Food security, harvest shocks, and the potato as secondary crop in Saxony, 1792-1811

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1. Introduction

This article has two aims: First, it is a contribution to development economics, in particular to the literature about food risk in rural economies. We contribute by emphasizing crop diversification as a means of reducing the variance of household food production, and by providing empirical evidence for the success of this strategy in a historical setting.

Second, the article contributes to economic history by addressing the relationship between early industrialisation and agrarian change. We interpret the structure of agricultural production in the context of a low energy-high labour input proto-industrial equilibrium, where household production of a diversified food bundle represents an effective way to fight food risk. This should be seen in line with a literature highlighting endogenous adjustment of agricultural production to demand shifts from the non-agricultural sectors (Grantham 1989, Kopsidis and Wolf 2012).

In the literature concerned with fighting poverty, Sen (1981) stresses the role of „food entitlements“ which are defined as the set of commodity bundles a person commands to satisfy food needs. According to this, food entitlement shortage could cause starvation even though the available per capita production of food in a certain area is theoretically sufficient to feed everybody. By stressing the role of income inequality in contrast to average income this literature points to the importance of government that needs to acknowledge market failure, and may thus need to redistribute incomes, provide short-run food relieve or install food storage facilities.

Anderson and Roumasset (1996) acknowledge the call for targeting a sufficient income *level* for everybody, but they add that a low *variability* of income is also an important factor in the lifes of poverty-endangered groups, and stress that this stochastic aspect of income has been neglected in the development literature.

In terms of policy, they make the distinction between long- and short-run strategies to fight poverty: The first aims at long run growth of income, while the second promotes solutions against short-run falls below the starvation line or reductions of income volatility. While the

[1] We thank Ulrich Pfister and Hakon Albers for their comments. Research support from the Deutsche Forschungsgemeinschaft (grants KO 1823/3-1 and PF 351/7-1) is gratefully acknowledged.

[2] Note that we mean the district „Erzgebirgischer Kreis“ when writing „Erzgebirge“.

[3] This notion of exchange entitlement differs from Sen's (1981) insofar as it only includes monetary income, while Sen includes household production as well. The difference is merely in wording and does not affect the substantial meaning of the model, but Sen's use of the term prevails in the literature and thus the use

first strategy may be regarded as the more sound strategy enabling poor countries to help themselves and become independent of short-run food aid, Anderson and Roumasset (1996, p. 53) emphasize not only passive help after famine has struck but also strategies to reduce short-run volatility ex ante, thus reducing the risk of falling below the poverty line and thus the need for aid. This paper extends their model by a particular strategy for reducing the variance of income, namely diversification of crops, especially in subsistence production. We also show for a particular time and place that this strategy really works.

There are numerous works in the empirical development literature showing the role of crop diversification in different countries and circumstances (e.g. Islam and Ullah 2012), but this paper stresses explicitly the covariance structure between marketable staple crops and non-marketable household crops, which may be used to hedge food price risks. Thus, we describe a trade-off between the use of the market and diversifying home production of food. Again, this market-diversification trade-off has been acknowledged elsewhere (e.g. Van Dusen and Taylor 2005), but not by emphasising the covariance structure of particular crops explicitly.

In economic history, the introduction of new crops, particularly of New World crops such as the potato, to Old World food bundles has caught attention primarily by explaining long run population and per capita income growth (Nunn and Qian 2011), and by being a necessary precondition for industrialization. This literature contributed substantially to our understanding of pre-industrial population increase, but drew its insights only from the potato's superior yield and high nutritional value in contrast to traditional crops such as rye and wheat. Less research, however, has been conducted on the second moment characteristics of the potato, while these characteristics are easily conceivable: If harvests of different crops are not or even negatively correlated, crop diversity can serve as an insurance device against shocks from weather or against price volatility of cash crops. Langer (1975, p. 54) documents, that already in the 18th century the potato had been endorsed by European governments for these benefits, but nevertheless this argument has not been recognised in the long run growth literature.

One of the few examples when the argument of crop diversification and uncorrelated harvests was used as an argument in a growth context is Appleby (1979). Contrasting the experiences of France and England in the 17th and 18th centuries, he drew attention to the fact that France relied more heavily on wheat only while England augmented its food bundle by oats, which is sown in the spring and not before the preceding winter. It is therefore especially susceptible to spring weather shocks. His empirical evidence, however, stems from grain prices only, and thus relies on the assumption that prices reflected actual scarcities. In contrast, the present study relies on production figures only, and is thus able to look behind the veil of the market.

The study closest to this one is perhaps C. Pfister (1978), which analyses the role of weather shocks and agricultural production in Berne in the 18th century. He finds that the potato, being a spring crop, responded differently to certain weather shocks than grains such as wheat and rye, especially to unusually cold winters with high snow covering, which of course is more relevant to more elevated regions than to lowlands. Apart from a different research question the difference to this study is mainly that Pfister has to rely on indirect evidence for harvests through tithe data while we have the luxury of explicit harvest statistics for five different crops at a very low geographical level. We can thus not only confirm Pfister's findings, but can augment them by a quantification of risk reduction in comparison to the theoretical maximum effects of trade. We also develop a simple strategy to show that even if transport was prohibitively costly, adding potatoes or oats to the food bundle reduced food risk substantially. We further reason about why Saxony's districts relied on crop diversification to different degrees, and why especially the Erzgebirge[2] district did more so than the other districts.

