The great moderation of grain price volatility: Market integration vs. climatic change, Germany, 1650–1789

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Abstract

Food prices are of major importance in economies with low levels of income. We show that pre-industrial grain market integration in Germany was one factor that could have increased total factor productivity. This finding is robust to weather shocks or climatic change. Grain market integration can thus explain how it was possible to feed a growing population before the French Revolution. This is relevant from the perspective of unified growth theory, because a larger population supports a higher innovation rate. Additionally, increasing price convergence is associated with a great moderation of grain price volatility. This has implications for mortality.

Keywords: Growth, Population, Malthusian, Market integration, Volatility, Price, Food, Climate, Weather, Little Ice Age, Grain, Germany

JEL codes: J11, N13, N53, N73, O14, Q54

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1 Introduction

In economies with low levels of income such as pre-industrial societies, food prices are of major importance for individual consumption and macroeconomic outcomes such as economic growth. The level of food prices and their volatility decisively influence demographic variables such as fertility and mortality and are related to agricultural productivity. Grain prices rank among the longest available economic time series, partly spanning hundreds of years.[1] Furthermore, bread from grain epitomizes the major spending share in consumer baskets for the pre-industrial period (Allen, 2001, 421).

This paper analyzes Germany 1650–1789. A quantitatively significant and sustained increase in the growth rate of per capita output occurred roughly since ca. 1800 (Pfister, 2011, 17). The period prior 1800, however, features a remarkable increase in the size of population by 40.7% from 13.5 million (1618) to 19 million (1800) (Pfister and Fertig, 2010, 5). In order to allow population and thus, agricultural production to grow at this pace, either aggregate factor input of land in agriculture (which is limited due to limited space) or total factor productivity (TFP) in agriculture must have increased or a combination of both. This is consistent with a characterization of a Malthusian equilibrium featuring a small progress of total factor productivity.[2]

Several explanations for the industrialization of Germany have been proposed: institutional reforms that came along with the French Revolution (e.g. agrarian reforms) or usage of coal (Acemoglu et al., 2011; Kopsidis and Bromley, 2015). The observed massive increase of population in Germany, which was happening long before the institutional reforms or coal was used at massive scale, however, has not been addressed although relevant from the perspective of growth theory.

In unified growth theory, a scale effect on the rate of innovation working through population size à la Kremer (1993) is crucial to explain the increase of the growth rate in earlier stages of development (Galor, 2011, 147). Whereas a scale effect refers to the rate of innovation for the whole economy without distinction of its different sectors, Matsuyama (1992) formalizes the intuitively positive effect of an exogenous increase in agricultural productivity (Agricultural Revolution) on the growth rate in a closed economy. Thus, apart from the scale effect as such, an additional channel of food production on economic growth exists. Following Matsuyama's work, people need food, agriculture must provide this food; its productivity is thus decisive for how much division of labor is possible. Non-homothetic preferences consistent with the empirically well documented Engel's law are the key driver

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[1] Agricultural output data instead is not readily available. Exceptions in the German context include Nuremberg on the basis of tithe (1339–1670) from Bauernfeind and Woitek (1999, 465) and Saxony, 1792–1830 (Pfister and Kopsidis, 2015; Kopsidis, Dube, and Franzmann, 2014).

[2] One might argue that the increase of population is just a transition back to the steady state level prior to the Thirty Years War. However, this is not plausible because already in 1740 population exceeded the pre-war level.

of this effect. Simplifying, only once basic needs like food are satisfied, other non-food goods can be consumed.

We focus on understanding how it was possible to feed the growing population in Germany, a pre-condition to any scale-effect related explanation for economic growth. The hypothesis is that integration of agricultural markets helped to increase allocative efficiency so that grain production could increase and made food prices more stable. In our analysis, we confront this hypothesis with a new data set of grain prices and one other explanation in particular: climatic change. A major question is whether the great moderation of grain price volatility which we document in this paper was caused by a weakening of exogenous shocks or by an improvement of the operation of markets—in certain analogy to investigations of 'The Great Moderation' during the 1980s to early 2000s (e.g. Summers, 2005). Additionally, we address how grain price data quality can be increased by converting prices to one common time base (calendar years) to render series from different sources comparable.

Market integration increases allocative efficiency via market access (cf. Federico, 2005, 82). According to Kelly (1997, 939): "There is no dispute that when markets expand, increased specialization will cause output to rise." In a European context, a recent contribution has documented that prices converged already in the eighteenth century although "a common market" did not exist in Germany 1620–1789 (Chilosi et al., 2013, 50–1, 55–6). The authors propose early formation of states and advances in the technology of shipping as drivers of this development (Chilosi et al., 2013, 62). One problem with research using price data is that the often used statistical measure of price convergence across cities to test the law of one price, the coefficient of variation (CoV), is not robust to weather shocks. However, the latter are particularly evident in grain price data, a common data source.

Not only small scale annual shocks might blur the picture drawn by a CoV. The Little Ice Age (LIA) is an often referred period of cooler climate in Europe. Authors date the end of LIA differently: some around 1700, others later (Kelly and Ó Gráda, 2014a, 1374). One could argue that the end of this cool period could have influenced grain output positively in a direct way. In addition, the disappearance of serious asymmetric weather shocks may have reduced the severity of local crop failures and resulting food shortages. If prices reflect scarcities this would have been reflected in a lower volatility of grain prices, given that markets were not integrated (cf. Federico, 2012, 448; Chilosi et al., 2013, 48). The discussion is complicated by recent research by Kelly and Ó Gráda (2014a) who do not find statistical evidence for a LIA in Europe (Germany).[3] Still, shorter periods of unusually cool or warm weather are not inconsistent with the non-existence of LIA (cf. Kelly and Ó Gráda, 2014a, 1388). A market integration based explanation of the population increase must therefore consider how weather shocks affect the used statistical measures.

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[3] These authors argue that the LIA is a statistical artifact from smoothing data and various techniques fail to identify the LIA statistically. See also Kelly and Ó Gráda (2013) and Kelly and Ó Gráda (2014b) for a reply to comments.

Alternative arguments other than market integration or climatic change, technological progress or institutional change, cannot explain the extent of the increase in total factor productivity mirroring in population growth. Science based innovations relevant for agriculture (breeding, mineral fertilizer etc.) were made rather since the 19th century (Mokyr, 2002, Mokyr, 2009; Kopsidis and Bromley, 2015). The introduction of the potato is considered as major cause for population growth in the Old World for the period 1700–1900 (Nunn and Qian, 2011). However, Pfister (2010, 8) reports that roughly 8 percent of consumed calories was provided by potatoes in 1800. Similarly, Uebele and Grünebaum (2014) find that potatoes accounted for only c. 5% in production of calories in Saxony, 1792. The potato gains a large share in caloric consumption after 1800 (Pfister, 2010); however, its explanatory power is limited prior 1800 for the German case.

Technical change in agriculture prior to 1800 was driven in an important way by improved crop rotations while the key point was to make use of nitrogen fixing legumes. Chorley (1981, 73, 82) estimates the role of nitrogen fixation by legumes around 1770 for Germany as minor; the beginning of regular usage starts around this date.[4] Following Chorley, nitrogen fixation from legumes is the major source for increasing yields in agriculture for Germany after 1770 but is limited before (cf. Pfister and Kopsidis, 2015, 14–5 on Saxony c. 1800). Other factors (liming, drainage, improvements of agricultural machinery, seed selection (possibly facilitated by trade), improved pest control (through improved crop rotations) might play a role but there relative importance prior 1800 is unknown (Chorley, 1981, 86; cf. Allen, 2008, 201).

