say that there is no difference between the methods

[17] Evidence on agricultural production trends can be found in Kopsidis & Pfister (2013).

[18] The price observations in 1805 are way beyond the regression line for all districts. A discussion of this can be found in Grünebaum (2012).

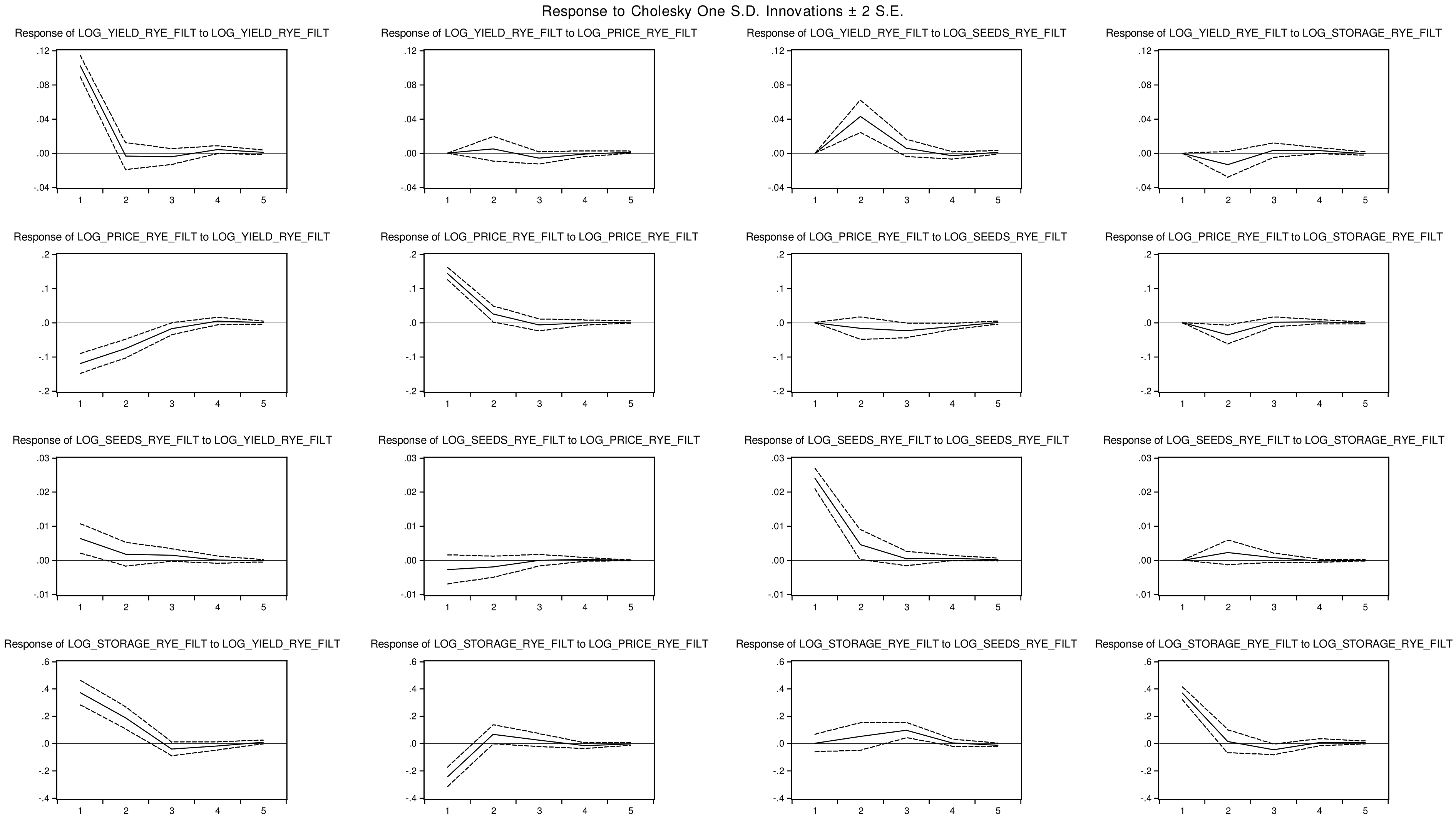


Figure 11: Impulse reaction functions of rye harvest, price, storage and seed quantity from a vector autoregression with Cholesky decomposition.

given data on output and prices are available. The discrepancies in the estimates by Campbell and Ó Gráda (2011, p. 877) are probably due to different transformations in both methods and/or the assumption of a perfect and negative correlation in Method 1. In general, such estimations are highly sensible to transformation and detrending. This has also been pointed out by Barquin Gil (2005) and Ejrnaes & Persson (1999).