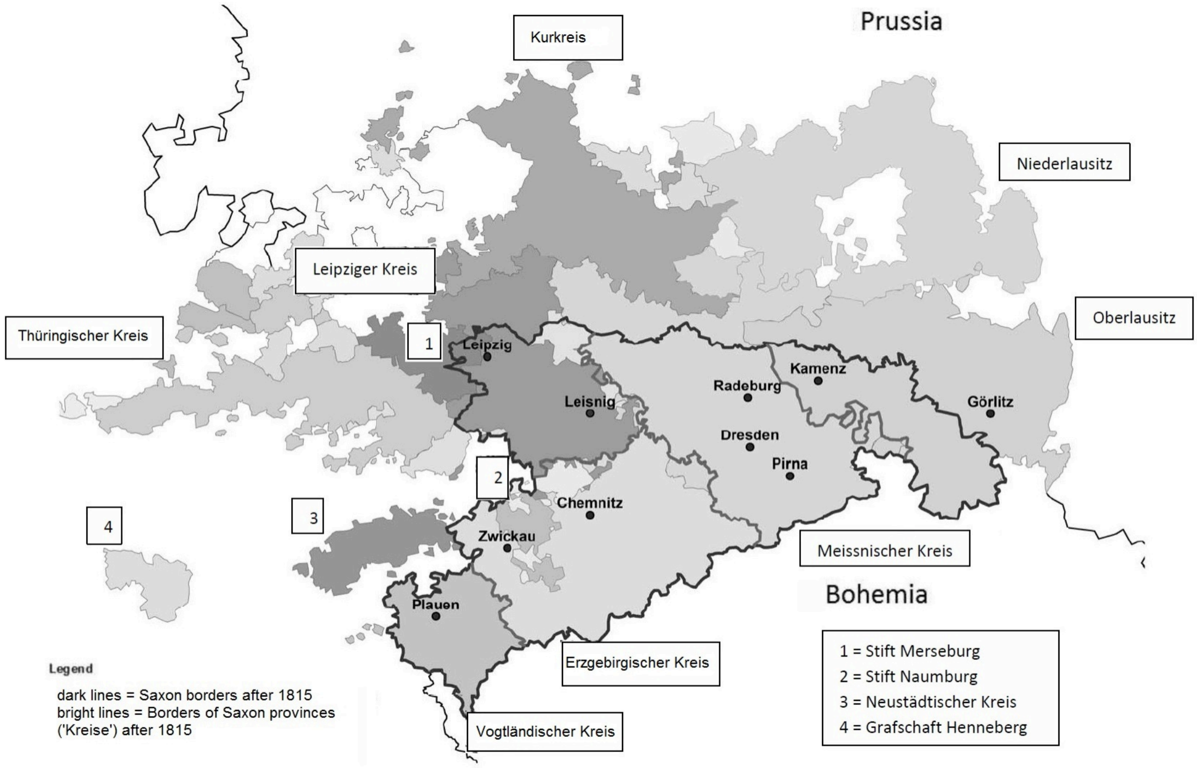
2. *Saxony in the 18th century*

Sectoral change is one of the essential explanations for long-run growth, especially the transition from a primarily agricultural to a primarily industrial economy. The traditional theory is a supply-side argument stating that an "agricultural revolution" or productivity advances through technological change (Overton 1996) would „relieve" labour from the primary sector into the manufacturing sector, where per capita output and wages would be even higher, and thus allowing for overall output growth (Lewis 1954; see also Schirmer 2000, p. 130, for a similar argument in the context of Saxony). However, some of the more recent literature has favoured rather demand-side arguments in order to explain the development of agricultural production (Grantham 1989, Kopsidis and Wolf 2012), emphasising industrialisation and urbanisation as primary causes for agricultural change, because they represent a stable demand base for marketable and high value agricultural products. Kopsidis (2012, 2006) showed this in a series of works for the Prussian province of Westphalia between 1820 and 1870.

In contrast to Westphalia, Saxony represents a different case in the industry-agriculture nexus. It had developed an unusual high share of non-agricultural labour in the 18th century already,

2 Note that we mean the district „Erzgebirgischer Kreis" when writing „Erzgebirge".

and at the same time saw substantial demographic change both in absolute population growth and social composition. Since this process happened mainly in the countryside it implied stagnant or even receding urbanisation rates, and an increase in rural non-agricultural population (Schirmer 2000, pp. 142, 170, Karlsch and Schäfer 2006, p. 24, Kopsidis and Pfister 2013, p. 5). Within Saxony, the highest share of non-agricultural population was to be found in Oberlausitz and Erzgebirge (Schirmer 2000, p. 143), which corresponds well with our findings presented below.



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

Figure 1: Map of Saxony, before and after Congress of Vienna (1815).

Given this demographical development it is important if (a) agriculture was able to support the increasing number of people, and if (b) it could even increase per capita production of food, which according to a supply-side view of agricultural development would be a necessary precondition for industrial growth. Karlsch and Schäfer (2006, p. 24) indeed present supporting evidence in this line that states that between 1755 and 1792 per capita grain and potato production substantially increased. However, while this is certainly true for potatoes, Pfister and Kopsidis (2013, p. 13) refute the grain output figures for 1755 as downward biased due to underreporting. Instead, according to an alternative estimate per capita production was at best constant in the second half of the 18th century at a level just above subsistence and even declined after the start of the Napoleonic Wars in 1792.

The potato began to be grown in Saxony between 1690 and 1720 (Schirmer 2000, p. 164) together with clover, but rather on marginal land, as the decision for growing new crops was not entirely up to individual farmers but had to be agreed to by the village community (Schirmer 2000, pp. 140-141, 165). The political repercussions were to a large extent caused by the fact that growing potatoes and clover implied a major change of traditional crop rotations. Moreover, and this is where this article draws on, it was paralleled by population growth especially of the land-poor as compared to farmers (Schirmer 2000, p. 142, Kopsidis and Pfister 2013, p. 5). The growing land-poor classes earned substantial income shares from proto-industrial manufacturing, especially textile production, but this labour-intensive, low-capital type of work generated lower wages than that of urban industrial workers shortly after in other parts of Germany, and thus created high demand for crops that provided many calories cheaply (Schirmer 2000, p. 153).

Given this historical framework in which we place our study of crop diversity the rest of the paper can be summarised in three paragraphs: First, we document the boom of potato production in Saxony at the end of the 18th century which shows that the market share of agriculture was not on the rise but rather a reversal to subsistence production as the potato was too cheap and too heavy to transport, and at the same time too easy to produce on rugged plots and without tools or animals to not grow it primarily close to the household.

Second, the „low wage-high energy cost" growth path chosen by Saxony is reflected in the increase of potato production, because it was a particularly laborious and low-capital crop both in terms of land and in terms of tools and animals.

Third, the geographical distribution of potato production fits the idea of a high share of low-income rural non-agricultural population, as we observe high potato shares especially in more elevated areas such as Erzgebirgischer Kreis, where the share of non-agricultural employment was higher than elsewhere in Saxony.

3. *A model of food risk*

In order to clarify why we think that the second moments of food provision matter, we borrow a model from Anderson and Roumasset (1996). It connects different elements of food risk including average provision of food supply and variability of food supply, reflecting a debate in development economics about long- and short-run approaches to food risk reduction or similarly macro- and micro-aspects.

Food insecurity may be described by the stochastic variable Z, where a variable is thought of to be stochastic if its exact value is unknown but its probabilistic characteristics are known, such as a normally distributed variable with a certain mean and variance.

Z contains several sources of risk for food provision in the following way:

1) $Z = P_v (C - Q) - E,$

where P_v= local food price, C = consumption of food needed, Q = subsistence production of food, and E = exchange entitlements, or monetary income from labour provided on the market.[3]

Entitlements may be modelled as the sum of a constant E_0 and a random income variable Y depending either on shocks to local manufacturing or agricultural labour.

Next, the risk of food insecurity is $R(Z)$, where

2) $R(Z) = \Pr(Z > 0)$.

Thus, food risk R equals the probability that Z is strictly positive, which is true only if the entitlement to buy food E on the market is smaller than the value of food needed minus household production $P_v (C - Q)$.

By setting the critical value of Z equal to 0, this can be rearranged into a condition for the maximum price local consumers are able to pay for just the sufficient amount of food needed:

3) $P_b = E/(C - Q)$.

If people are too poor to pay this price, then the required amount of food $C - Q$ is larger than the entitlements E, and $Z > 0$, i.e. the case of insufficient food provision has occurred.

The local price of food is bounded in two dimensions: First, as just discussed, the local quantity dimension: There is a higher bound P_b, the maximum offer price by local consumers, determined by local entitlements relative to food requirements. The lower bound P_s is the price below which households would not buy from the local market but instead sell to the world market (see below) as is summarised in the following:

4) $$P = \begin{cases} P_b = D_c(C) \text{ for } C < C_b; \\ P_d = D_d(C) \text{ for } C_b \leq C \leq C_s; \\ P_s = D_s(C) \text{ for } C > C_s, \end{cases}$$

where the demand function $D_d(C)$ is negatively sloped, and $D_b(C)$ and $D_s(C)$ are constant in their respective segments.

3 This notion of exchange entitlement differs from Sen's (1981) insofar as it only includes monetary income, while Sen includes household production as well. The difference is merely in wording and does not affect the substantial meaning of the model, but Sen's use of the term prevails in the literature and thus the use by Anderson and Roumasset (1996) needs to be distinguished from it.

The second dimension is trade: It bounds local prices by the theoretical world price P_w and transport costs t:[4]

$$5)\quad P = \begin{cases} P_b \leq P_w + t; \\ P_s < P_d < P_b; \\ P_s \geq P_w - t. \end{cases}$$

Here, the local price P_d cannot rise above the world price plus transport costs, i.e. P_b, otherwise local producer-consumers would buy from the world market. Similarly, the local price P_d cannot fall below the world market price minus transport costs, i.e. P_s, otherwise local households would decide to sell there.

Note that this model works with stochastic variables, but abstracts from dynamic relationships between periods in order to keep it simple. This excludes reasoning about the effects of storage for example. Thus, we focus only on the stochastic properties of the relevant variables in a given period.

Now, frequently recurring issues of food security can be discussed in that framework, particularly by addressing the question of independence of the model variables.

