WEATHER EFFECTS ON EUROPEAN AGRICULTURAL PRICE INFLATION 1870–1913

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ABSTRACT

This paper considers the non-linear agro-weather price relationship for Britain and Germany during the period 1870–1913. A comparison of Britain and Germany during this period is particularly interesting because of differences in economic structure and trade policy. The share of agriculture in the German economy was significantly larger than in Britain and agricultural protection in Germany contrasts with Britain's unilateral free trade stance. In these circumstances national specific weather shocks are found to have larger sectoral and macroeconomic effects on the German economy.

INTRODUCTION

The relationship between weather and agricultural prices has been extensively studied for the early modern and pre-1850 period (Ashton, 1959; Matthews, 1954; Mathias, 1969; Jones, 1964; Post, 1974; Wrigley, 1989). In contrast, the period of the late 19th Century has been systematically neglected. This neglect does not seem to be justified on the grounds that the agricultural sector was no longer influenced by weather or that agricultural prices were being determined

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only by international markets and not by nation-specific factors, such as domestic weather conditions. Studies of the agro-weather production relationship suggest that there are significant weather effects on agricultural output. In the case of Britain, France and Germany weather shocks account for one third to two thirds of the growth variations of agricultural output during the period 1870–1913 (Solomou & Wu, 1999; Khatri, Solomou & Wu, 1998). Such production effects are likely to feed through to price effects.

These feedback effects are particularly interesting in a comparative setting because of differences in national trade policy. Tariffs create a wedge between the prices of domestic and international agricultural products. Although this is expected to be observed as a price level effect, if the tariff level was high enough this may amount to a prohibitive tariff allowing country-specific weather shocks to have an effect on domestic inflation even in the era of globalization in the late 19th Century. Under free trade, as exemplified by Britain during this period, we expect production effects not to be fully reflected in price movements since imports can take place at international market prices. Nevertheless, even in these circumstances we are likely to observe imperfect substitution between domestic and international goods, such that there will be some price effect arising. Quantifying the magnitude of this effect will be important to understanding the determinants of agricultural prices and domestic inflation. In this paper we compare Britain (a non-tariff country) and Germany (a protected economy) to evaluate the nature of these agro-weather price linkages.

Addressing the nature of the agro-weather relationship offers us an opportunity to study the effects of shocks on the economic system. Neal (2000) has made the important point that economics, like geology, is an historical subject. In considering the coupling of a natural system such as weather shocks with an economic system, such as the fluctuation of output and inflation rates in a weather sensitive sector, we will be better informed on our understanding of inflation within a specific historical period. In addition, the magnitude and nature of weather shocks varied over time allowing us to model how particular shocks affected the economic system. Given the structure of late 19th Century economies, the agro-weather relationship was still central to sectoral movements in output and inflation and had significant macroeconomic implications. In Germany the agricultural sector accounted for approximately 40% of GDP in 1870, declining to 23% by 1913. In Britain the sector accounted for 15% of GDP in the early 1870s, declining to approximately 6% by 1907. This major difference in economic structure between Britain and Germany allows us to glimpse into the implications of the observed agro-weather relationship in present day developing economies. The economic structure of Britain in the early 20th Century is comparable to the economic structure that evolves in most of the major industrial countries after 1950. However, for many developing economies, the kind of economic structure we observe in Germany at the end of the 19th Century is relevant to the present era.

The paper is structured as follows: Section 1 outlines a statistical framework for modelling the effects of weather on sectoral inflation and considers the data being used in the analysis. Since the agro-weather price relationship is expected to be non-linear we employ semi-parametric models to estimate this relationship. Section 2 estimates the weather effect on British and German agricultural prices respectively. Section 3 quantifies the aggregate effect of weather shocks by considering the weighted effect of sectoral weather shocks on the GDP deflator.

1. MODELLING WEATHER EFFECTS ON AGRICULTURAL PRICES

The starting point of our methodology is that the effect of weather on agricultural prices is expected to be non-linear and asymmetric, if only because the effect of weather on agricultural output is observed to be non-linear (Solomou & Wu, 1999; Khatri et al., 1998). A classical approach for estimating this non-linear relationship is to use a low order polynomial, the coefficients of which are estimated by least squares. However, in using this approach, individual observations may exert a large effect on the shape of the estimated function. An alternative approach is the semiparametric smoothing approach, which relaxes the model assumptions in classical regression. Let,

$$y = \mathbf{x}\beta + g(z) + \varepsilon \qquad (1)$$

where y is the dependent variable; $\mathbf{x}$ is the $p \times 1$ vector of linear economic explanatory variables; β is the coefficient matrix; $g(z)$ is the nonparametric function allowing for a non-linear relationship between y and z (in this case various measures of weather); and ε is an iid disturbance term. The effect of weather on prices, g, is expected to be non-linear, but of unknown form. An important property of the nonparametric estimation of weather effects is that the methodology does not assume an a priori form for the dependence of the response on the explanatory variables (an outline of the methodology can be found in Appendix 1; a fuller outline is found in Khatri, Solomou & Wu, 1998).