A method-consistent interpretation is thus possible for the central question of this section of our paper. The literature on food security has always been interested in the role of storage as a means of precaution. However, the actual impact of storage on supply variability and thus elasticity of demand was seldom actually tested in any historical context because of lack of data.

Tables 3 and 4 now provide direct evidence for the impact on storage in Saxony, late 18th and early 19th centuries.

Firstly, we see a higher correlation coefficient between price and supply in Method 1 as well as a higher R^2 in Method 2 if storage is included. This may imply that reserves left from the previous year did actually have an impact on price, which may be because grain potentially but not actually entering the market (which was known to the public) was priced in as well. We may conclude that stored grain was likely to be released to the market and was not taken as a public reserve held back for extremely hard times. The main purpose of storage might therefore have been general supply smoothing at all times, not only in years in which people had to suffer heavily from hunger.

A second observation is that the standard deviation of supply is always slightly lower when storage is included, which is plausible and should result in lower elasticities. However, the higher correlation coefficients run counter this effect. The effect is that elasticities are only occasionally marginally lower including storage, and often even higher. Thus, there are two channels through which the introduction of storage data affects estimates price elasticity of demand: volatility of quantity and correlation of price and quantity.

Finally, the results confirm that storage smoothed output volatilities but the size of the effects were small. The next section presents an analysis of the respective relations between harvest, seed quantities, prices and storage ratios.

5 Determinants of storage

5.1 Introduction

In this section we analyze the determinants of grain storage, especially the sign and size of harvest and price shocks. Preliminary results from a linear regression in Grünebaum (2012, p. 53) show that both prices and harvests affected storage strongly. However, a more appropriate model is a vector autoregression (VAR) because harvest, price, seed and storage might affect each other and a linear regression model cannot account for endogeneity. In a VAR model, all variables are treated as endogenous, and thus reverse causality is accounted for.