- Is the world price of food independent of local subsistence production Q? Since we assume local production Q to be small, this is an easily defendable assumption, and leads to $COV(Q, P_w) = 0$. However, if weather shocks were spatially correlated, such as following the outburst of the Tambora volcano in 1815, which affected the whole northern hemisphere, covariance would become significantly negative.
- Are household production and entitlements correlated? Since entitlements may be earned by offering labour to local agricultural production, this may well be. However, if they are earned at rural manufacturing production, such as in a proto-industrial setting with decentralised sources of energy, E and Q may be assumed to be uncorrelated.

The sources of instability are now E, Q, and P, since food requirements C may be assumed to be constant. Anderson and Roumasset (1996, p. 58) conduct a simulation experiment with some reasonable ad-hoc distributions for the variables, and vary the parameters in the model in order to arrive at a quantification of the elasticity of food risk R with respect to the various sources of instability. They identify the variability of household food production S(Q) to be the variable to which food risk responds most strongly. The expected level of subsistence production E(Q) turns out to be similarly but slightly less important in this respect.

[4] The original model assumes asymmetric costs of transportation depending on the direction of trade, which, however, is not essential for our purpose.

This is a very interesting result to our paper, because these are exactly the two variables of our concern. In the literature on the role of the potato for world population growth, the focus was mainly on its contribution to the expected *level* of food provision E(Q), which is evidently a valid and important aspect. However, the *variability* of household production S(Q) has been discussed only marginally in this literature, which seems to be a gap given the role it plays according to the results cited here.

What this paper adds to the model by Anderson and Roumasset (1996, pp. 59-60) concerns the reduction of the variability of household food production S(Q). What they discuss in terms of reducing S(Q) is the role of weather shocks in absence of irrigation. Although their model does not directly speak to that, they presume that local storage may help to keep S(Q) low.

We attempt to build on their framework, however, by abandoning the assumption that households produce only one food staple. Instead, we measure food requirements in grain equivalents (GE) and satisfy them by differing food bundles, consisting of up to five different crops:[5] rye, wheat, potatoes, oats, and barley, or q_i, where i = *1, 2, ..., k* stands for the different crops. Now, if Q is the sum of different food bundles consisting of k elements of Q, its variance $S(Q) = VAR\left(\sum_{i=1}^{k} q_i\right)$ is the sum of their covariances:

6) $VAR\left(\sum_{i=1}^{k} q_i\right) = \sum_{i=1}^{k}\sum_{j=1}^{k} COV(q_j, q_i)$

If the production outcome of the crops has large positive covariances, total variance S(Q) and thus food risk R(Z) is large. If their covariances are zero or even negative, total variance falls, which reduces the risk of food shortage R(Z) accordingly. (The sum will never become negative, because the own variances of each product are also part of the sum.) For subsistence production it is therefore important not to produce only crops that have a high yield in expectation but also to produce a food bundle whose single items have low or even negative covariance.

Note that there are actually two channels via which the covariance of production of different crops may reduce food risk: via subsistence production Q or the correlation of P and Q, since some food items such as wheat may have to be bought on the market, while others are easier to produce at home such as potatoes. While for the historical setting the latter may be more appropriate, the principal argument of the role of correlation of different crops' production outcomes remains the same. For the sake of simplicity, we will thus act as if every household chose different crops in order to increase E(Q) but also to reduce S(Q).

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5 Grain equivalents are measured per kilogram and expressed relative to the nutritional value of barley: rye = 1.01, wheat = 1.07, barley = 1, oats = 0.85, potatoes = 0.22. See the appendix in Kopsidis and Pfister (2013, p. 69) for details.

The rest of the paper now stands to show that in Saxony in the late 18th century, potatoes were not only produced to support a growing population on a constant surface of arable land, but also because they reduced the overall risk of food shortage, since their harvest outcome was uncorrelated or even negatively correlated with that of the main bread grains, rye and wheat. In the last section we also give some insights into the relation between manufacturing income and household production, exploiting the geographically disaggregated evidence of our data set.

What the empirical part does not do is to test the role of price fluctuations for food risk, although the model places an important role to prices. However, the main contribution in terms of data of this paper is the highly spatial resolution of harvests, and local market prices cannot be found in the archives at the same level. The empirical section discusses why this may or may not be a problem for answering our research question.

4.1. Data sources

Food provision had been a subject matter of public interest for a long time in Saxony. Already 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, the next harvests were measured, thus data of the harvest years 1755 and 1772 are available today. But in 1791, a general duty to disclose harvest outputs was enacted by elector Friedrich August III. Additionally, two more recent registers for the years 1789 and 1790 were created, as 1789 was again a year of bad harvests. About the data quality it can be said that the registers after the crises 1754 and 1770/71 are of dubious quality, while the regular data after 1791 are much more reliable, especially for time series analysis (Pfister and Kopsidis 2013, p. 11).

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 half of the concealed grain was at risk. Furthermore, the results were kept secret so tax evasion could not have been an incentive to hold back information.

To provide some spatial orientation, the borders of the Electorate of Saxony and its districts in the late 18th century and after the Congress of Vienna can be found in **Figure 1**. After the Congress of Vienna, Saxony lost many of its northern and western territories to Prussia, which is also shown.

4.2. Construction of the data set

The harvest data consists of two sets: The first is for 93 counties with harvest outcomes for five crops in the years 1792-1811. It misses information on seeds and storage, though. The second data set provides data at the higher district level only, but covers the years 1789-1830 (with some gaps), five crops more, and seed and storage statistics. In this paper, we will use only the first data set, since its high geographical detail allows for comparisons across levels of spatial aggregation.

In order to prepare the data set for analysis, we treated the data in the following way:

Outliers: Almost all observations were missing for the year 1806, probably due to war action. All other missing values are mainly single ones, quite randomly distributed and well below 5% of the total number of data points. We replaced the missing values by linear interpolation of neighbouring values. If more than one year in a row was missing, we used the average growth rate of all other series between the years in question to extrapolate the last known value into the future. This procedure should distort the standard deviation estimates only minimally.

Detrending: The supply series do not have strongly changing trends. However, theory requires operating with short-run deviations from long-run trends, as this is the unexpected part of supply variations. We decided to use the Hodrick-Prescott filter with a smoothing parameter value of 6.25 to exclude the trend from the series. This procedure is widely used in the literature and therefore guarantees maximum comparability. Explicitly, for each city we divide each year's harvest observations with the respective HP-trend estimate and thus receive a percentage deviation from trend as a result. Of the resulting series we then estimate the standard deviation as explained below.

Crop aggregation: For the different food bundles of the different crops, we decided to add up the raw harvests measured in grain equivalents after having removed eventual outliers. In a second step, we transformed the resulting food bundles into deviations from trend as explained above. Lastly, we estimated the standard deviations. For the aggregation between regional levels, we added up all harvests measured in grain equivalents in the respective districts and for the respective food bundles. Again, we estimated standard deviations of the resulting detrended series. This procedure captures the standard deviations consumers actually were faced with, depending on the food bundles they consumed. Because of adding up quantities first the resulting standard deviations also reflect the relative volume shares of harvests in the respective areas.

5. Analysis

In this section we will do three things: First, we describe the change in agricultural production expressed mainly in the drifting combination of crops. Second, we provide statistical evidence that potato production was uncorrelated or even negatively correlated with other crop production at the county level. Third, we explore some explanations for the geographical distribution of potato production within Saxony, and especially within Erzgebirge.

Figure 2: Shares of total crop production, corrected for nutritional values, Saxony 1791-1830. (Note the territorial changes after 1815 as can be seen from Figure 1.)