Our aim is to estimate the magnitude of the effect of weather on aggregate agricultural prices, which can be thought of as a weighted average of crop and livestock prices. Finding a relevant index for the weather conditions influencing the agricultural sector is not straightforward, partly because there does not exist a unique relationship between individual weather measures and agricultural output/prices. The impact of weather on agricultural output/prices depends on a number of factors including rainfall, temperature, sunshine hours, soil type and wind speed (Oury, 1959). Selecting only one element of weather might thus be considered an over-simplification. An index of agricultural drought that relates these different weather inputs may provide a good summary measure of relevant information. The effect of weather on soil moisture levels during the growing period is a key mechanism through which weather conditions affect output. A combination of precipitation and evapotranspiration (evaporation from the soil surface and transpiration from plants) will determine soil moisture levels. Evapotranspiration itself will depend on climate, soil moisture, plant cover and land management (Thornthwaite, 1948; Oury, 1959).

A useful practical index of weather is the soil moisture level during the growing season. Rodda et al. (1976) concludes that soil moisture deficits (SMD) provide the best practical drought index. The most fundamental problem with this approach is the requirement of complex measurements needed to calculate the soil moisture level. Such data requirements limit the availability of soil moisture measurements over long-run time periods to a handful of areas. Extreme deviations from mean SMD in either direction (high values implying drought and low values implying excess moisture) are thus predicted to have adverse effects on output. Wigley and Atkinson (1977) calculate growing season SMD values for Kew back to 1698. In other work we have shown that estimation of the agro-weather production relationship for Britain gives similar results when using the SMD index, annual temperature and rainfall and growing period temperature and rainfall (Khatri, Solomou & Wu, 1998). For simplicity of presentation, here we focus on the results using temperature and rainfall information in the light that the results are not sensitive to the weather data used. Annual average temperature and total rainfall are employed as measures of contemporaneous weather conditions. Lagged effects are also considered; since crops are harvested in the autumn, the weather effects on crop output is likely to have a lagged effect on current crop prices. Thus, we also consider the effect of average temperature and total rainfall in the last growing period.[1]

To avoid the problem of spurious regression, it is necessary to determine the order of integration of the data series to be analysed. Tables 1–3 and Tables 4–6 report the results of ADF tests for the U.K. and Germany respectively. ADF tests suggest that over this period economic variables in logarithms are not trend stationary and are all integrated of the same order ($I(1)$), whereas all weather variables are stationary in levels ($I(0)$). We consider a very simple long-run model where agricultural prices are seen as being co-integrated with import prices and (in the case of Germany) agricultural tariffs.[2] The relevance of this relationship between import prices and domestic prices is discussed extensively in Blake (1992) and Lewis (1978). The empirical evidence suggests

Table 1. ADF Tests of U.K. Economic Series (1872–1913).

	*log*Agr. Prices	*log*Money	*log*Imp. Prices	Critical Value
Without trend				
ADF(0)	−2.23*	1.47	−2.08*	−2.94
ADF(1)	−2.20	0.33	−2.01	−2.94
ADF(2)	−2.15	0.81*	−2.02	−2.94
ADF(3)	−2.07	0.71	−1.90	−2.94
ADF(4)	−2.00	0.78	−1.90	−2.94
With trend				
ADF(0)	−1.10*	−3.85	−0.81*	−3.53
ADF(1)	−0.82	−4.42	−0.87	−3.53
ADF(2)	−0.93	−3.49*	−0.62	−3.53
ADF(3)	−0.91	−3.57	−0.88	−3.53
ADF(4)	−0.35	−3.46	0.47	−3.53

* suggested by the AIC.

Table 2. ADF Tests of U.K. First-differences of Economic Series (1873–1913).

	∇*log*Agr. Prices	∇*log*Money	∇*log*Imp. Prices	Critical Value
Without trend				
ADF(0)	−5.80*	−3.04	−4.90*	−2.94
ADF(1)	−3.30	−3.74*	−3.78	−2.94
ADF(2)	−2.54	−2.94	−2.34	−2.94
ADF(3)	−2.92	−2.85	−2.52	−2.94
ADF(4)	−2.78	−2.34	−2.56	−2.94
With trend				
ADF(0)	−6.82*	−3.06	−5.81*	−3.54
ADF(1)	−4.20	−3.85*	−4.92	−3.54
ADF(2)	−3.50	−3.08	−3.24	−3.54
ADF(3)	−4.44	−3.05	−3.80	−3.54
ADF(4)	−4.70	−2.52	−4.41	−3.54

* suggested by the AIC.

Table 3. ADF Tests of U.K. Weather Series (1872–1913).

	Annual Temp.	Annual Rainfall	Temp. May–Aug	Rainfall May–Aug	Critical Values
Without trend					
ADF(0)	−4.95*	−6.11*	−7.96*	−6.12	−2.94
ADF(1)	−3.08	−4.24	−5.03	−3.22*	−2.94
ADF(2)	−3.11	−2.05	−3.43	−2.64	−2.94
ADF(3)	−2.64	−1.96	−2.82	−2.75	−2.94
ADF(4)	−2.36	−1.55	−2.85	−3.07	−2.94
With trend					
ADF(0)	−5.58*	−6.35*	−8.06*	−6.49*	−3.53
ADF(1)	−3.66	−4.53	−5.20	−3.51	−3.53
ADF(2)	−3.71	−1.98	−3.60	−2.94	−3.53
ADF(3)	−3.26	−1.90	−2.97	−3.12	−3.53
ADF(4)	−2.97	−1.18	−3.02	−3.68	−3.53

* suggested by the AIC.