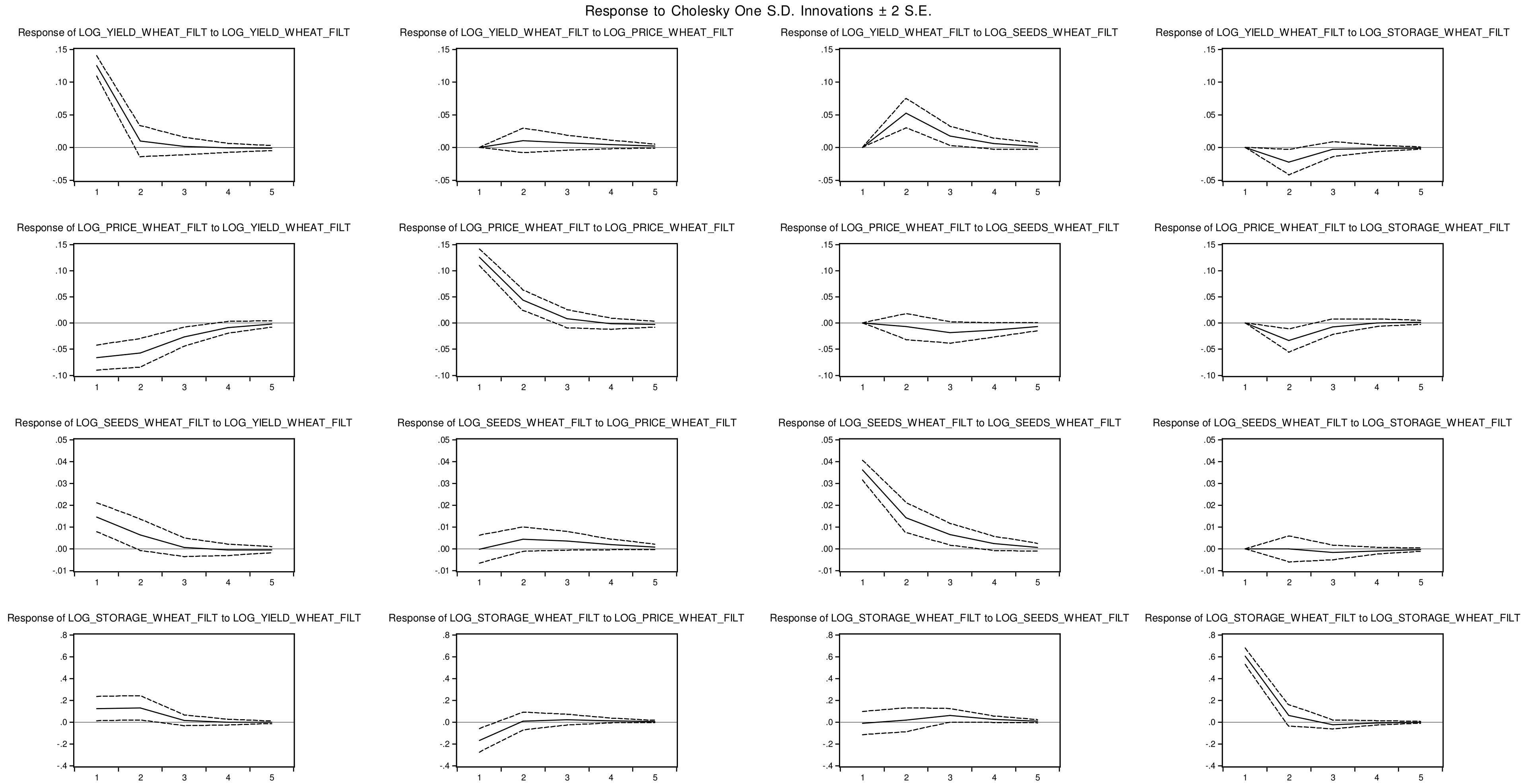


Figure 12: Impulse reaction functions of wheat harvest, price, storage and seed quantity from a vector autoregression with Cholesky decomposition.

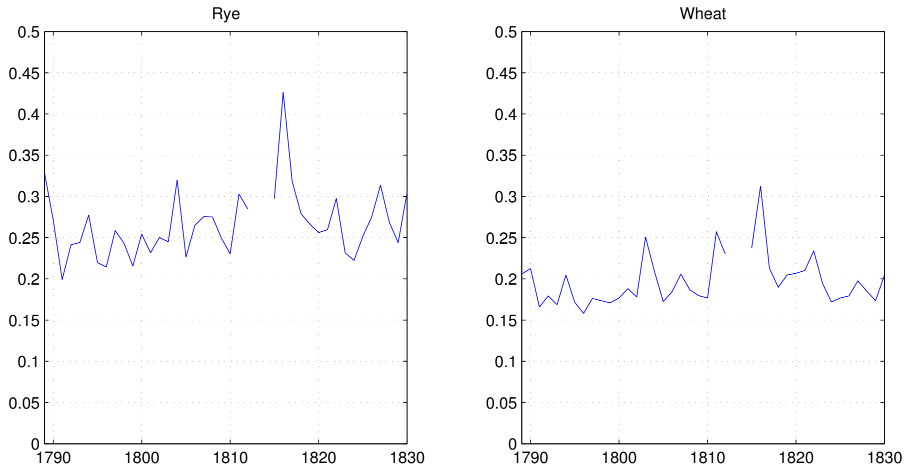


Figure 13: Average seed quantity for rye and wheat in Saxony.

5.2 Method

The most important fact to discuss when estimating a VAR model are the restrictions for effects in the same year, because otherwise the shocks for which reactions are estimated are not identified. The most frequent method is the Cholesky-decomposition, which implies that in a given year one variable is strictly exogenous, the next one reacts only to this one, the next to the first two ones, and so on. This is implemented by a particular ordering of the variables. In many circumstances, the theory behind the ordering of variables is highly debatable. In our case, however, there is a quite straightforward ordering:

$$\mathbf{v}'_{ijt} = [y_{ijt}, p_{ijt}, z_{ijt}, s_{ijt}],$$

where y_{ijt} is the harvest output of product *i* in district *j* in year *t*, p_{ijt} is the price, z_{ijt} is the amount of seed sown and s_{ijt} the grain stored for the next year.