5.1. The late 18th century potato boom in Saxony

One of the particular strengths of our data set is that it provides an accurate and complete overview at annual frequency about agricultural production in Saxony over 20 years.[6]

A first overview is presented in **Figure 2**. It shows the production of ten different crops in the state of Saxony as shares of total output measured in grain equivalent. Next, **Figure 3**

6 See Kopsidis and Pfister (2013) for an extensive discussion of the development of Saxon agriculture in this period based on the present dataset.

presents the same information at county level, and **Figure 4** presents the respective absolute numbers measured in grain equivalents in a five-by-five array of graphs.

Figure 2 shows the share of potato production controlling for nutritional value as a share of total production. The upper white area represents the share potatoes had in absolute food production, then five many less relevant crops follow, after which oats, barley, wheat, and rye follow, respectively.

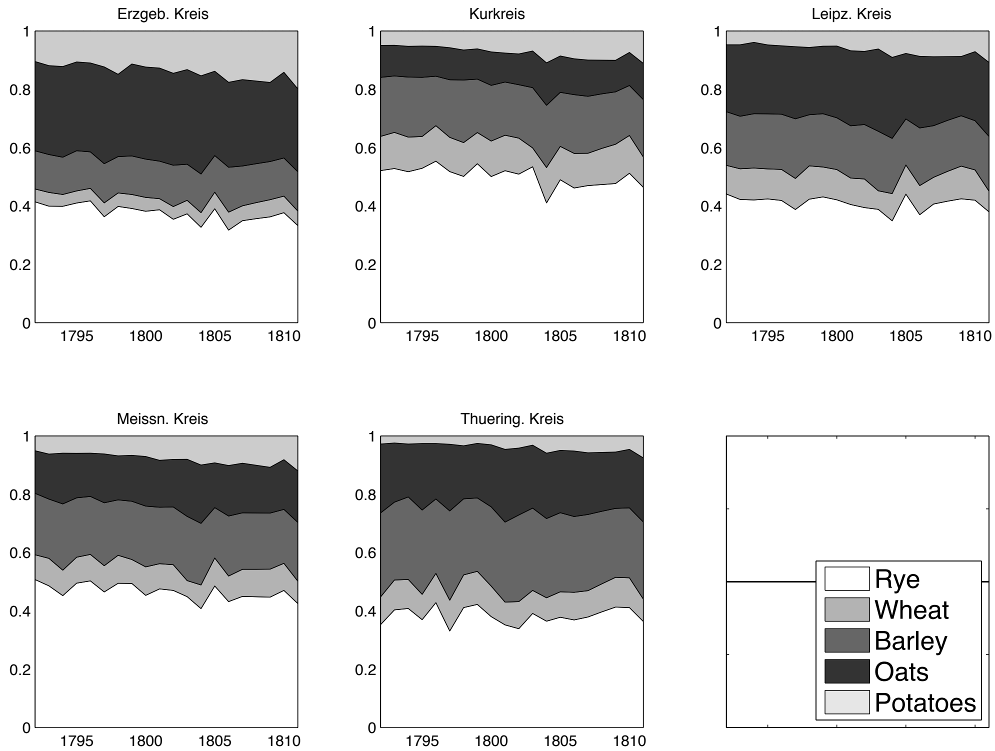

Figure 3: Output shares of five different crops at district level.

R = Rye, W = Wheat, B = Barley, O = Oats, P = Potatoes. Saxony, 1792-1811.

Two things can be easily seen for the period until 1830: First, the share of potatoes in food production increased from about 5% to just below 20%. Second, rye was the major food grain for the whole period, but it was also the crop that made place for the potato starting at 50% in 1792 and delivering just above 35% of total food production in 1830. When singling out the period up to 1811, potato's share was at about 12%, and rye had fallen to below 40% already, while all the other crops were basically produced at the same relative levels.

Proceeding to **Figure 3**, we learn that this structural change was not equally distributed across districts.[7] Focussing on the absolute share of potato production, the northern districts of Leipziger Kreis and Thüringischer Kreis were obviously less affected by the move toward the potato than especially Erzgebirge. However, it becomes also clear that the share of the potatoes increased at the expense of rye in all districts.

A second observation is that the districts reveal large differences in agricultural structure during the whole period 1792-1811. Some of the crops were more valuable for direct consumption by humans, especially potatoes, and some were more frequently used for commercial purposes, namely barley and wheat, possibly also rye. The status of oats is unclear, since it could be fed to animals and then would be rather an input for the production of other crops and meat, or consumed directly by humans. Leipziger Kreis and Thüringischer Kreis are clearly the districts with the largest share of barley and oats, closely followed by Meissnischer Kreis, which could hint at a large share of commercial agricultural production if oats was primarily used as an input good.

In comparison, Erzgebirge produced the largest amount of oats, but relatively little barley and wheat. Thus, if people ate a substantial share of oats directly, then Erzgebirge had in fact the lowest share of commercial agricultural production of all districts in our sample.

Finally, Kurkreis had again a different production structure with the by far largest shares of rye and wheat production in Saxony and at the same time the lowest share of oats production. Some additional insights can however be made when looking at the absolute numbers in **Figure 4**, again controlling for nutritional value by transforming harvests in grain equivalents. This reveals that despite Kurkreis having the highest shares of bread grain production, it was not the main supplier of these crops, but the amounts produced in Leipziger Kreis, Meissnischer Kreis and Thüringischer Kreis were much higher, while Erzgebirge grew about the same volume of rye and wheat as Kurkreis. This ranking holds as well for barley and oats. The only exception is the production of potatoes, where Erzgebirge did not only produce the highest share, but also the largest amount in absolute numbers.

As this section shows, Saxony experienced a potato boom at the end of the 18th century, similar to many other regions in Europe. This could be explained by the much higher yields of the potato as compared to other crops and the need to feed a growing population on a more or less constant arable land area (Pfister and Kopsidis 2013, p. 14). What is, however, often overlooked are the potato's advantageous characteristics as an insurance against weather

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[7] Our data set allows for producing crop shares for each of the 93 counties, but this large amount of information is difficult to process for the reader. We are happy to provide these graphs on request.

shocks and thus as a means to reduce food risk. Using our geographically disaggregated time series, the next section will demonstrate this effect.

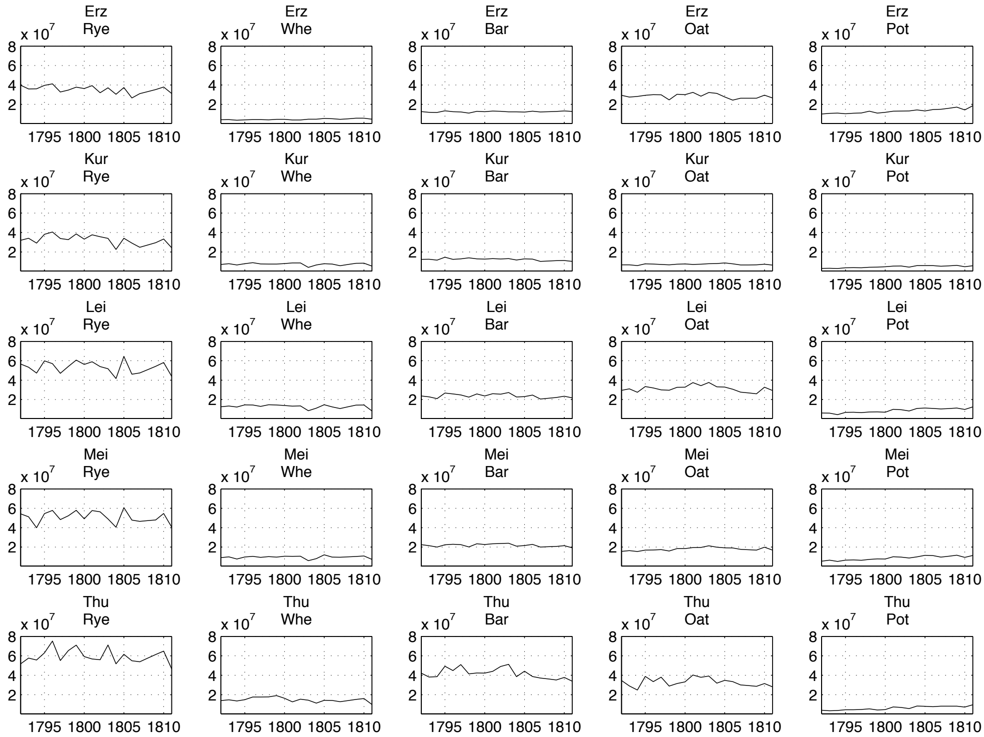

Figure 4: Production of rye, wheat, barley, oats, and potatoes in five districts, measured in grain equivalents, Saxony 1792-1811. Erz = Erzgebirgischer Kreis, Kur = Kurkreis, Lei = Leipziger Kreis, Mei = Meissnischer Kreis, Thu = Thüringischer Kreis.