Table 4. ADF Tests of German Economic Series (1872–1913).

	*log*Agr. Prices	*log*Money	*log*Agr. ImportPrice	Agr. Tariff	Critical Value
Without trend					
ADF(0)	−0.91	0.87*	−2.63	−1.19*	−2.94
ADF(1)	−1.18	0.73	−2.88*	−1.03	−2.94
ADF(2)	−0.17	0.54	−2.86	−0.90	−2.94
ADF(3)	−0.93*	0.33	−2.73	−0.82	−2.94
ADF(4)	−0.72	1.05	−2.76	−0.71	−2.94
With trend					
ADF(0)	−2.01	−3.38*	−1.59	−2.67*	−3.53
ADF(1)	−2.24	−3.59	−2.12*	−2.43	−3.53
ADF(2)	−1.33	−3.53	−2.05	−2.24	−3.53
ADF(3)	−1.68*	−3.49	−1.60	−2.20	−3.53
ADF(4)	−1.43	−2.98	−1.61	−2.05	−3.53

* suggested by the AIC.

Table 5. ADF Tests of German First-differences in Economic Series (1873–1913).

	∇*log*Agr.Pr	∇*log*Money	∇*log*Agr. Import Price	∇Agr. Tariff	Critical Value
Without trend					
ADF(0)	−5.64	−6.02*	−4.28*	−6.90*	−2.94
ADF(1)	−6.07	−5.24	−3.41	−5.08	−2.94
ADF(2)	−3.17*	−4.47	−3.62	−4.07	−2.94
ADF(3)	−3.24	−4.65	−2.88	−3.72	−2.94
ADF(4)	−2.95	−3.19	−3.39	−3.17	−2.94
With trend					
ADF(0)	−5.98	−5.84*	−4.76*	−6.81*	−3.54
ADF(1)	−6.72*	−5.07	−3.98	−5.01	−3.54
ADF(2)	−3.63	−4.06	−4 41	−4.00	−3.54
ADF(3)	−3.94	−4.33	−3.77	−3.65	−3.54
ADF(4)	−3.90	−2.72	−4.56	−3.11	−3.54

* suggested by the AIC.

Table 6. ADF Tests of German Weather Series (1872–1913).

	Annual Temp.	Annual Rainfall	Temp. May–Aug	Rainfall May–Aug	Critical Values
Without trend					
ADF(0)	−4.76*	−6.82*	−6.68	−7.14*	−2.94
ADF(1)	−3.16	−3.84	−6.61*	−4.73	−2.94
ADF(2)	−3.20	−2.68	−4.27	−4.24	−2.94
ADF(3)	−2.16	−2.29	−3.81	−3.97	−2.94
ADF(4)	−2.08	−2.37	−3.41	−4.18	−2.94
With trend					
ADF(0)	−5.20*	−7.20*	−6.64	−7.24*	−3.53
ADF(1)	−3.58	−4.12	−6.72*	−4.89	−3.53
ADF(2)	−3.71	−3.00	−4.42	−4.38	−3.53
ADF(3)	−2.67	−2.63	−3.98	−4.13	−3.53
ADF(4)	−2.57	−2.75	−3.63	−4.41	−3.53

* suggested by the AIC.

a prima-facie case that domestic agricultural prices shared common trends with international prices, reflecting the integration of commodity markets at the end of the 19th Century.

Since weather variables are $I(0)$ whereas agricultural prices are $I(1)$, we estimate the effects of weather on the growth of agricultural prices (i.e. agricultural price inflation) using an error correction model. Table 7 reports the results of the Johansen cointegration tests for Britain. British agricultural prices and import prices are cointegrated.[3] Table 8 presents the Johansen cointegration tests for Germany treating import prices and tariffs as exogenous variables. The variables are cointegrated. Thus, in the long run domestic agricultural prices were being determined by changes in import prices and, in the case of Germany, domestic trade policy.

In using import prices as an important variable we should note that a number of processes determined import prices. Both Britain and Germany were on the gold standard during much of this period,[4] with their exchange rates pegged to gold. However, paradoxically, the period saw significant variations in nominal effective exchange rates (Solomou & Catao, 2000). Alternative exchange rate regimes, such as the silver standard and paper currencies, prevailed in many primary-producing countries – some of which witnessed considerable exchange rate variability (Ford, 1962; Nugent, 1973; Bordo & Rockoff, 1996). In this situation monetary policy in the periphery countries gave rise to nominal exchange rate variations that affected import prices. Variations in import prices

Table 7. Johansen's Test for U.K. Agricultural Price Cointegrating Vector (1873–1913).[5]