All presented arguments argue that the causality runs from agricultural sector to the rest of the economy. However, output might grow as a result of (urban) demand (Kopsidis and Wolf, 2012, 635). These authors reveal an empirical Thünen-pattern for 19th century Prussia. During the pre-French-Revolution period, this argument is of limited importance though, because it applies in a second step once a minimum level of division of labor between agriculture and non-agriculture is already supported by the productivity of agriculture. Then, increases in TFP or higher agricultural input intensities might be demand driven. Demand-side explanations become more important with a deeper division of labor, reflected in an increasing non-agricultural (urban) population.

The analysis develops as follows. First, we present our data. Second, we introduce the set of methodologies we apply. We ascertain how the CoV is affected by shocks, and present a way to still measure price convergence. Furthermore, we develop an empirical model to understand how aggregate volatility is driven by market integration or climate. Third, we present our results. We document how price convergence evolves and what we call *the great moderation of grain price volatility.* We then analyze whether the volatility decline stems from market integration or is driven by climate. The last section concludes.

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[4] Allen (2008, 183, 188–9) emphasizes that increasing nitrogen supply worked at a slow pace.

2 Grain price data: four criteria of comparability

We draw on newly compiled grain price data from edited and selected archival sources, partly unused thus far. This section introduces the necessary preliminary steps and informed decisions to make the available price series comparable. For data sources and details, we relegate the reader to the supplementary appendix (SA). Price series have to fulfill four conditions for comparisons (Gerhard and Engel, 2006, 19–100). First, the considered prices should be market prices of the same stage of marketing. We included retail prices, because those mattered for consumption. Second, we assume that the compared prices are for a homogeneous commodity.[5]

Third, for analyses in levels prices need to be in one currency and one measurement unit. A major problem for price comparisons is that grain prices are reported in various local currencies and measures. Historical grain prices are usually given for volume units and not in weights. Thus, converting to litres is preferred compared to weights (kilograms). Furthermore, converting historical volume units to kilograms would also ignore that the weight of grain varies with its water content. In addition, the relationship between weight and volume is not linear (Rahlf, 1996, 43–7). Prices are reported in silver based currencies for the majority of German speaking cities. Hence, we converted all prices to grams of silver per litre via the fine metal content.[6]

Four limitations of using silver contents remain. (i) Information on the silver content of local currencies is deficient since it mostly rests on normative prescriptions; if not available we omitted series (e.g. Lüneburg 1550–1762). (ii) Our information on metallic content usually refers to a time point previous to an inflationary episode. Thus, our series overestimate silver price inflation during a period of currency debasement. To the extent that the intensity of currency debasement differed across towns and territories, inter-urban price dispersion is overestimated. Three periods of intensive currency debasement, during which the quality of our silver price information is highly doubtful, stand out: the *Kipper and Wipper* era at the beginning of the Thirty Years War (1620–1623; Kindleberger, 1991), the Seven Years' War (1756–1763; Denzel and Gerhard, 2005, 169–76) and the Napoleonic Wars (c. 1799–1815). Following Denzel and Gerhard, during the Seven Years' War, prices in Hamburg were not affected by currency debasement whereas exactly this was happening in the rest of Lower Saxony, leading to diverging prices in Northern Germany. Price dispersion would also be overestimated in this case. Apart from these wars, we can assume a system of stable

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[5] This assumption is reasonable. E.g., sources exist for Emden, which contain two rye prices: locally produced rye and a price series for rye from the Baltic Sea (Gerhard and Kaufhold, 1990, 156–160), indicating different qualities. Sources also distinguish brewing qualities from others, showing that different market qualities existed and that contemporaries considered them in case they were relevant for the price.

[6] Alternatives to this procedure are index building and conversion to an inter-regional currency like *Rheinischer Gulden*. Index building, see e.g. Rahlf (1996, 142–147), does not allow for insights in market integration measured in absolute price dispersion. The problems with inter-regional currencies are that often exchange rates are not reported, that deciding for a certain currency is not possible for the German speaking region, and that international comparisons of prices would not be possible.

currencies at least from about 1763 (Rittmann, 1975, 187). Rittmann (1975, 214–6) argues that no different developments in the German territories could exist, because the *Reichstaler* was the stable currency for trade (1566–1806). Mints could not issue coins of minor value, simply because they were not accepted and remained local. Thus, it is plausible to argue for an equally distributed error in the currency conversion. (iii) Converting to grams of silver uses numbers with several decimals. However, inaccuracy of the minting process and variability of the fine content as such existed (Rittmann, 1975, 174, 178–9). (iv) Money of account (which has no metal content; Gerhard and Engel, 2006, 40–6, 59; Metz, 1990) is converted to silver using exchange rates with gold currencies (*Rheinischer Gulden*) and gold-silver ratios.

According to the fourth criterion, comparable prices need to refer to the same time base. Most annual values are based on several data points covering different seasons of the year. Data obtained from official sources typically rest on monthly intervals; price information from urban institutions such as hospitals is more irregular. High frequent data for longer periods remain exceptions (see SA). In case of available monthly averages we use them to calculate calendar year averages. The predominant part of the here used data is obtained as annual calendar year average from the literature. However, two forms of data require a transformation of the original series: crop year and *Martini* prices.

Martini prices are reported for a particular time of the year.[7] We refer to these prices as average prices for November and December.[8] *Martini* prices cannot be compared with calendar year averages. Hence, we develop a method to extrapolate calendar year prices from *Martini* prices. A *Martini* price contained the information about the last crop (Elsas, 1933, 228). The information about the next crop in August of the following year, however, was not incorporated since information on the latter did not exist during that time of the year. Extrapolation of calendar year prices rests on the idea by Phelps Brown and Hopkins (1959, 31) (in the context of crop year prices; see also Bateman, 2011, 451): The *Martini* price of the actual calendar year and the one observed the calendar year before provide relevant information to approximate the calendar year price. For this approximation, we specify a reduced form relationship without any explicit supply and demand functions as follows:

$$\log(p_{it}) = \alpha + \beta_1 \log(pm_{it}) + \beta_2 \log(pm_{it-1}) + \mu_i + u_{it} \tag{1}$$

with p : calendar year price, pm : *Martini* price, i indicating the city, t: time index for the respective year, individual fixed effect μ_i, and error term u_{it}. The coefficients α, β_1, and β_2 are estimated for four data sets, one for each commodity.[9]

The most important result is that the calendar year price can be regarded as a weighted

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[7] A *Martini* price is defined as follows: They are averages of a period of four to twelve weeks around Martinmas (November 11) and often served as a base for the calculation of taxes in the time of observation (translation of definition by Gerhard and Kaufhold (1990, 396).

[8] The definition shows that there are regional differences in the time base a *Martini* price covers.

[9] The number of observations for which both *Martini* and calendar year prices are available is limited. In

average of *Martini* prices (high model fit). The weights, i.e. the parameters, are roughly $\beta_1 = 0.5$ and $\beta_2 = 0.5$. Further panel regressions show that parameters are slightly different for other commodities (barley, oats, wheat) than rye, whereas time series regressions show that weights are sometimes different for particular cities (results in SA). The first effect can be explained by different price to volume ratios and thus, the profitability of trade. The second effect can be explained by the degree a city is integrated in a larger market.

For some series only *Martini* prices exist. We used the parameters from the commodity specific panel model to extrapolate calendar year prices for these cities. Wherever we find overlapping *Martini* prices and calendar year prices for the same city, we fill gaps in calendar year price series using the regional specific results from time series regressions to preserve local information (details in SA).