The theoretical underpinning for this is as follows: y_{ijt} depends only on weather but may affect all other variables in the same year. p_{ijt} obviously may affect seed and storage decisions but these affect harvest and thus price only a year later. The ordering of z_{ijt} and s_{ijt}, is more ambiguous but since they presumably do not affect each other in *t* anyway, it does not matter very much as long as they are the last two variables in $\mathbf{v}'_{\mathbf{ijt}}$.[19]

We decided to include the seed quantity, because it may affect the next year's harvest. Furthermore, we can estimate harvest and price elasticity of seeds and test the argument made by Hoskins (1968, 1964) of a high harvest elasticity of sowing. In addition, the influence of storage on the next year's price level can be investigated. A significant and positive impact would strengthen our argument of including food reserves in the consumption function as we did in section 4.

All series enter the VAR in natural logarithms. Furthermore, they have been detrended using the Hodrick-Prescott filter with $\lambda = 100$. The usual unit root tests have been applied to all series with various results. Some series turned out to be stationary while others contain a unit root: We decided to use the filter for every series, since it changes the series only marginally if it has no trend.

[19]A different ordering for seeds and storage did not change the results in any significant way.

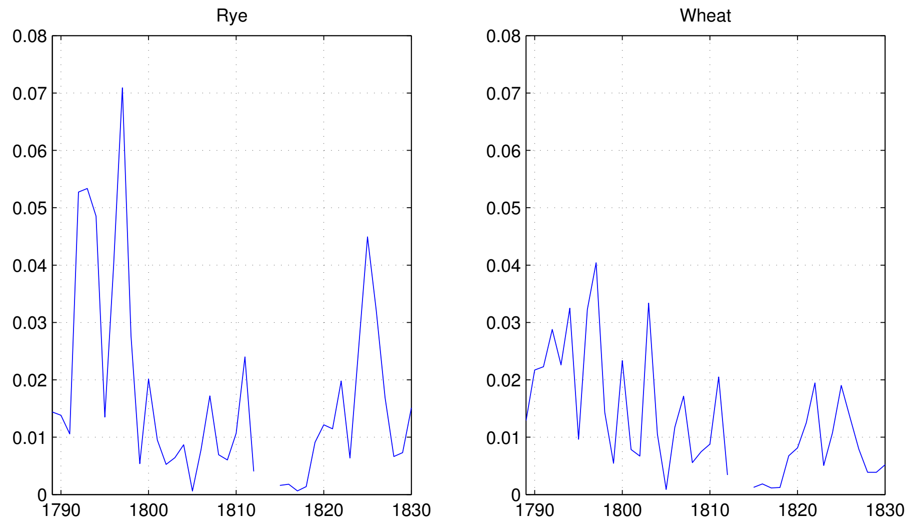


Figure 14: Average storage ratios for rye and wheat in Saxony.

We execute the analysis at the Saxony level and pool all observations. By doing so we can expect more robust results because we have more observations. As the linear regression in Grünebaum (2012) shows, there was no regime change after 1815, so that it is also reasonable to assume equal dynamics over the whole period. The model then includes 137 observations and four variables.

As deterministic variables we included an intercept, and dummies for the crisis years 1790, 1804, 1816 and 1827. The lag order was chosen as one. Two lags might account for back-to-back harvest failures (Campbell & Ó Gráda 2011), and seed quantities affected by bad harvests. However, we also estimated a model with two lags which yielded no additional information than the normal one-lag-model but suffered from a lower R^2.

5.3 Results

After estimating the model with OLS, we produced plots of reactions to particular shocks or impulse response functions. Fig. 11 and 12 summarize the results. The first row contains reactions of harvest to all other three variables of one standard deviations. Note that because harvest has been chosen to be exogenous in period 1, its reaction is always zero except to itself, and its own-reaction is exactly one standard deviation in period 1 (column one, row one).

The second row contains reactions of price to all variables, the third of seed and the last, the one of most interest to us, of storage. The continuous lines show how a variable changes as a reaction to a certain shock, and the broken lines depict significance. If the zero line lies within the sigificance band we do not regard the reaction as signicantly different from zero.