H_0	H_a	Statistic	Crit. Val. 95%	Crit. Val. 90%
λmax:				
r = 0	r = 1	10.46	11.47	9.53
λtrace:				
r = 0	r = 1	10.46	11.47	9.53

Table 8. Johansen's Test for German Agricultural Price Cointegration (1873–1913).[6]

H_0	H_a	Statistic	Crit. Val. 95%	Crit. Val. 90%
λmax:				
r = 0	r = 1	17.05	14.35	12.27
λtrace:				
r = 0	r = 1	17.05	14.35	12.27

also reflected the effect of real variables. For example, technological changes resulted in a large fall in shipping costs in the late 19th Century and the development of agricultural production in the 'New World' resulted in large productivity gains for the sector. Since the focus of this paper is on the effect of weather, which is assumed to have a short-term stationary effect, we do not focus on explanations of the long-run movements in import prices; instead we use these long run relationships to form appropriate models for analysing weather effects.

2. ESTIMATES OF AGRO-WEATHER PRICE EFFECTS

Britain

We estimate a semiparametric model of agricultural price inflation. The linear economic variables included are: (a) the growth of domestic money supply to capture macroeconomic effects on sectoral price inflation; (b) the growth rate of import prices, which follows directly from the long-run cointegration model between agricultural prices and import prices; (c) the lagged growth rates of agricultural prices, money supply and import prices to capture autoregressive and lagged exogenous effects; and (d) the error correction term from the cointegration model. In the nonparametric part, we include both the annual temperature/rainfall and the temperature/rainfall over last growing period.[7]

Table 9 presents the results of the best-fit semiparametric model, based on the Akaike Information Criterion.[8] There are two significant weather variables – annual rainfall (capturing a contemporaneous effect) and the rainfall over last growing period. Annual temperature is only marginally significant.[9] As shown in Figs 1–3, whereas the average annual temperature in the current year has a linear effect on agricultural price inflation, the response patterns of both the

Table 9. Statistics of U.K. Semiparametric GAM (1874–1913).[10]

Parametric Part	t-ratio	Pr (> | t |)
∇log Import Price	6.50	0.01
Lagged EC	−4.63	0.01
Annual Temperature	1.62	0.12
Nonparametric Part	Npar F-test	Pr(F)
s (Annual Rainfall, 3)	2.93	0.10
s (Last Growing Period Rainfall, 3)	5.10	0.01

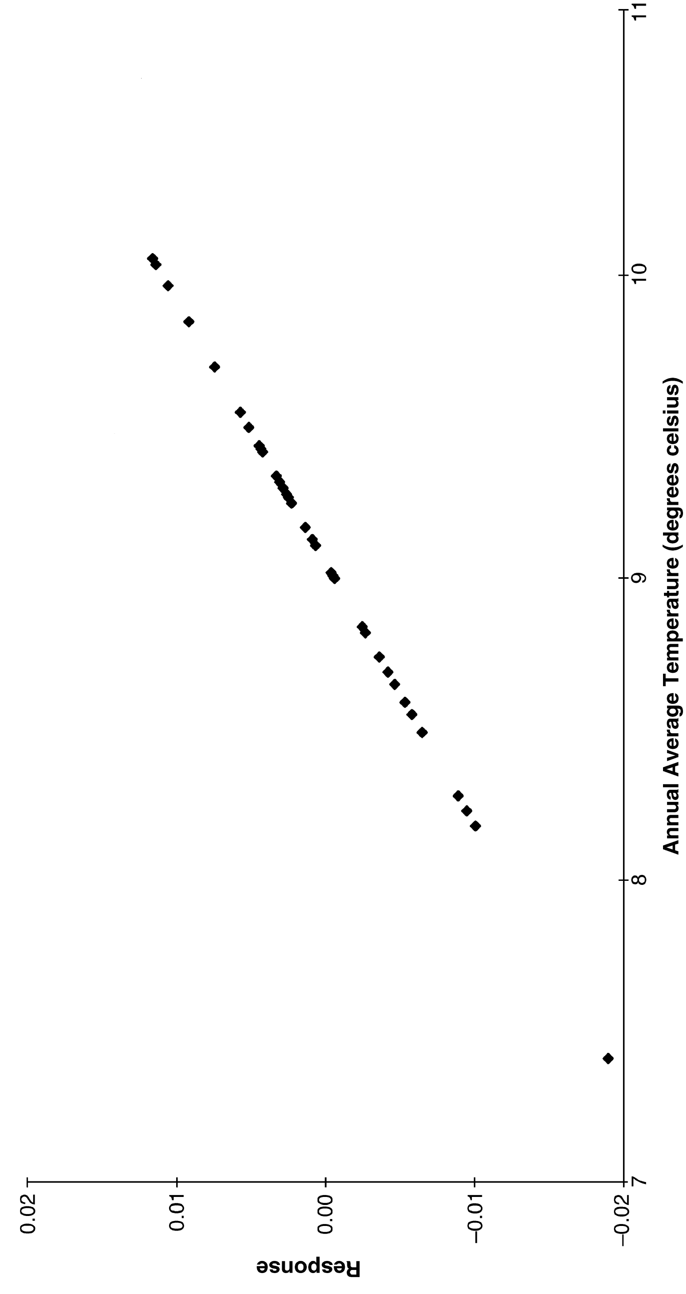

Fig. 1. Temperature Effect on U.K. Agricultural Price Inflation.