Another problem for adjusting all prices to an equivalent time base are crop year prices, the idea being that the supply of the recent harvest has a considerable impact on the price. The respective year for the annual mean should refer to the time between two harvests in order to show the yearly fluctuations better. This point, however, depends on the degree of market integration. The more a market is integrated with others, the less important local supply is in determining the price. We find two versions of the crop year, a concept introduced by researchers, in the literature. First, Elsas discussed this topic and defined the crop year for e.g. 1501 to be the period from August 1, 1501 until July 31, 1502 (Elsas, 1933, 224–5; Elsas, 1936, 92–3). Bauernfeind (1993, 63) confirms this view. Contrary, Ebeling and Irsigler (1976, XXXI–II, 672–83) chose July until June. Extrapolating calendar year prices from crop year prices should take into account these differences.

There are three reasons for using all data in calendar years instead of crop years. (i) Dates for the harvests vary with the considered region and the considered agricultural commodity. Defining the precise dates for the crop years is rather difficult, as already Elsas admitted (Elsas, 1933, 224–5; Elsas, 1936, 92–3). Thus, defining a period always constitutes an average over the regional and commodity specific differences. In this sense the crop year concept appears more specific than it is, illustrated by the different versions authors used. (ii) It is reasonable to choose a time base allowing for international comparisons and for comparisons with other variables, e.g. nominal wage data. (iii) To keep the data preparation as low as possible it is reasonable to extrapolate for calendar years constituting the major part of the available data.

Several German price series refer to crop years and we analyzed the relationship between calendar year prices and crop year prices rather than a priori applying the arithmetic mean like Phelps Brown and Hopkins (1959, 31). Extrapolating calendar year prices from crop year prices is based on the estimated parameters from equation (1), with the difference that

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order to increase the number of observations, we additionally calculate synthetic *Martini* prices as averages of monthly prices of November and December.

we use crop year prices instead of *Martini* prices. We draw on cities where both crop and calendar years are available or we calculated them from monthly data (details in SA).

One important result of the crop year regressions (results in SA) is that that choosing the lagged crop year price yields a higher model fit, demonstrating that comparing crop year prices directly to calendar year prices is not appropriate. We explain the stronger lag with threshing of grain as a labour intensive task prior to the mechanization. It lasted considerable time until the actual yields were determined so that storage of the former crop and expectations rather than the actual new harvest influenced the price. As for extrapolation based on *Martini* prices, regional specific parameters from time series regressions are preferred. Only if no local calendar year prices were available, we applied parameters from a panel regression; for August-July $\beta_1 = 0.4$ and $\beta_2 = 0.6$ and for July-June $\beta_1 = 0.45$ and $\beta_2 = 0.55$, respectively (details in SA).

In summary, converting local currencies to grams of silver and the local volumes to litres yields comparable price series. Although there remain shortcomings of this methodology, namely overrated inflation in times of war finance, there are no sufficient alternatives. Additionally, we believe it is crucial to convert *Martini* and crop year prices to one common time base, the calendar year.

3 Methodology

This section unfolds two major topics. First, we formally analyse the coefficient of variation and develop our empirical strategy accordingly to measure price convergence robust to weather shocks and climatic change. We then present a way to analyse aggregate price volatility, another important aspect of market integration influenced by weather shocks.

3.1 Anatomy of the coefficient of variation

The aim of the subsequent analysis is to understand whether increasing grain market integration can contribute to explain the increase in population levels. Measuring market integration needs a measure robust to weather shocks, given the discussion of the LIA. This section shows formally how the CoV, an often applied measure to test the law of one price (loop) is affected by weather shocks. The main result is that the CoV does not exclusively signal market integration; it can signal changes of supply shocks. Furthermore, we show that the standard deviation is not affected by symmetric weather shocks and develop our empirical strategy based on this insight.

The CoV (standard deviation divided by mean) is a commonly applied multivariate measure to test price convergence, one important aspect of market integration. According to Federico (2012, 478–80, 493), this measure can be used to test the loop, and if computed for a group of cities over a period of time the CoV provides information on price convergence which is important for long-run growth.

Using the CoV, one intends to measure a signal of lowering transactions costs (e.g. for transport) and thus price convergence as a decrease in the CoV. If transport costs are some constant absolute amount per volume for the given distance between two cities, a decrease in transport costs *decreases* the CoV. The intuition is that the spread of prices between cities becomes relatively smaller with respect to the price level.[10]

A known limitation of the CoV is that it provides times series information only on the degree of market integration, whereas other measures could provide cross-sectional results on top (Uebele, 2011). Measures of comovement, however, are not robust to shocks. Price comovement might be caused by asymmetric weather shocks to production which are transmitted to other regions through efficient markets and symmetric weather shocks to production that affect all markets even if not integrated.

The CoV, however, is neither robust to symmetric or asymmetric shocks. It is calculated as follows:

$$CoV_t = \frac{\sqrt{\frac{1}{N-1}\sum\limits_{i=1}^{N}(p_{it}-\bar{p}_t)^2}}{\bar{p}_t} \tag{2}$$

with city $i = 1, \ldots, N$, year t, and $\bar{p}_t = \frac{1}{N}\sum\limits_{i=1}^{N} p_{it}$.

3.1.1 Symmetric shock

The effect of a symmetric shock to the price of all cities on the mean price of the market is:

$$\begin{aligned} \bar{p}_t &= \frac{(p_{1t}+s)+...+(p_{Nt}+s)}{N} \\ \bar{p}_t &= \frac{p_{1t}+...+p_{Nt}}{N}+s \end{aligned} \tag{3}$$

with s: shock. This shock cancels from the sum of squared deviations:

$$\sum_{i=1}^{N}(p_{it}-\bar{p}_t)^2 = (p_{1t}+s-[\bar{p}_t+s])^2+...+(p_{Nt}+s-[\bar{p}_t+s])^2. \tag{4}$$

Thus, a symmetric shock remains in the denominator of the CoV.

$$CoV_t = \frac{\sqrt{\frac{1}{N-1}\sum\limits_{i=1}^{N}(p_{it}-\bar{p}_t)^2}}{\bar{p}_t+s} \tag{5}$$

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[10] Transport costs as such were plausibly not dependent on the price level of the traded commodity: why should it have become cheaper (more expensive) to transport 1000 litres of grain from city A to B, when the grain price level decreased (increased)? Even if grain was part of feed for draft animals, it could easily be substituted with forage which is not suitable for human consumption (cf. Denzel and Gerhard, 2005, 169).

A positive price shock decreases the CoV. Severe weather shocks leading to price increases in all markets might thus be misunderstood as price convergence signalling market integration.

3.1.2 Asymmetric shock

The effect of an asymmetric shock to the price of all cities on the mean price of the market depends on whether arbitrage between cities takes place or not.

Perfect arbitrage

Assuming that prices reflect equilibrium values, arbitrage leads to equal distribution of the shock between all cities:

$$\begin{aligned} \bar{p}_t &= \frac{(p_{1t} + s_{1t}) + ... + p_{Nt}}{N} \\ \bar{p}_t &= \frac{p_{1t} + ... + p_{Nt}}{N} + \frac{s_{1t}}{N}. \end{aligned} \tag{6}$$

This shock affects the sum of squared deviations as follows:

$$\sum_{i=1}^{N}(p_{it} - \bar{p}_t)^2 = (p_{1t} + \frac{s_{1t}}{N} - [\bar{p}_t + \frac{s_{1t}}{N}])^2 + ... + (p_{Nt} + \frac{s_{1t}}{N} - [\bar{p}_t + \frac{s_{1t}}{N}])^2. \tag{7}$$

The local shock cancels. However, The CoV is still affected and decreases as well, but to a lower extend ($\frac{s_{1t}}{N}$ in the denominator, not s).