The results for rye and wheat look similar, whereas the strength of the responses varies. Harvest reacts strongly to increased seed quantity in the previous year (first row, third column), but is otherwise not affected by any other variable. In row two, prices fall as reaction to a positive harvest (first column), and are somewhat depressed in the following year after storage went up (third column). Next, in row three, seed quantity goes up if harvest was abundant (column one), but does not react to higher prices (column three). Finally, in row four, storage increases as a reaction to better harvest and decreases if prices go up.

A positive response of the next year's harvest to a positive seeding shock is according to expectations and supports the model's accuracy. Another interesting result is the slightly negative effect of a storage shock on the next year's price. It shows that reserves left from the previous year had an impact on price making decisions. We may interpret the positive reactions of seed to harvest shocks in the sense of Hoskins' (1968, 1964) hypothesis about autocorrelation through endogenous seed quantities. This is somewhat surprising since eyeballing average seed volumes implies rather inelastic seed quantities (Fig. 13). On the other hand, there is no significant effect of a price shock on seed quantity, which does not support Hoskin's (1968, 1964) hypothesis.

Regarding the determinants of storage it is most significant that storage levels were both driven by abundant harvest as well as price shocks, because this means that both effects can be clearly separated. Increasing storage when prices are low supports a rational investor view of storage decisions. The fact that when controlling for price variations harvest shocks did still affect storage creates room for an additional explanation, however. Grain was accordingly also stored to a larger extent when harvest was good independent of the price level. This supports a view of precautionary saving and consumption smoothing independent of market signals.

6 Conclusion

In this paper, we present a new data set about early modern agriculture in one of the most advanced economies of Continental Europe of its time, Saxony in Germany, in the years 1789-1830. The data set consists of annual and partially monthly time series of grain harvests, market prices, seed quantities and storage volumes.

We undertake three analyses: First, we estimate monthly returns of rye and wheat prices to test for rational investment behaviour. We find roughly rational behaviour for rye but not for wheat and overall low returns which would not have covered even low levels of storage costs and interest rates throughout most of the year. However, we argue that for market efficiency liquidity may have been important which should be tested in future research.

Second, we estimate price elasticity of demand to contribute to the debate on King's Law. With our new data set, we reconciliate the diverging views whan abandoning a standard assumption and replacing it with estimations from our data set. Persson's (1999, 1996) estimates of higher elasticity than King's Law can thus largely be confirmed, but King's Law remains when taking the estimated correlation of price and quantity into account.

Thirdly, we fully exploit the time series characteristics of our data set and escape the endogeneity trap by estimating a vector autoregression consisting of harvest, price, seed quantity, and storage, which is the first of this kind for this period to our knowledge. This yields results consistent with theory. Especially, storage reacts to both, price and harvest shocks, independently, suggesting a commercial and a precautionary element in storage decicions.

We may relate the evidence on storage decisions with the results on intra-year price movements. The early modern storage literature usually fails to document rational investor behaviour in monthly price data (see literature review in section 4). Maybe our vector autoregression provides a reconciliating view: Storage decisions were a mix of commercial and precautionary behaviour, and taking the low levels of storage into account (Fig. 14) carry-over storage was presumably too expensive to hold grain at relevant quantities. Thus, as monetary incomes stagnated or even declined during the late 18th century, alternative strategies such as subsistence production of potatoes may have become more important to reduce food risk (Uebele & Grünebaum 2013) as well as increased consumption of oats Kopsidis & Pfister (2013).

The outcomes of this paper can be easily placed in works our research group produced recently on agricultural output in Saxony (Kopsidis & Pfister 2013), per capita consumption (Pfister & Kopsidis 2013), and the potato as insurance mechanism against food risk (Uebele & Grünebaum 2013). We have seen that Saxony was an early mover in terms of proto-industialization with a diverse and productive agriculture, but that average incomes were not high enough to induce an "agricultural revolution", and that per capita consumption of food reached levels of mid-18th century only in the 1820s again. We also found that demographic and socio-economic change was accompanied with defensive strategies by low income households to reduce the risk of hunger.

Still, these papers merely scratch the surface of the data gathered from Saxon archives for this research project. We are confident that deeper analysis in the near future will reveal more insights on early modern growth in this important period.

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