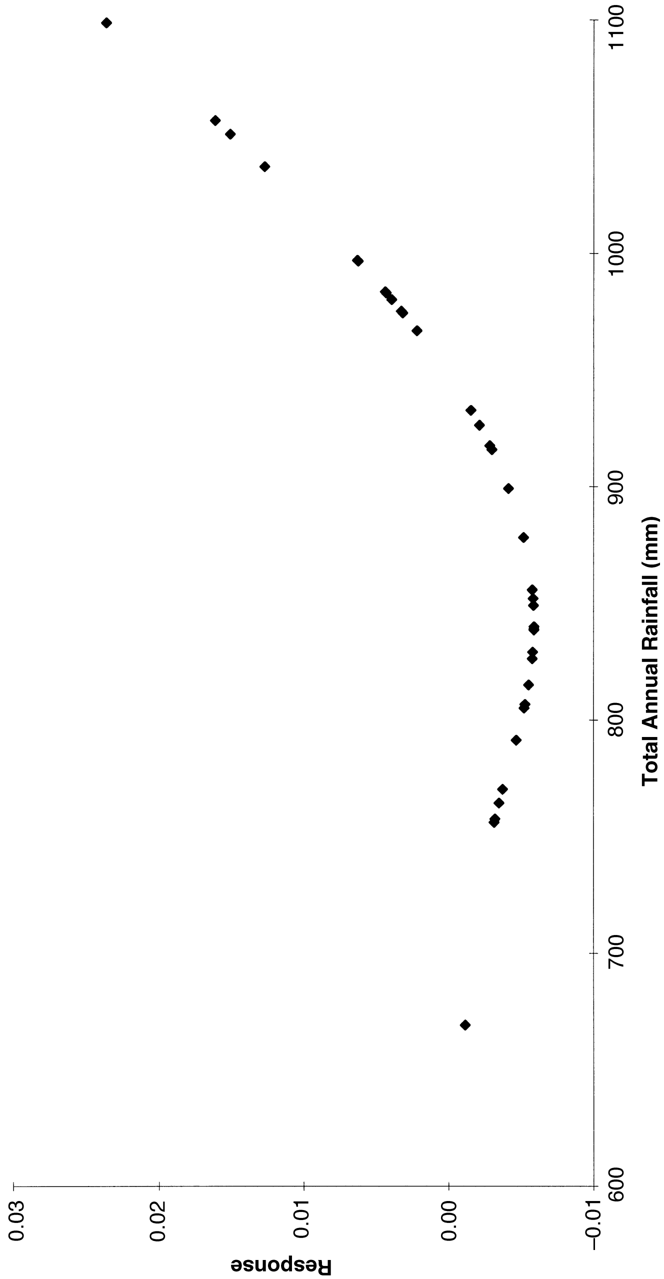

Fig. 2. Rainfall Effect on U.K. Agricultural Price Inflation.