No arbitrage

In this case the shock to one city affects the squared deviations as follows:

$$\begin{aligned} \sum_{i=1}^{N}(p_{it} - \bar{p}_t)^2 &= (p_{1t} + s_{1t} - [\bar{p}_t + \frac{s_{1t}}{N}])^2 + ... + (p_{Nt} - [\bar{p}_t + \frac{s_{1t}}{N}])^2 \\ &= (p_{1t} + (1 - \frac{1}{N})s_{1t} - \bar{p}_t)^2 + ... + (p_{Nt} - [\bar{p}_t + \frac{s_{1t}}{N}])^2. \end{aligned} \tag{8}$$

The shock does not cancel. In addition, the effect is ambiguous in sign. Whether the sum of squared deviations increases or decreases, depends on whether the shock s_{1t} moves the price of the city experiencing the shock, p_{1t}, closer to other cities or further away. For example, the prices of three cities might be $2, 4, 6$. An adverse weather shock increases the price of the first city to 4 as well, leading to a *decrease* of the sum of squared deviations and thus, the standard deviation from 2 to 1.15.

3.1.3 Measuring price convergence

Annual series of silver prices for different grain types in individual towns constitute the basis of our analysis of market integration below. Similar as Chilosi et al. (2013) we split the sample in politically determined sub-periods: pre-French-Revolution and post-French-Revolution. We focus on a stable sample for the pre-French-Revolution period in particular, because of its relevance for the population increase. Additionally, to put the results into a broader context, we provide selected results for an unbalanced sample covering 1600–1850.

Based on the insights of the the formal analysis of the CoV, we perform our empirical analysis of price convergence as follows. We use the standard deviation of prices instead of the CoV to make our measure of price convergence robust to symmetric shocks. To account for price increases resulting from inflation, we deflate all price series using the consumer price index developed by Pfister (2010).

Cereals are annual crops and thus, annual local price data is influenced by weather shocks as long as the degree of market integration is not perfect arbitrage. This would be an unreasonable assumption and moreover, showing an increase in arbitrage, i.e. market integration is the aim of the paper.

To attenuate the influence of asymmetric weather shocks on the standard deviation, we average the price for each city over five years. Weather can be regarded as random for years (Schlenker and Roberts, 2009, 15596). Thus, the choice of a five-year-period is based on the idea of approximating a zero mean shock for each city, i.e. to nullify the effect of annual asymmetric shocks to supply and resulting fluctuations of local grain prices.[11] In addition, this procedure brings prices closer to the notion of equilibrium than using annual averages.

Still, series of unusually good or bad years or even more fundamental, climatic change experienced by a sub-sample of cities might affect changes between standard deviations of five-year average prices. To further account for this possibility, we split the entire sample in climatologically motivated regional sub-samples: North-Eastern and South-Western Germany. We assume, that we capture substantial changes in this way, however, strictly speaking, the possibility that again only one or few cities within theses sub-samples are driven by climatic change remains.

3.2 Aggregate grain price and its volatility

First, we explain how the aggregate grain price is derived. Second, we introduce the model we use to ascertain how inter-urban price dispersion and climate affect grain price volatility.

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[11] In climatology, standard normals are defined over 30-year-periods, however, this would leave very few data points.

3.2.1 Aggregate grain price

In view of the analysis of price volatility, we constructed aggregate price series for each commodity. Since the price series for individual towns cover different time periods, we opt for the specification of an unbalanced panel with fixed effects for cities and years:

$$log(P_{ij}) = \alpha_0 + \sum_{i=1}^{I-1} \alpha_i C_i + \sum_{j=1}^{J-1} \beta_j T_j + \epsilon_{ij} \tag{9}$$

with P_{ij} being the mean price index in city i and year j, C containing city-specific dummies and T being a set of year dummies. Prices are put in natural logarithms in order to reduce the weight of outliers. The aggregate price for individual years (P_j) is then calculated as the exponential of the sum of the constant c, the mean of the city effects α_i (i.e. the average deviation from the constant), and the individual elements of the parameter vector β.

To isolate grain price shocks from inflationary shocks that affected the price level as a whole, we consider real rather than nominal grain prices. Deflation of the aggregate series is based on the consumer price index (CPI) developed by Pfister (2010). This index is the silver price of a basket of fixed quantities of eleven goods presumably consumed annually by an adult town dweller. Thus, we calculate the real price as the ratio of the silver price of 1000 litres of a particular grain type to the annual silver price of a consumer basket. In addition to deflating the grain price, this ratio preserves the information of how much these 1000 litres of grain cost relative to the consumer basket.

3.2.2 Volatility: market integration or climate?

Integrated markets are expected to have a lower price volatility than non-integrated ones (Chilosi et al., 2013, 48). However, the disappearance of serious symmetric and/or asymmetric weather shocks may have reduced the severity of adverse shocks to agricultural production and resulting food shortages. This would have been reflected in a lower volatility of grain prices even if cities did not trade with each other (cf. Federico, 2012, 484).

In order to measure effects of climate (i.e. long-run averages of weather) and price convergence on volatility we develop the following model.

$$V_s = \alpha_0 + \alpha_1 t_s + \beta_1 sd_s + \beta_2 c_s + \gamma_1 d_s + u_s \tag{10}$$

Using this model, we can evaluate a direct effect of market integration (price dispersion across space sd_s) on volatility V_s controlling for climate variables c_s. The parameter α_1 accounts for a linear time trend. Subscript s denotes 5-year-periods. Dummy variable d_s accounts for temporary disintegration caused by the Seven Years' War and/or related measurement problems due to asymmetric war inflation.

Volatility is calculated based on the aggregate price series. Market integration is measured calculating the standard deviation based on five-year-average prices in each city.

As c_s we test several temperature series (annual, spring, summer) developed by Luterbacher et al. (2004) as provided by Kelly and Ó Gráda (2014a). As an alternative to the five-year-means of the annual temperature series for c_s, we also consider the respective volatility of the underlying series as explanatory variable. Temperature ranks among the most important weather variables affecting cereal yields. Modest temperatures are positively related to yield, whereas higher than optimal temperatures affect yield negatively (Roberts, Schlenker, and Eyer, 2013; price effects with reverse sign). However, effects in the model above should be seen as a proxy for climate not as sole temperature effects as such. Other yield determining variables, namely solar radiation and evapotranspiration are correlated with temperature. Contrary to temperature, precipitation, which is important for plant available water, exhibits usually spatially diverse patterns and its effects are difficult to catch without spatially disaggregated data.

Although V_s and sd_s are calculated based on the same prices, they each capture different variation of the data. Volatility is calculated over the aggregate price series which captures through time fixed effects the variation shared by all cities in the sample. The standard deviation instead is based on the dispersion of prices between all cities. If a common shock affects all prices (which means variation of the aggregate price series), this does not affect the standard deviation.

4 Results and Discussion

We first show and discuss increasing price convergences and the the great moderation of grain price volatility. Second, we investigate in how far market integration or climatic change caused the great moderation of grain price volatility. We focus on rye, the most important food grain.

4.1 Stylized facts: increasing price convergence and the great moderation of grain price volatility

Clearly, figure 1 shows price convergence in the pre-French-Revolution period (stable sample, 12 cities, black solid line). We can exclude analytically that both *symmetric* weather shocks or climatic change affect the standard deviation, our used measure of price convergence. The formal analysis of the standard deviation, however, has shown that *asymmetric* weather shocks affect the standard deviation. Using five-year-mean-prices for each city, we can further exclude substantial effects of asymmetric weather shocks under the assumption that in each city the mean shock is zero in five-year-mean-prices. The standard deviation calculated in this way exhibits again a clear downward trend as visible in figure 2 (a). Thus, we confirm Chilosi et al. (2013), who pointed towards market integration as a gradual process in Europe starting before the 19th century but on top we show that this result is not affected by asymmetric/symmetric weather shocks or symmetric climatic change.