5.2. Correlation of harvests

We can easily document the degree of correlation over time of harvests between pairs of five different crops. Moreover, we can do that at the very low geographical level of the county. This has two great advantages. First, the lower the geographical unit at which we can observe harvests, the closer we come to evaluate the situation households faced right after harvest and before they decided to sell or buy food. If we were to observe harvests only for Saxony, in comparison, it would be very difficult to know if the result was relevant to individual households or not, since the actual harvests at the ground level were for obvious reasons different from state averages.

The second advantage is that we can still add up to district and state sums and compare. Doing this implies the assumption of pooling a region's output and distributing it equally to all citizens as if transport costs had been zero. Thus, the maximum effect of internal trade can be quantified.

This section will present four tables: The first aggregates the information of correlation at the county level. Having established that, the second table presents volatilities of different food bundles for the state of Saxony. The third and fourth tables present the same information for each of the five districts.

The information about correlations in **Table 1** is presented in a somewhat unusual way. The reason is that although the correlation coefficients at the county level are of great importance, ten correlation coefficients and p-values for each of the 93 counties in five different districts cannot be digested easily by the reader and preclude conclusions about our subject matter. Simply averaging correlation coefficients and p-values, however, is a questionable procedure, because correlation coefficients can be negative, thus averaging may lead to zero results although the underlying values may be large in absolute value.

For **Table 1** we proceeded in two steps. First, we counted the correlation coefficients that are different from zero at a level of significance of at least 10%. Then for each district and pair of crops we tabled the occurrences of negative (-), insignificant (0), and positive correlations (+). As a first observation, we find a number of significantly positive correlations between rye and wheat (upper left cells in all panels). In Leipziger Kreis, Meissnischer Kreis, and Thüringischer Kreis we find this positive correlation in all but two or three counties; in Erzgebirgischer Kreis and Kurkreis in more than half of all counties. Second, we find a high number of positive correlations between oats and barley in all but two counties in Leipziger Kreis, Meissnischer Kreis and Thüringischer Kreis, and in all but four counties of Kurkreis, while in Erzgebirge more than half of all counties feature positive correlations. In all other cases barley and oats harvests were uncorrelated, and never negative.

This pattern seems to be connected with the sowing seasons of the crops involved. Usually, rye and wheat are sown before the preceding winter, and oats and barley in the spring. Each pair should thus react to a particular seasonal weather shock. Especially long winters with snow covers into spring would destroy crops sown in the previous calendar year, as C. Pfister (1978, pp. 232-233) shows for the state of Berne for the late 18th century. Potatoes are usually also sown or planted in spring, and their harvest outcomes may thus be stronger correlated oats and barley (C. Pfister 1978, p. 235; Langer 1975, p. 54).

In addition to the correlation of winter and spring crops, we find more occurrences of strong correlations, especially in Erzgebirgischer Kreis. There, oats harvests were positively correlated with all other crops except potatoes in many counties. Especially the large number of positives correlations with rye can be explained by the fact that in Erzgebirge rye was often sown in the spring, not before the preceding winter, and thus prone to be hit by the same shocks as summer crops (Herz 1964, pp. 61-62). Similarly, but to a less degree, are oats harvests correlated in Meissen, and to an even less degree in Kurkreis, but still worthy to be mentioned.

According to the model presented above, these correlations should matter for the volatility of the food bundles people consumed. It would thus have been advantageous to consume bundles with items whose harvests were contemporaneously less correlated than others. Thus, if oats were correlated more with rye and wheat in Erzgebirge, Meissen and Kurkreis, adding oats to the food bundle should have lowered volatility less than in Thüringischer Kreis and Leipziger Kreis. This will be checked below.

Negative correlations can be found only once in all 93 counties between rye, wheat, oats or barley; namely between oats and wheat in Leipzig, while in all other cases, harvests are uncorrelated.

When it comes to the potato, correlations also differ between districts. Especially in Erzgebirge, Leipziger, and Thüringischer Kreis positive correlations are rarely observed in any county, and negative correlations can be observed much more often than for other crops.

Starting with Erzgebirge, in all but two or three counties potato harvests are insignificantly or even negatively correlated with other crops. In Leipziger Kreis, this is also true except five positive correlations with barley. The same can be said for Thüringischer Kreis, however in six counties potato harvests are positively correlated with oats. The district Kurkreis is different in that wheat correlates positively in twelve counties with potato harvests, and barley in five, however never rye. Finally, in Meissnischer Kreis, in eight out of 18 counties, potato harvests correlate with rye harvests, and in ten counties the same is true for wheat.

Given these findings we conclude that in four districts, Erzgebirge, Kurkreis, as well as Leipziger and Thüringischer Kreis, the potato could be used as an insurance device against unexpected harvest fluctuations of the other crops, especially the major food staple rye, while in Meissnischer Kreis this was true for only half of the counties.

In addition, oats could have insured consumers against food insecurity in Leipziger Kreis and especially Thüringischer Kreis, whereas it was incapable of serving in this way in Erzgebirge especially. Since it is unknown if oats was consumed directly by the population at all or fed to the animals completely (Kopsidis and Pfister 2013, p. 23), according to the model presented above, this hints at higher shares of direct consumption of oats in Leipziger and Thüringischer Kreis, and lower shares elsewhere in Saxony.

Finally, Meissnischer Kreis was the one where both oats and the potato harvests were often positively correlated. As can be seen from the correlations at the county level, it were mostly the same counties in which potatoes and oats both correlated positively with the staple crops rye and wheat, and thus in these counties neither could be used to offset major crop failures.[8]
Having established that the potato and sometimes oats correlated negatively or insignificantly with output fluctuations of major food staples; the next section will document the effect of this on the volatility of harvest fluctuations as a measure of food risk.

5.3. Volatility of harvest fluctuations

In this section, we discuss how much diversification of agricultural production may have contributed to reduce food risk. In order to provide a comparison of the size of volatility reduction, we present a second possibility of reducing food risk. This will be the volatility of the sum of harvests at district and state level compared to county level. By exploiting the high geographical detail of our data set, we can thus simulate the theoretical upper bound of the volatility reducing effect of trade.[9]

Table 2 contains the standard deviations of harvest fluctuations, and varies the underlying variable in two dimensions: Vertically, by adding up harvests measured in grain equivalents to various food bundles: First, bread grains only, then bread grains plus potatoes, then additionally oats, finally also barley. We started with the crops most frequently consumed directly, and added crops less often used as food in declining frequency. Note that this procedure implies a weighting by volume shares, because of adding add up first and calculating standard deviations next, and thus the algorithm accounts for the fact that some crops were eaten much more often than others.

The second dimension varies along the horizontal axis with the levels of aggregation. We have output outcomes for 93 counties. In the first column headed „County" we first computed 93 times the standard deviation of the different food bundles as explained above. Then we averaged the standard deviations for Saxony and produced standard errors to provide a measure of statistical precision.[10] In the next column to the right we added up the county harvests for each food bundle in each of the five districts for which county data are available: Kurkreis, consisting of 18 counties, Erzgebirgischer Kreis with 24 counties, Meissnischer Kreis with 18, Leipziger Kreis with 15, and Thüringischer Kreis with again 18 counties.