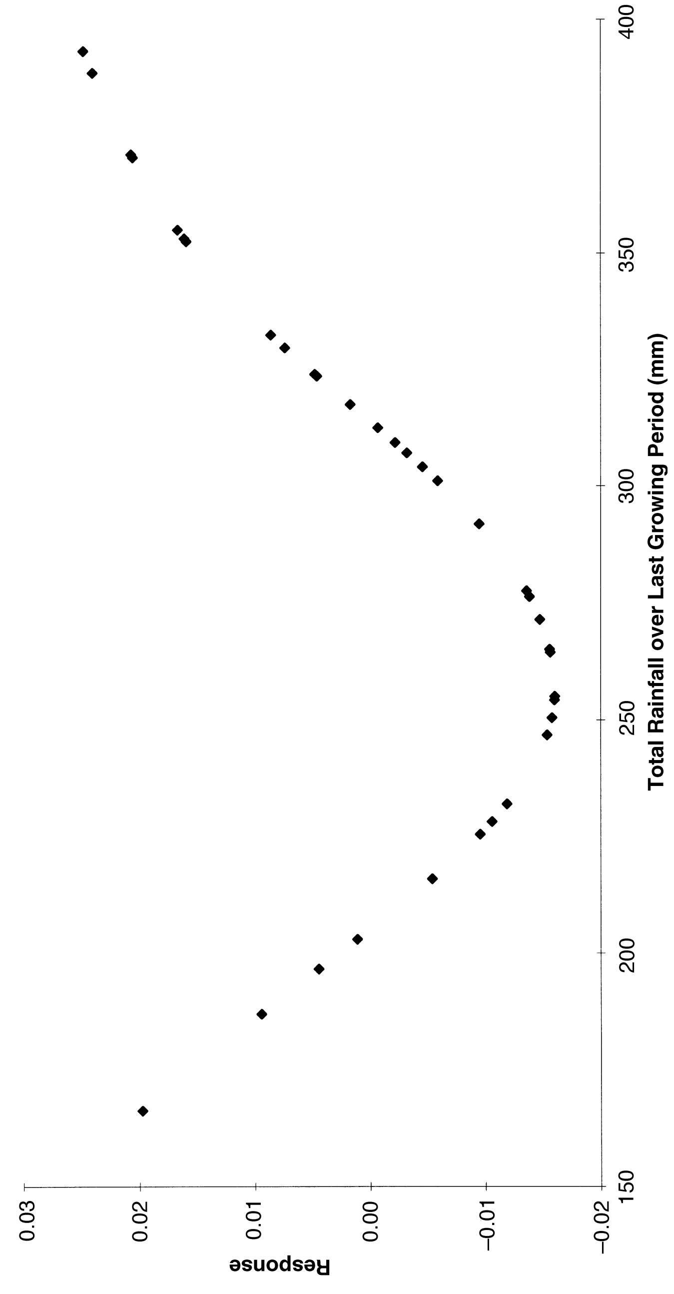

Fig. 3. Rainfall Effect on U.K. Agricultural Price Inflation.

total rainfall in the current year and the rainfall in last growing period are non-linear and asymmetric.

The semiparametric model explains 79.2% of the total variation of the U.K. agricultural price inflation. The weather effects account for 16.5% of the total variation. The total weather effect ranges from –3.0% to +5.0% around the average[11] (see Fig. 4). Although weather continued to have a marked effect on agricultural prices, the effect only explains a relatively small proportion of the total variation of agricultural price inflation. In contrast, weather had a relatively large effect on agricultural output (Khatri, Solomou & Wu, 1998), explaining approximately half the variations of agricultural production. Weather explains less than one sixth of the variations in agricultural price inflation; most of the variation of agricultural prices is explained by variations in import prices. However, weather continued to have an effect, even in an era of free trade. Another robust result is that weather had both contemporaneous and lagged effects on agricultural price inflation, with the lagged growing period rainfall having a significant non-linear effect on price inflation, with low and high rainfall extremes leading to inflationary effects. The existence of lagged weather effects and the fact that weather variations are cyclical adds cyclical impulses to agricultural price inflation rates.

Germany

We consider a similar semiparametric model for Germany.[12] Table 10 reports the results from the best-fit semiparametric model in terms of the Akaike Information Criterion. Three weather variables are statistically significant: annual temperature in the current year, annual rainfall in the current year and average temperature in last growing period. The estimated effect of the contemporaneous annual temperature is linear whist the effects of the annual

Table 10. Statistics of German Semiparametric GAM (1874–1913).[13]

Parametric Part	t-ratio	Pr (> | t |)
∇log Import Price	1.91	0.07
∇log Money	2.66	0.01
Lagged EC	−3.94	0.01
Annual Temperature	1.77	0.09
Nonparametric Part	Npar F-test	Pr(F)
s (Annual Rainfall, 3)	2.74	0.08
s (Last Growing Period Temperature, 3)	4.24	0.05