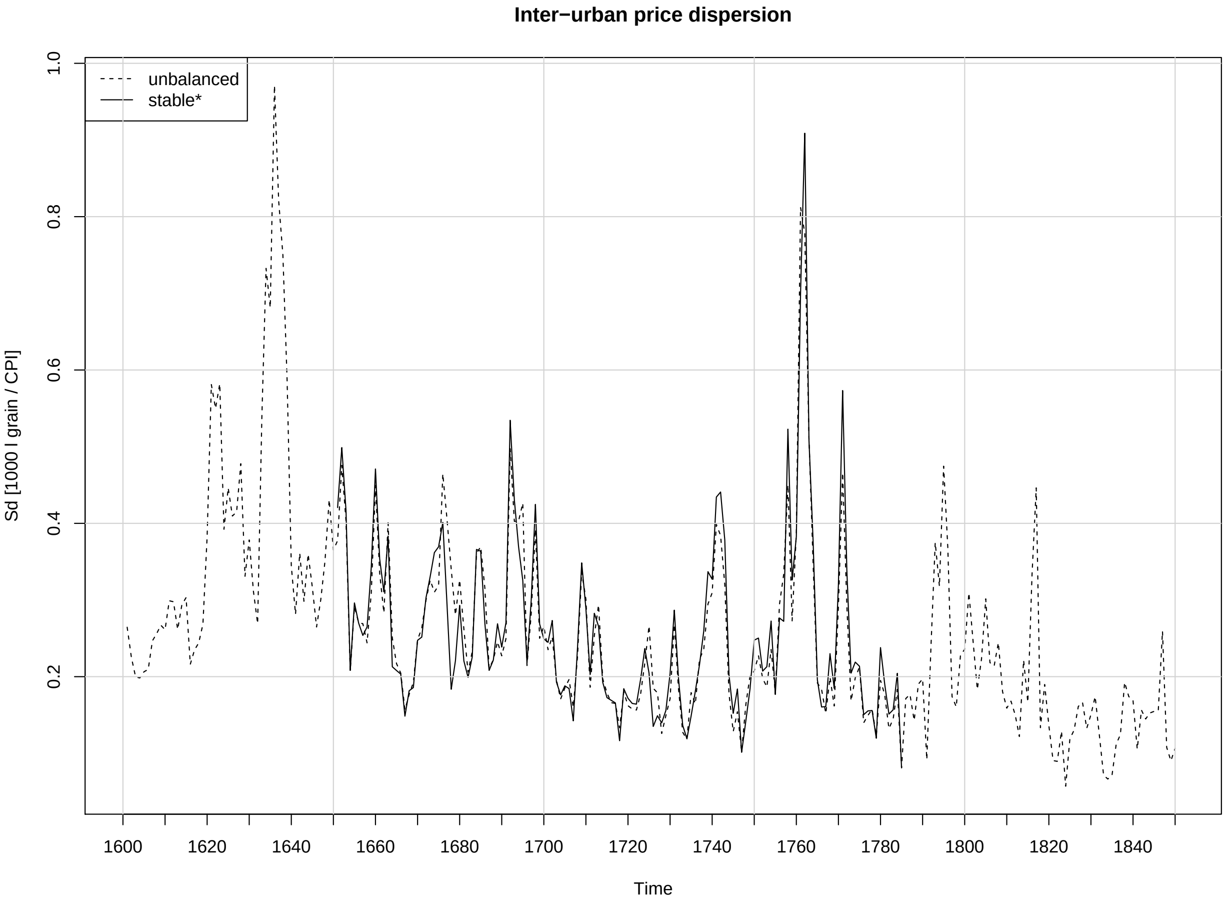
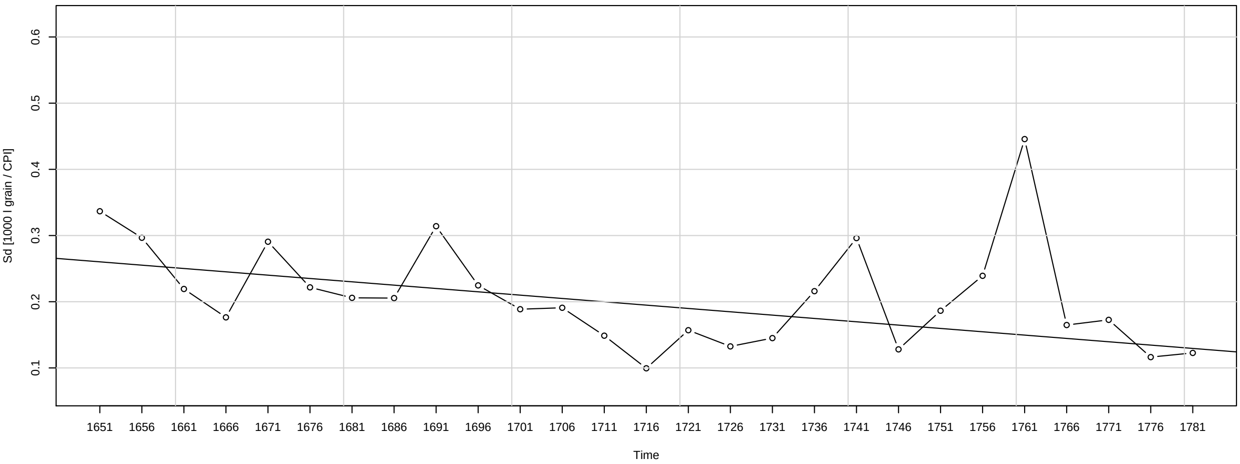


Figure 1: Inter-urban price dispersion: standard deviation, deflated rye prices Germany. *: stable sample contains less than 5% missing observations per individual series. Source: own calculation.

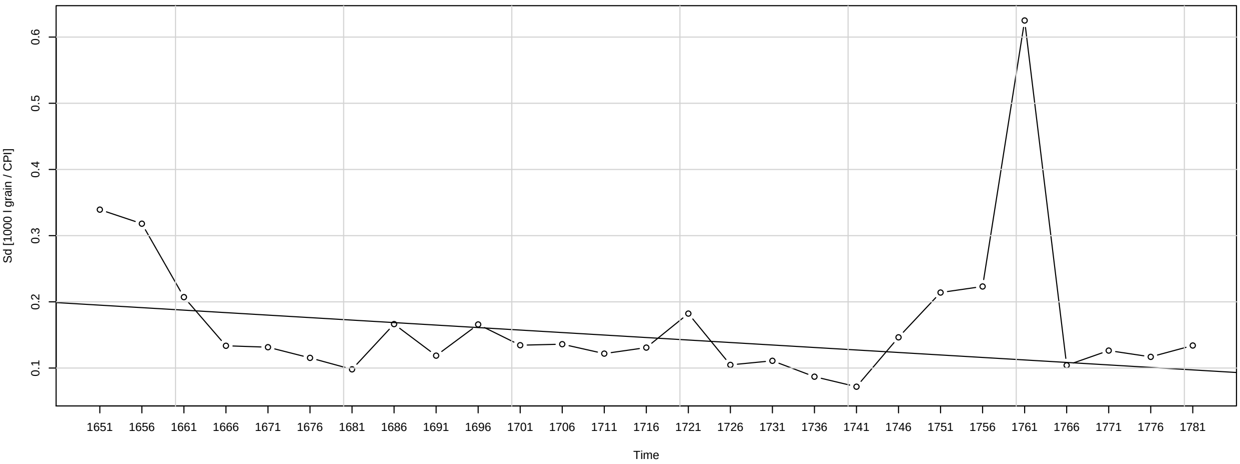
As noted in our formal analysis, we cannot exclude effects of asymmetric climatic change on the variation of the standard deviation between the five-year-sub-periods in the complete market. That is, one region within Germany might have experienced on average better growing conditions for grain because of climatic change and thus, less crop failures while the other region did not. Although both regions might not have been integrated as one market (no arbitrage between regions), we would measure changes in the inter-urban price dispersion (ambiguous in sign, see formal analysis). To ascertain the importance of this argument, we produced a set of results for two sub-regions: North-Eastern (Berlin, Braunschweig, Gdansk, Göttingen, Hamburg, Leipzig) and South-Western Germany (Augsburg, Cologne, Dueren,