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8 County level plots and tables are available from the authors.

9 Actual data on physical trade flows earlier than the mid-19th century are extremely hard to find. While short-distance trade surely occurred, overland trade on long distances was probably neither profitable nor effective in alleviating local shocks (Kopsidis 1999, pp. 15-16; Franz 1960, pp. 22-24).

10 **Table 3** provides averages for all five districts.

Table 1: Numbers of positive and negative correlations.

CORRELATIONS OF HARVEST DEVIATIONS FROM TREND

Erzgebirgischer Kreis

	Wheat			Barley			Oats			Potatoes		
	+	-	0	+	-	0	+	-	0	+	-	0
Rye	14	0	10	5	0	19	18	0	6	3	4	17
Wheat	0	0	0	6	0	18	11	0	13	0	3	21
Barley	0	0	0	0	0	0	15	0	9	2	3	19
Oats	0	0	0	0	0	0	0	0	0	2	2	20

Kurkreis

	Wheat			Barley			Oats			Potatoes		
	+	-	0	+	-	0	+	-	0	+	-	0
Rye	10	0	8	9	0	9	9	0	9	0	0	18
Wheat	0	0	0	5	0	13	4	0	14	12	0	6
Barley	0	0	0	0	0	0	14	0	4	5	0	13
Oats	0	0	0	0	0	0	0	0	0	2	0	16

Leipziger Kreis

	Wheat			Barley			Oats			Potatoes		
	+	-	0	+	-	0	+	-	0	+	-	0
Rye	15	0	0	7	0	8	5	0	10	2	1	12
Wheat	0	0	0	3	0	12	2	1	12	2	0	13
Barley	0	0	0	0	0	0	13	0	2	5	1	9
Oats	0	0	0	0	0	0	0	0	0	2	0	13

Meissnischer Kreis

	Wheat			Barley			Oats			Potatoes		
	+	-	0	+	-	0	+	-	0	+	-	0
Rye	16	0	2	11	0	7	9	0	9	8	0	10
Wheat	0	0	0	8	0	10	5	0	13	10	0	8
Barley	0	0	0	0	0	0	16	0	2	4	1	13
Oats	0	0	0	0	0	0	0	0	0	2	1	15

Thüringischer Kreis

	Wheat			Barley			Oats			Potatoes		
	+	-	0	+	-	0	+	-	0	+	-	0
Rye	15	0	3	3	1	14	3	0	15	0	7	11
Wheat	0	0	0	4	0	14	1	0	17	0	8	10
Barley	0	0	0	0	0	0	16	0	2	2	0	16
Oats	0	0	0	0	0	0	0	0	0	6	0	12

Notes: Col. '+' refers to positive correlation significant at 0.10, '-' to significantly negative correlations, '0' to insignificant ones.

The idea behind adding up to various levels of aggregation is to simulate equally distributed harvests between counties. Local harvest output depends mainly on local determinants such as weather shocks and soil quality, and especially their interaction: Different types of land may react differently to weather shocks – as do different agrarian products – for example depending on altitude (C. Pfister 1978, p. 232).[11] Counties with bad harvest shocks, however, could (given enough money) buy from counties with good harvests, thus reducing harvest volatility. Trade costs would naturally impede the reduction of volatility through physical exchange, but even zero trade costs would not eradicate volatility completely. The amount of volatility due to symmetric shocks in the whole district would still be left. The standard deviations in columns two and three thus contain measures of the size of symmetric shocks at district and state level.

The first finding is that as expected both diversification and trade had the potential of reducing food risk substantially. If transport costs within districts had been zero, thus comparing columns one and two, harvest volatility would have been reduced by at least 20%, no matter which food bundle was consumed. Similarly, with or without trade, thus comparing rows one and two, adding potatoes to the bread grain bundle shrank harvest volatility by 13-15%. Adding oats to the diet resulted in a further reduction of about the same size. In total, a reduction of production volatility by more than a quarter could be achieved.[12] In conjunction with within-district trade, volatility could thus be reduced by more than 40%. The maximum reduction possible in this data set is reached by the food bundle of all five crops combined with trade across the whole state. This would result in a 58% reduction of harvest fluctuations.[13]

The two ways of reducing harvest volatility are both covered by the model of food risk presented above. The different food bundles show a way to influence S(Q), while the different levels of aggregation correspond to the discussion of price boundaries connected to the „world price". If prices correctly reflect the relation of supply and demand, and assuming price elasticity of demand for food to be low, harvest shocks would translate almost directly into inverted price variations at the food market. The trade dimension of **Table 2**.would then

[11] This was already recognized by Davenant (1699, p. 82): "We enjoy the benefit of such different soils, High Lands and Low Lands, where one hits when the other fails." Saxony had all different kinds of farmland, in particular flat and fertile areas in the north, and the more elevated and less fertile Erzgebirge in the south (Hörschelmann 1834, pp. 473-475).

[12] **Table 3** shows differences between districts, however.

[13] This implies direct consumption of barley. The most plausible way to account for that is beer that is able to provide with considerable amounts of calories.

be a representation of the upper and lower price for food faced by local consumers at a zero transport cost wedge.

The trade and the diversification dimensions are of the same order of magnitude. That means that the fundamental variables in the model, volatility of subsistence production and volatility of local prices, both influencing food risk, could be kept in control by consumers to about the same degree. Two arguments would however favour crop diversification over trade as a food risk reduction strategy: First, in the late 18th century, transport costs were to our best knowledge very high, at least for medium to long run-distances, and especially compared to the cost of growing potatoes, which was mainly a question of labour cost. Second, the simulation reported above reports a higher elasticity of food risk with respect to changes in variance of home production than with respect to reduction of local price variance. Every hour of labour spent on diversification, in our case planting potatoes, was thus more valuable in reducing food risk than the same spent in trading.

Would testing these outcomes against actual price data weaken our conclusions, provided they were available at the necessary spatial resolution? If local prices would be more variable than district prices for reasons of market inefficiency that is not reflected in supply variations, this cannot be excluded. However, this is not the case when assuming local prices to be a linear function of district („world") prices such as in the model presented above the reason being that then prices would be exactly as volatile as the district prices. Our outcomes therefore rest on the assumption of local markets working not less efficient than central district markets. Quintessentially, this is unfortunately an assumption that is very unlikely to be refuted or confirmed ever for lack of appropriate data.

Having established the effectiveness of negative harvest correlations in reducing food risk, the last part of the analytical section aims at explaining the geographical distribution of potato production within Saxony.

5.4. Geographical distribution of crop diversification in Saxony

This section presents two more pieces of evidence in order to explain better the nature of crop diversification in Saxony. First, we will show how the reduction of harvest volatility through diversification differed between districts and connect this information to the degree of correlation between harvests seen in **Table 1**. Second, we delve deeper into the district of Erzgebirge, and look at its geography as well as the related employment structure.

Table 2: Standard deviations of harvest fluctuations, Saxony, 1792-1811.