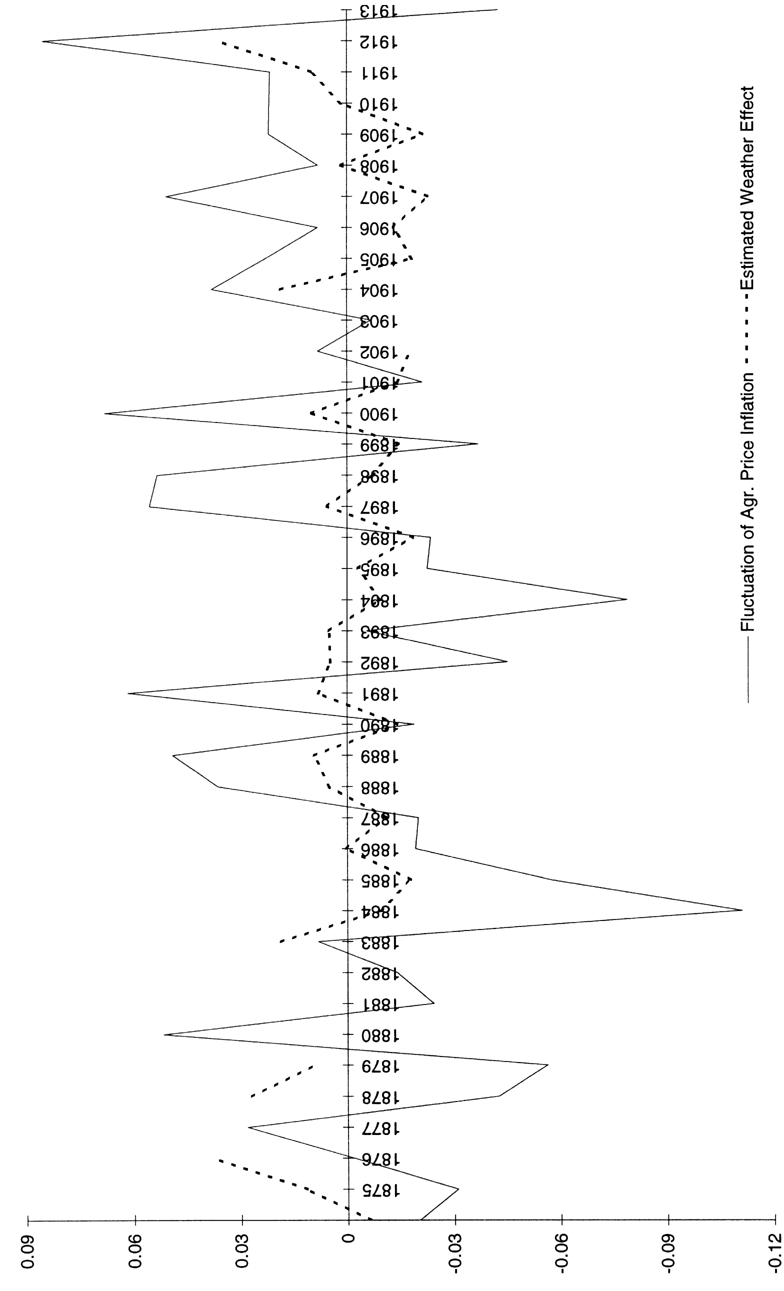

Fig. 4. Fluctuation of U.K. Agricultural Price Inflation and Estimated Weather Effect.

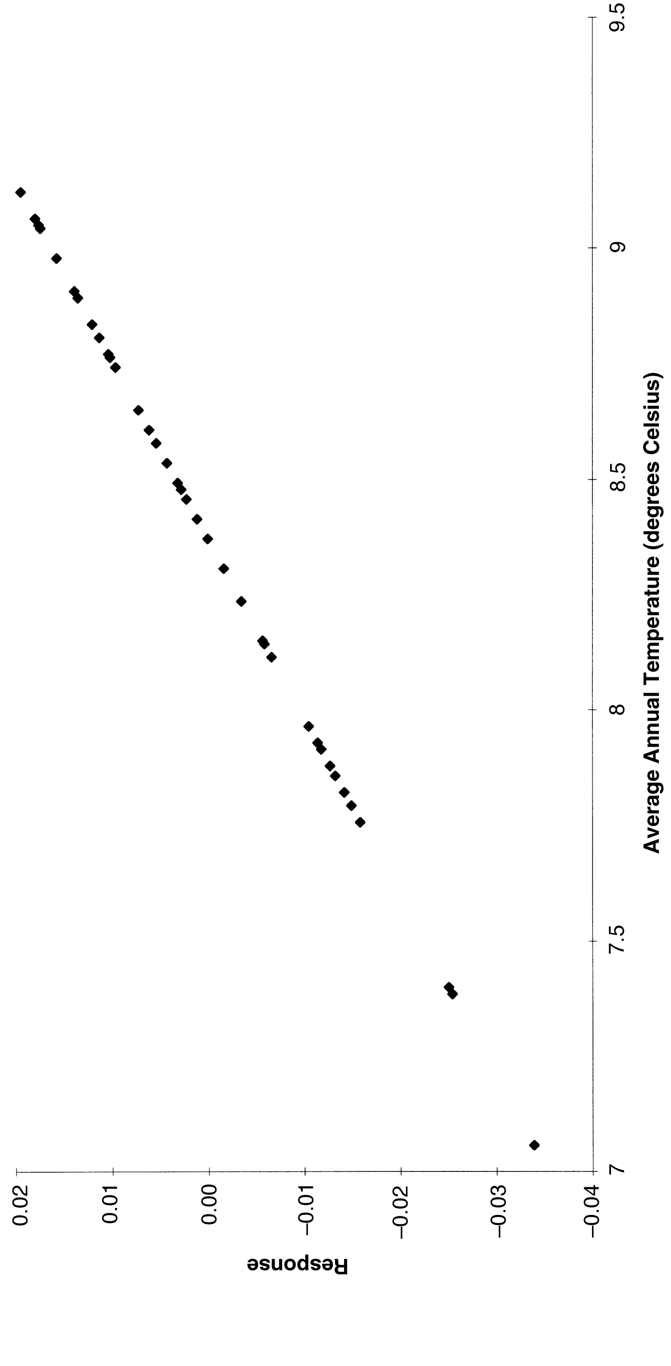

Fig. 5. Temperature Effect on German Agricultural Price Inflation.