(a) Germany



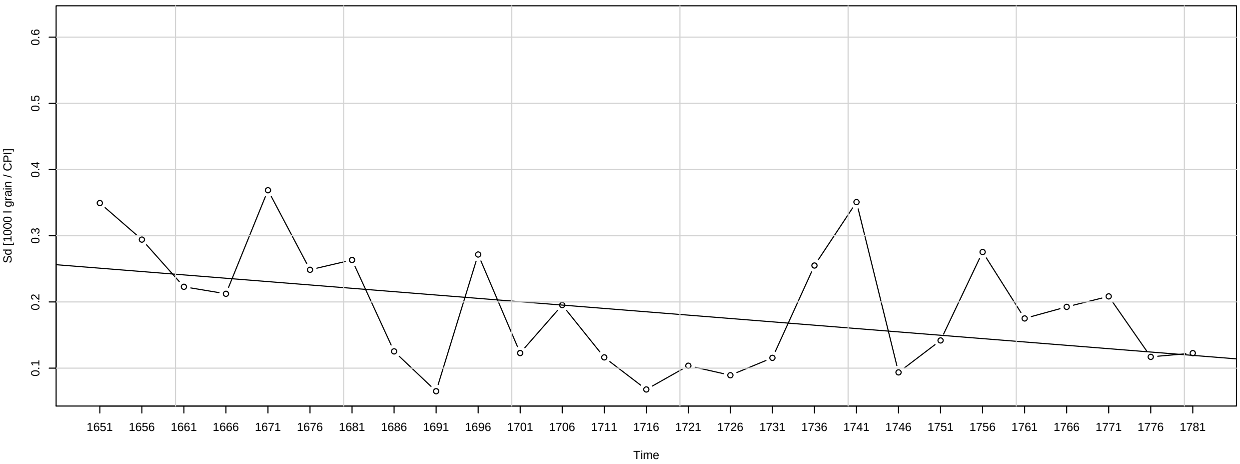
Coefficient for linear trend =−0.001, (White) se = 3e−04, p−value = 8e−04

(b) North−Eastern Germany



Coefficient for linear trend =−8e−04, (White) se = 3e−04, p−value = 0.0082

(c) South−Western Germany



Coefficient for linear trend =−0.001, (White) se = 3e−04, p−value = 7e−04

Figure 2: Inter-urban price dispersion: standard deviation of deflated 5-year-mean-prices, rye (stable sample). Each circle represents a 5-year-period starting with the given year. Underlying regressions for linear trends include dummy variable for Seven Years' War (1756–1763). Source: own calculation.

Munich, Würzburg, Xanten).[12] The idea is that an asymmetric shock for the complete stable sample, becomes analytically a symmetric shock for either of the sub-regions and thus, cannot affect the measurement of price dispersion within the affected region. The result of decreasing inter-urban price dispersion remains robust within these two sub-regions (figures 2 (b) and (c), respectively).

Interestingly, a reduction of the price dispersion between the two regions is visible in the period of 1671–1711, roughly when the LIA was ending or warmer decades happened. This is visible in figure 3, which plots the standard deviation of the five-year-mean-prices of the two regions. Admittedly, one could argue that again the results within these sub-regions are driven by a sub-group of cities experiencing climatic change. However, we doubt that larger scale climatic changes could develop independently within one of the, by climatic standards, geographically rather small areas of North-Eastern or South-Western Germany.

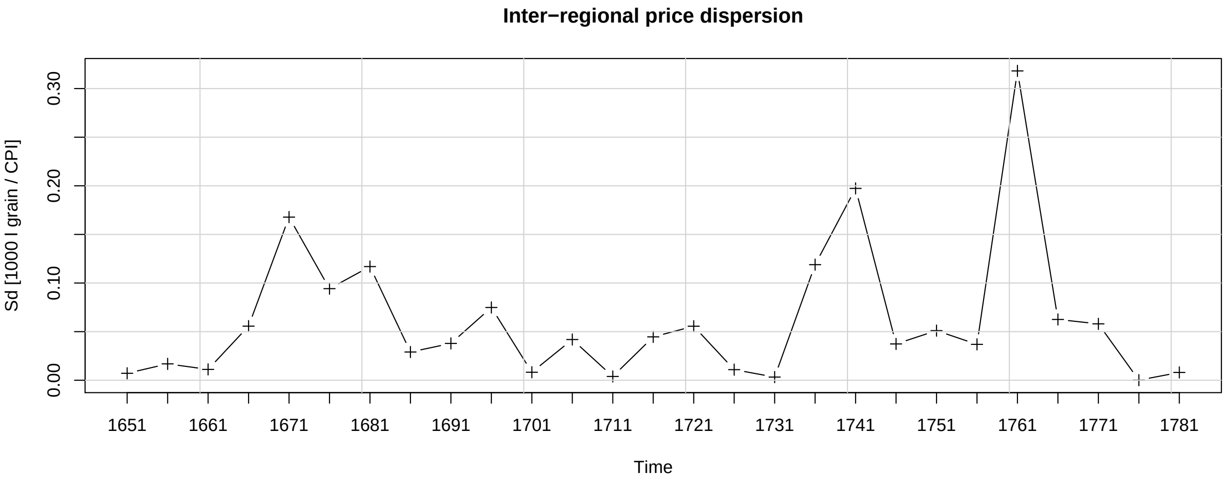


Figure 3: Inter-regional price dispersion: standard deviation of deflated 5-year-mean-prices of North-Eastern and South-Western Germany, rye (stable sample). Source: own calculation.

Notably, the regional results reveal that price dispersion during the crisis of 1741 (Post, 1985), was solely affected in South-Western Germany, indicating regional different price effects within this region. This effect might be explained by *Fruchtsperren*, trade restrictions preventing arbitrage (cf. Göttmann, 1991, 93–4). The period of the Seven Years' War showed a higher level of price dispersion in North-Eastern Germany. However, the data during the Seven Years' War are of doubtful quality because of war inflation as discussed above.

In short, the results show a process of market integration in the 17/18th century. This adds market integration as an—at least—additional explanation for increasing TFP and thus, increasing population levels within a Malthusian economy like Germany at that time.

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[12] Additionally, we considered to analyze two sub-regions where regions are determined from the data using factor analysis as by Chilosi et al. (2013), however, no stable results were obtained.