Volatility of harvest fluctuations of different food bundles at different levels of aggregation

1792-1811		County	Province	State
Food bundle	N	93	5	1
R+W	MEAN	0.14	0.11	0.09
	(S.E.)	*(0.003)*	*(0.009)*	*(0.015)*
R+W+P	MEAN	0.12	0.09	0.08
	(S.E.)	*(0.003)*	*(0.012)*	*(0.012)*
R+W+P+O	MEAN	0.10	0.08	0.06
	(S.E.)	*(0.003)*	*(0.009)*	*(0.010)*
R+W+P+O+B	MEAN	0.09	0.07	0.06
	(S.E.)	*(0.002)*	*(0.008)*	*(0.009)*

R = Rye, W = Wheat, P = Potatoes, O = Oats, B = Barley

Std.dev. unbiased.S.E. of means "County" = std.dev./sqrt(n). S.E. of std.dev. "Province" and "State" = std.dev./sqrt(2*n)

A: Effects of diversification in five Saxon districts

Table 3 is an expansion of column one of **Table 2**. Instead of averaging the standard deviations at county level to the whole state it does so only to the district level. To ease comparison, **Table 4** presents the same information in percentages of the respective rows above. Presenting these percentage numbers is important, because rounding error in **Table 3** creates a biased appearance of the actual ratios. For example, the reduction of 0.09 to 0.08 appears to be a decline of 11.11 per cent; however, when rounding to four digits after the comma, the decline is from 0.0899 to 0.0762, or 15.30 per cent.

Three main observations can be made from this. First, considering **Table 3**, the overall level of harvest volatility differed significantly between districts. Independent of the food bundle consumed, it was lowest in Erzgebirge, and highest in Kurkreis, while the three remaining districts experienced a similar degree of volatility in between.

Second, easier to be seen in **Table 4**, the addition of potatoes to the food bundle caused harvest volatility to go down by various degrees. The reduction was strongest in Erzgebirge with 24%, but only half of that or less in the other districts.

Table 3: Standard deviation of various food bundles across different levels of aggregation. Saxony, 1792-1811.

1792-1811		Volatility of harvest fluctuations at distric level				
		Mean of std. dev. of harvests at county level				
Food bundle		Erzgeb. Kr.	Kurkr.	Leipz. Kr.	Meissn. Kr.	Thür. Kr.
		N=24	N=18	N=15	N=18	N=18
R+W	MEAN	0.12	0.15	0.14	0.14	0.14
	(S.E.)	*(0.005)*	*(0.005)*	*(0.008)*	*(0.006)*	*(0.010)*
R+W+P	MEAN	0.09	0.13	0.13	0.13	0.13
	(S.E.)	*(0.005)*	*(0.005)*	*(0.006)*	*(0.006)*	*(0.009)*
R+W+P+O	MEAN	0.08	0.12	0.10	0.11	0.10
	(S.E.)	*(0.003)*	*(0.005)*	*(0.005)*	*(0.007)*	*(0.006)*
R+W+P+O+B	MEAN	0.07	0.11	0.09	0.10	0.09
	(S.E.)	*(0.003)*	*(0.003)*	*(0.004)*	*(0.007)*	*(0.006)*

R = Rye, W = Wheat, P = Potatoes, O = Oats, B = Barley S.E. of means in "County" = std.dev./sqrt(n).

S.E. of std.dev. in "Province" = std.dev./sqrt(2*n). All std.dev. are unbiased.

Third, adding oats to the food bundle also had varying effects, which can be seen when comparing rows two and three in **Table 4**. The effect of oats was strongest in Leipziger and Thüringischer Kreis with a reduction of about 20%, and Meissnischer Kreis and Erzgebirge following with 15%. In Kurkreis, however, adding oats to the food bundle could decrease harvest volatility by only 7%.

Thus, one district benefited strongly from potatoes *and* oats, one from neither, while the others benefited much more from adding oats to the diet than from adding potatoes, especially Leipziger and Thüringischer Kreis.

We may try to connect these observations with findings made in the first and the second part of this analytical section, namely information on relative and absolute amounts of crop production as well as correlation between harvest outcomes. This entails recognising that the volatility estimates depend on the correlations but also on the relative amounts of crops produced. Thus here we assume that all of the produced crops were directly consumed, which is of course not warranted, especially in the case of oats.

Having said that, we start with Kurkreis: It had the least diversified crop structure (**Figure 3**), and additionally a high degree of positive correlations between potatoes and wheat as well as between oats and rye (**Table 1**).

Table 4: Volatility of harvest at district level as percentage of rows above, respectively.

1792-1811	Volatility of harvest fluctuations at district level *Mean of std.dev. of harvests at county level as percentage of the row above, respectively*				
Crop	Erzgeb. Kr.	Kurkr.	Leipz. Kr.	Meissn. Kr.	Thür. Kr.
R+W	1.00	1.00	1.00	1.00	1.00
R+W+P	0.76	0.89	0.87	0.90	0.88
R+W+P+O	0.85	0.93	0.80	0.85	0.81
R+W+P+O+B	0.93	0.90	0.90	0.89	0.86

R = rye, W = wheat, P = potatoes, O = oats, B = barley

This is the immediate reason why it experienced high overall harvest volatility and only small diversification effects. However, the deeper reasons remain unclear. Only two things may be remarked: First, Kurkreis was one of the lowland regions, but not one of the highly fertile ones (Kopsidis and Pfister 2013, p. 41). In addition, it was not one of the densely populated proto-industrial regions such as Erzgebirge and Oberlausitz, which makes it stand out in terms of its socio-economic profile.

Also, Kurkreis featured the institution of „Gutsherrschaft", meaning farmers were not individually free, and thus could not migrate freely, while for example in Meissnischer Kreis, „Grundherrschaft" was practised, meaning that farmers owed only certain goods and services, but were individually free. The roots for these diverging agricultural institutions within Saxony go back to at least the 16th century but the reasons are basically unknown (Schirmer 2000, p. 139).

With our findings presented above we so far only add another piece to a bigger puzzle. Future research may be able to explain better the unique features of Kurkreis involving our findings as well.

At the other extreme in terms of harvest fluctuations is Erzgebirge with the lowest overall volatility and highest diversification effects through potatoes. First, it has the most diversified crop structure (**Figure 3**) and second, potato harvests are almost always un- or even negatively correlated to a larger extent than elsewhere in our sample. It is somewhat surprising, however, that oats could reduce food insecurity so much, because it is positively correlated with rye and wheat in many counties. The reason may be the very high shares of oats production in the overall food bundle. Thus this result is meaningful only to the extent that the population in Erzgebirge actually ate all of the oats it grew instead of feeding it to the animals. If this is a too strong assumption this increases the role of potatoes for diversification in Erzgebirge.

The remaining districts have medium levels of volatility across all food bundles corresponding well with their somewhat but not very diversified crop structures (**Figure 3**). The small effects of the potato on volatility can be explained relatively well by a combination of production shares and correlations: While in Thüringischer Kreis, the potato's production share is very low, potatoes are negatively correlated in more counties than anywhere else, two effects cancelling each other out. In Meissnischer Kreis, the potato has the lowest effect with 10% only, most likely because it grew in symmetry with rye and wheat in half of all counties, while in Leipziger Kreis, the low correlation with bread crops may be the reason for the still relatively large effect of 13% volatility reduction.

Finally, the larger effects of oats on volatility in Leipziger and Thüringischer Kreis relative to Meissnischer Kreis can again be explained by the correlations between oats and rye and wheat, respectively, given that the production shares are relatively similar. In Meissnischer Kreis, half of the counties show positive correlations with rye and almost a third with wheat, while in Thüringischer Kreis the respective numbers are only three for rye and one for wheat, and five for rye and two for wheat in Leipziger Kreis with even one negative correlation for wheat. In comparison, in Erzgebirge, where rye was often sown in spring such as oats, 18 out of 24 counties exhibit positive correlations between harvests.

Thus, we have shown that both the crop mix and the relative growing patterns of the different crops contributed to the reduction of food risk in Saxony. In the next section, we will also show that within one of the districts the variation of potato production depended clearly on altitude, and thus create a connection between subsistence production, climatic conditions and employment structure.