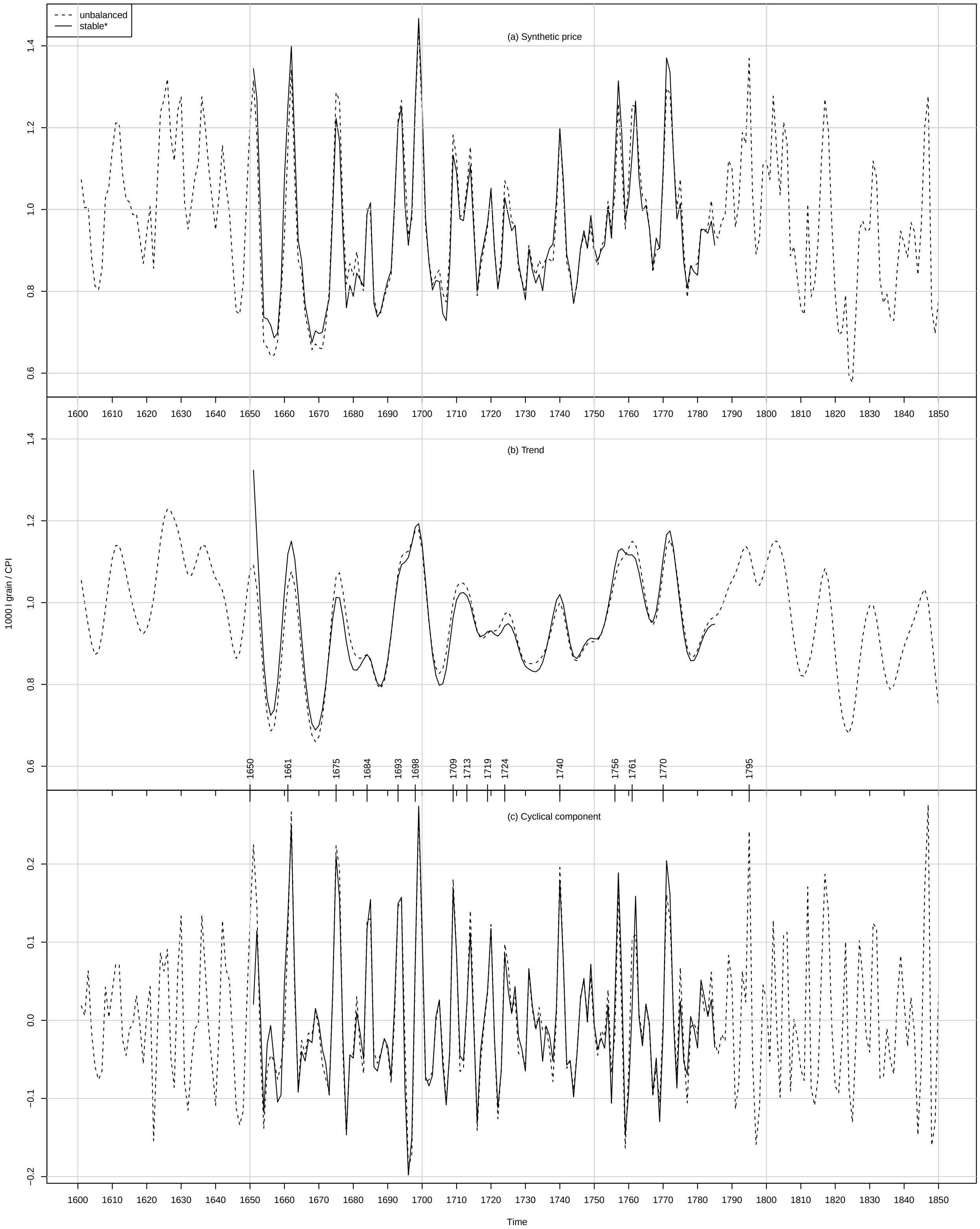

Figure 4: Synthetic real rye price Germany. Trend and cyclical component from Hodrick-Prescott-Filter, $\lambda = 6.25$ (Ravn and Uhlig, 2002). Vertical lines and given years on upper horizontal axis in panel (c) mark major price peaks associated with subsistence crises. *: stable sample contains less than 5% missing observations per individual series. Source: own calculation.

We now turn to the analysis of aggregate volatility. First, we discuss the aggregate synthetic real price for Germany against the background of subsistence crises (figure 4). Second, we calculate the volatility (as CoV over time) of the synthetic real price.

Figure 4 (a) shows the real rye price for Germany, panel (b) its trend and (c) its cyclical component. The cyclical component indicates several serious food crises during the second half of the 17th century: 1650–52, 1661/62, 1675/76, 1684/85, 1693/94 and 1698/99. All but the crises of 1684/85 and 1698/99 also show up in the series of mortality crises documented for France by Dupâquier (1989, 191–2); they obviously correspond to continental food crises. In addition, from 1675/76 all crises show up in regional series of vital events developed by Pfister and Fertig (2010). The crisis of the early 1690s is reputed as one of the worst food shortages of the post-Thirty Years Ancien Régime (cf. Ó Gráda, 2005; Ó Gráda and Chevet, 2002). The crisis of 1698/99 seems largely unknown but appears to have been particularly severe in Germany.

The first quarter of the 18th century saw four price peaks in 1709, 1713/14, 1719/20 and 1724/25. All but the one in 1713/14 also show up in demographic data for France, and all crises can be identified in the regional series of vital events for Germany. Compared to the second half of the 17th century, the crises of the first quarter of the 18th century were mild in that the peaks remained far below the level of five of the six crises documented for the period 1650–1700.

The remainder of the eighteenth century saw only five price peaks, two of them occurring during the Seven Years' War (1756-1763): 1740/41, 1756/57, 1761/62, 1770–1772 and 1795. The crises of 1740/41 (Post, 1985) and of the early 1770s are well-known European crises. The others are less known and may be specific to Germany; those of the late 1750s and early 1760s may be confounded with inflationary pressures as discussed in the data section. However, all crises can be clearly identified in national series of vital events (Pfister and Fertig, 2010, 31) and thus represent serious food crises.

The leveling-out of price peaks during the first part of the 18th century implies a reduction in price volatility. Figure 5 shows what we call, in analogy to 'The Great Moderation' during the 1980s to early 2000s (e.g. Summers, 2005), *the great moderation of grain price volatility*: Aggregate volatility decreased substantially over time until the French Revolution as illustrated by the statistically significant negative linear trend. The pattern visible in figure 5 is confirmed by a regression of 5-year volatilities of individual series on a linear trend (details in SA).

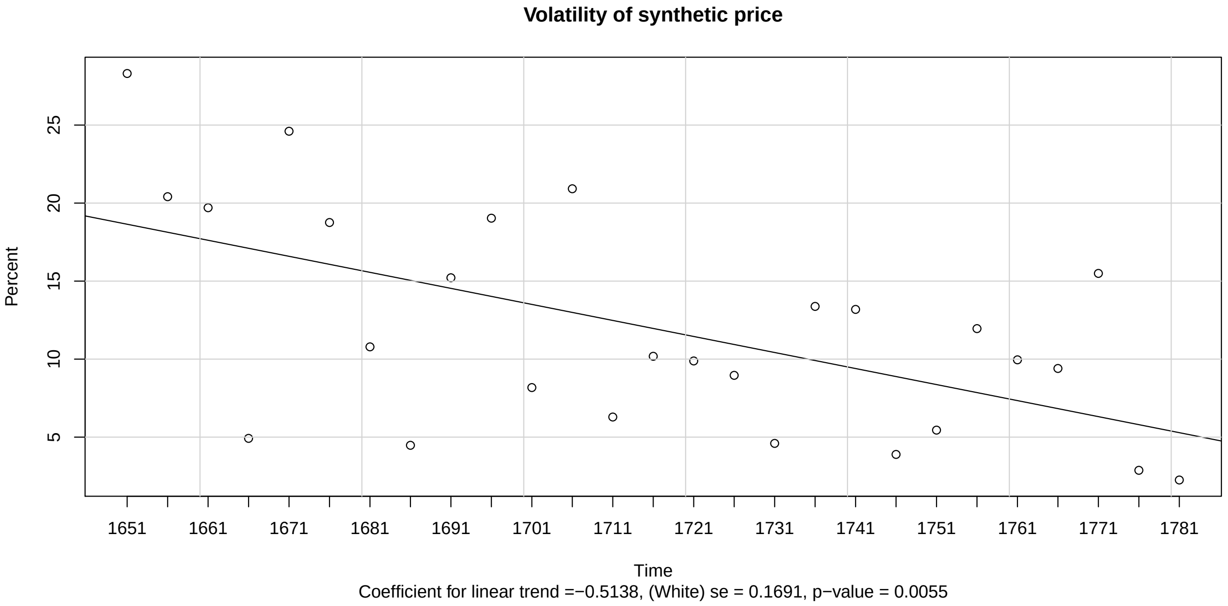

Figure 5: The great moderation of grain price volatility. Volatility of synthetic rye price Germany (stable sample). Each circle represents a 5-year-period starting with the given year. Source: own calculation.