B: Crop diversification in Erzgebirge

In this section, we look at the district of Erzgebirge, because it was in many ways different than other districts in Saxony at the end of the 18th century. From the section above, we saw that Erzgebirge had the lowest overall harvest volatility, and profited the most from diversifying its agricultural production. We also showed that this might be explained by the fact that Erzgebirge had the most diversified grain production in Saxony. However, this raises of course the question for why the diversification strategy was followed in Erzgebirge to a greater extent than in other districts of Saxony. We may shed some light on this question by listing some of Erzgebirge's economic and geographic characteristics.

Erzgebirge was part of Saxony's proto-industrial region (a kind of early manufacturing belt) and thus had a higher labour share in manufacturing than the northern flatlands (Schirmer 2000, p. 143).The proto-industrial production featured first of all linen weaving, and flax production.

Erzgebirge suffered most from crop failure of 1770/71 because of its high share of rural proto-industrial population, and thus potato growing as a counter measure seems to have been more urgent than elsewhere (Schirmer 2000, p. 163).

The name „Erzgebirge", meaning in translation „ore mountains," points to its mountainous and rugged geography as well as to the existence of natural resources valuable for (proto-) industrial production. However, many but not all counties had an elevated and rugged landscape, thus there is variance in these explanatory variables.

Another effect of the mountains was that winters were on average colder and longer than in the northern flatlands, and weather conditions varied stronger between counties. This had consequences for agriculture in Erzgebirge. Crops sown before the preceding winter, i.e. rye and wheat, with a growing season right after the melting of the snow cover could be easily harmed by these longer winters and were thus less frequently cultivated than crops sown in the spring such as oats and potatoes. As a direct consequence, rye was sown in the spring in many counties of the Erzgebirge (Herz 1964, p. 62), which may result in high correlation of rye and oats harvests because of being subject to the same seasons' weather anomalies. Interestingly, potato harvests were still negatively or uncorrelated in 20 out of 24 counties and could thus provide insurance against rye crop failures.[14]

Also, ruggedness prevents the use of animals and machines, which is particularly important for all grains, but does not matter for potatoes, which is labour intensive anyway. Thus, potatoes and oats are likely to have been sown more often on average in Erzgebirge because of climatic and geographic features.

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[14] Ulrich Pfister (1992, p. 451) presents an analysis of the determinants of potato growing in the Kanton Zürich in the same period, which is in line with our findings for Erzgebirge: The more elevated an area, and the smaller the share of arable land of the total surface, the more land was used for potato growing. Also recall our reference to Christian Pfister (1978) in the introduction above emphasising the relation of elevation and potato growing.

However, geography had not only an effect on agriculture directly, but mattered also indirectly via Erzgebirge's proto-industrial features. In combination with the high share of rural non-agricultural employment these agricultural growing conditions led to a higher share of subsistence production of agricultural goods. While rural textile production was profitable and created sufficient incomes in the early and middle 18th century, it was carried out with rather small capital input and was therefore relatively unproductive when compared to (later) heavy industry workers. Especially at the end of the 18th century incomes went further down because textile exports suffered from the disruption of international trade through the Napoleonic Wars (Kopsidis and Pfister 2013, pp. 4, 26).[15] In the model presented above, the lower share of income from market production meant less exchange entitlements E to buy food at the market, and thus provided the need to increase subsistence production Q in order to reduce food risk R(Z).

An additional incentive for subsistence food production played high transport costs in the rugged environment, which created high barriers to trade, and prevented insurance of local harvest volatility by imports from neighbouring counties.

We may speculate about the mechanism behind the negative correlation of potato and other crops' harvests. One channel of causality may have been the labour market. U. Pfister (1992, pp. 450-451) presents evidence for the Swiss Kanton of Zürich that planting potatoes was increased in times of emergency when grain harvests were bad. The reason for this was the large labour input needed to produce potatoes, and as a consequence the labour supply curve for potato growing was bent backwards if incomes were at or below subsistence level.

Table 5: Standard deviations of grain and potato food bundle as well as potatoes only.

		Mean of std.dev. of harvests at county level				
Food bundle		Erzgeb. Kr.	Kurkr.	Leipz. Kreis	Meissn. Kr.	Thür. Kr.
Rye+Wheat+Potatoes	MEAN	0.09	0.13	0.13	0.13	0.13
	(S.E.)	*(0.005)*	*(0.005)*	*(0.006)*	*(0.006)*	*(0.009)*
Potatoes	MEAN	0.08	0.11	0.12	0.11	0.14
	(S.E.)	*(0.003)*	*(0.005)*	*(0.007)*	*(0.005)*	*(0.004)*

S.E. of std.dev. = std.dev./sqrt(2*n)

Finally, **Table 5** provides evidence that if people had produced and consumed only potatoes instead of rye, wheat and potatoes in the observed quantities, food risk would have been

15 Further reasons for low and declining incomes (valid for the whole of Saxony) may have been the institutions for inheritance and old-age care discussed in Schirmer (2000, pp. 159-162). Farms were not divided when given to one of the children, but siblings had to be compensated, which created increasingly high debt burdens as the number of children per household grew. Moreover, retirees often formally received rights to substantial food and other transfers probably disproportionally draining resources from marginal farms.

lower. Adding to this the superior yield ratios and the low per capita-food production (Pfister and Kopsidis 2013, p. 13) in Saxony especially during the Napoleonic Wars, it may be asked why the share of potatoes did not increase even quicker than observed. As **Table 5** also bears out, even with potato shares of ca. 20-25% only, substantial reductions of volatility could be reached. Given the large labour input needed, the marginal volatility reduction may thus have been too small for further increasing potato production. In addition, taste for variety may well have played a role. At least for Zürich, Pfister (1992, p. 451) provides compelling qualitative evidence that a diet consisting too much of potatoes were considered to be unattractive, and it is plausible to expect similar attitudes in Saxony.

6. Conclusion

In this article, we argue that in comparison to England and Westphalia in the early 19th century, Saxony's „low wage-high energy cost" growth path represented a combination of factors that led to more subsistence production of agricultural goods, and favoured crop diversification. Additional to marketable crops such as rye and wheat, potatoes and possibly oats were consumed whose harvests were often uncorrelated or negatively correlated with those of rye and wheat. This is to be seen in contrast to the „high wage-low energy cost" growth path chosen in energy rich regions such as England or Westphalia, which led to rapid urbanisation, stable demand for marketable agricultural goods, and regional specialisation in connection with a higher market share in agriculture enabled by growth of trade and market integration.

Using a dataset of 20 years of annual harvests for five crops in 93 counties in Saxony, 1792-1811, we can easily show that especially the potato reduced food risk, because it was uncorrelated or sometimes even negatively correlated with rye and wheat harvests. We also show that the reduction of food risk through local crop diversification was about as much as the theoretically maximum reduction through trade within Saxony. When using the theoretical result that diversification and trade were substitutable strategies to reduce food risk, this illustrates the importance of a well-chosen crop mix.

In terms of the long-run growth literature this means that the role of the potato was not only big because of higher yields and its superior nutritional value compared to grains, but also because it represented an insurance device against crop-specific weather shocks in the presence of trade barriers. In turn this is also consistent with famines in potato-dependent societies such as Ireland during the Great Famine, because crop diversification was not practised there.

For the contemporary development literature this study presents theoretical and empirical evidence that crop diversification works especially if harvests are uncorrelated or even negatively correlated, and in circumstances where transport costs are high or income from market labour is unstable.

Finally, our interpretation of late-18th century agricultural development in Saxony is consistent with economically rational individuals. Parts of the agricultural history literature see mentality as an obstacle for capital accumulation by farmers, and thus indication if not proof for non-capitalistic behaviour. For example, Schirmer (2000, pp. 162-163) describes rich farmers that nevertheless did not invest in new techniques or risky endeavours and instead preferred to consume their surpluses. In contrast to this interpretation, we think that given the low incomes and high risks an increasing number of rural proto-industrial workers was facing, and in the absence of large urban demand centres, the present value of expected future income from investments was too low, and thus immediate consumption may have been a perfectly rational decision.

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