Lower price peaks and more stable grain prices have substantial implications. As our descriptive analysis of the aggregated rye price notes, a decrease of the *level* of mortality is visible in recent reconstruction of the German death rate for the 18th century, paralleled by a decline of the level of fertility until ca. 1740 which then remained relatively constant (Fertig and Pfister, 2012, 6, figure 1). Thus, there was an increase in population growth (and thus size) prior industrialization. Households do not seem to have restricted fertility further after 1740 so that more children survived, consistent with evidence for other European countries and theoretically explainable e.g. by better usage of the physiologically possible births per woman, which might act as a binding constraint in a high mortality regime (cf. Galor, 2011, 120–3).

In addition, the moderation of grain price volatility can also be seen as not only influencing the *level* of mortality but also as acting like an increase in the *survival probability* of a child (cf. Galor, 2011, 121–2). The increase in survival probability is likely to increase the risk adjusted rate of return to human capital accumulation (Pfister and Fertig, 2010, 54–6). In England, the volatility of the death rate declined by about 75 per cent between the early seventeenth and the late eighteenth century (Wrigley and Schofield, 1981, 56–62). For Germany, a more limited volatility decline occurred for both the annual number of births and deaths between the last quarter of the seventeenth and the middle of the eighteenth century (Pfister and Fertig, 2010, 24–7, 31–2). A further fall of the volatility of the death rate took place between the first and the second quarter of the nineteenth century.

4.2 How is aggregate volatility affected by market integration and climate?

The findings of increasing price convergence, robust to weather shocks, symmetric climatic change, and asymmetric climatic change given our two defined sub-regions, begs the question whether the great moderation of grain price volatility can be explained by market integration. The problem for the empirical analysis is that aggregate volatility is not robust to asymmetric or weather or climate shocks.

The results show a positive association between inter-urban price dispersion and aggregate volatility. The lower inter-urban price dispersion, the lower aggregate volatility, controlling for a linear trend. None of the climate variables, however, has a statistically significant influence. That is, the results support the view of early modern market integration increasing food security by attenuating the volatility of rye, the most important food grain in Germany during this period.

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11
Intercept	19.1585^{***}	19.4439^{***}	6.5093	5.1485	9.7450^{**}	8.9356	10.3139^{**}	10.5509^{**}	9.8475^{**}	9.1809^{**}	9.1934^{**}
	(2.3057)	(2.3378)	(5.0768)	(5.8153)	(3.9528)	(5.2330)	(4.4612)	(4.0816)	(4.0420)	(4.1657)	(4.3781)
Periods	-0.5138^{***}	-0.5554^{***}	-0.3101^{*}	-0.2753	-0.3995^{***}	-0.3806^{**}	-0.4183^{**}	-0.4674^{***}	-0.3936^{***}	-0.3997^{***}	-0.3935^{***}
	(0.1439)	(0.1520)	(0.1604)	(0.1769)	(0.1341)	(0.1576)	(0.1507)	(0.1560)	(0.1380)	(0.1363)	(0.1380)
Seven Years' War		4.0081	-5.2727	-5.3195							
		(4.5193)	(5.1963)	(5.2830)							
Inter-urban price dispersion			48.7559^{**}	56.1036^{**}	37.3944^{**}	38.0591^{**}	37.6982^{**}	37.1505^{**}	36.9392^{**}	39.7145^{**}	38.9570^{**}
			(17.4828)	(22.9189)	(13.4352)	(13.9776)	(13.7359)	(13.5093)	(13.7693)	(14.3898)	(14.5286)
Inter-regional price dispersion				-10.6556							
				(20.9870)							
Mean spring temp.						-0.7999					
						(3.2960)					
Mean annual temp.							1.8914				
							(6.3605)				
Mean summer temp.								3.7315			
								(4.3153)			
Volatility spring temp.									0.0326		
									(0.1028)		
Volatility annual temp.										-0.0672	
										(0.1322)	
Volatility summer temp.											0.1296
											(0.4028)
R^2	0.3377	0.3587	0.5208	0.5263	0.4993	0.5006	0.5012	0.5151	0.5015	0.5049	0.5015
Adj. R^2	0.3112	0.3053	0.4582	0.4402	0.4576	0.4354	0.4362	0.4518	0.4365	0.4403	0.4365
Num. obs.	27	27	27	27	27	27	27	27	27	27	27

$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$. Dependent variable: 5-year volatility of synthetic rye price. Standard errors in (). Heteroscedasticity and autocorrelation tested using Breusch-Pagan and Duban-Watson test, respectively. Only model 1 suffers from Heteroscedasticity. For adjusted standard error see figure 5. Temp.: Temperature.

Table 1: Drivers of aggregate rye price volatility, 1651–1785

5 Conclusion

The aim of the paper was to understand how population in Germany grew to such a high level prior the French Revolution, because a large population was associated with a higher innovation rate from a theoretical point of view (scale effect). We analysed how market integration, measured as inter-urban price dispersion, could have contributed to a higher total factor productivity in agriculture to feed the growing population. As noted in the introduction, authors agree that market integration has positive effects on output (Federico, 2005; Kelly, 1997). Other explanations such as technological change are unlikely to explain the massive increase of agricultural production needed to provide the growing population of Germany with food.

We find increasing price convergence and a substantial moderation of grain price volatility. To our judgement, the results are not affected by weather shocks or climatic change. Against the background of the LIA, we showed formally how weather shocks and climatic change could affect the usually used measure of price convergence, the CoV, and adjusted our empirical strategy accordingly. We diverge from the market integration literature by relying on standard deviations of deflated five-year-mean-prices. The result of increasing price convergence might only be affected if asymmetric developments within the sub-regions again drive the aggregate results. This is not plausible, however, given the already relatively small geographical scale of the sub-regions.

Both inter-urban price dispersion and aggregate grain price volatility exhibited a negative trend for the period 1650 until the French Revolution. The regression model shows that decreasing price volatility was associated with decreasing inter-urban price dispersion, our measure of market integration. Aggregate climate variables instead showed no robust effect on volatility. Given our careful empirical strategy with regard to weather shocks and climatic change, our results show that market integration decreased grain price volatility.

This analysis has several implications for future research. We believe we can present the most comprehensive grain price data set for Germany thus far, allowing for more detailed insights compared to earlier studies. Furthermore, our methodological approach could be applied to other European cases to understand the general relevance of our findings. Moreover, the great moderation of grain price volatility, which we document in this paper, is likely to have increased food security by both decreasing the *level* of mortality related to hunger and increasing the *survival probability*, which again might have affected output growth. It remains open to future research to establish the causality of these effects empirically.

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