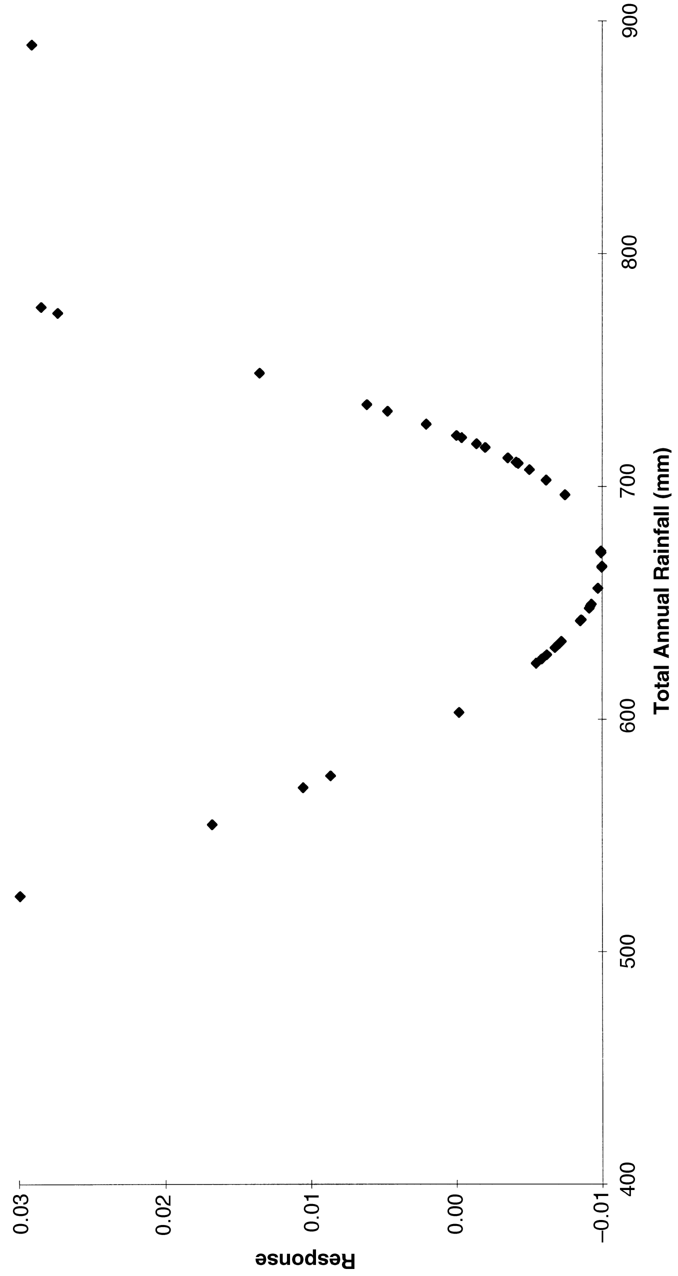

Fig. 6. Rainfall Effect on German Agricultural Price Inflation.

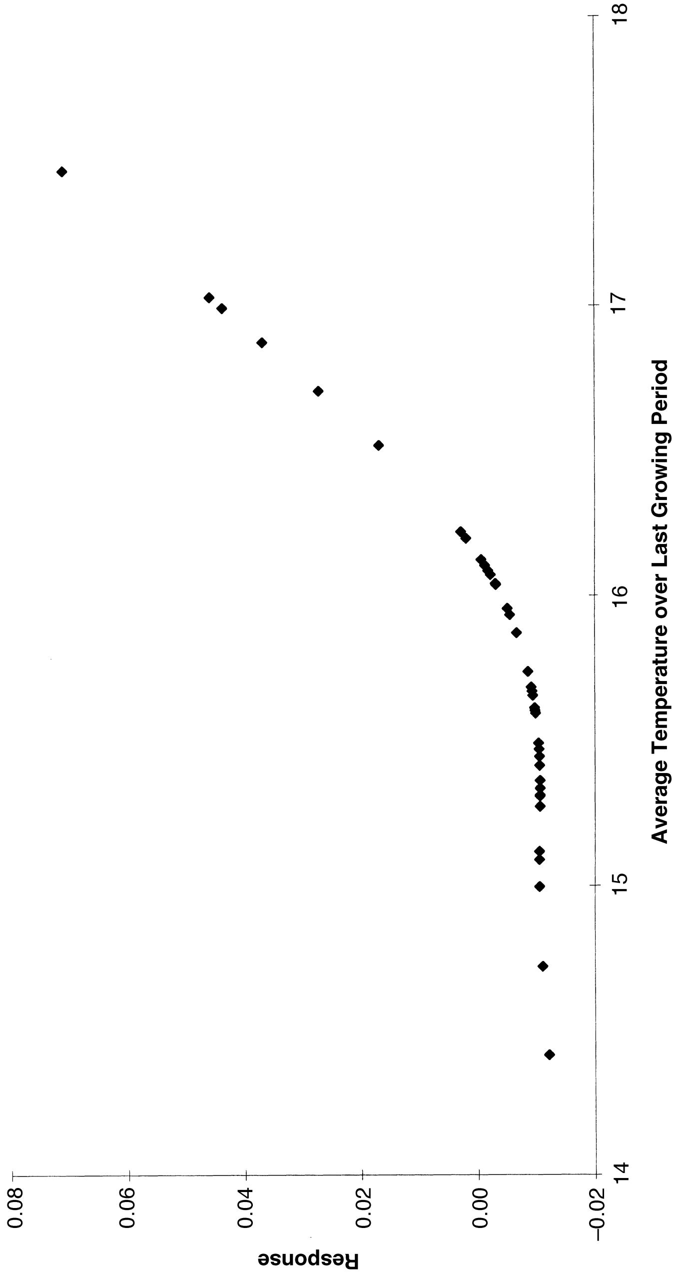

Fig. 7. The Effect of the Last Growing Period Temperature on German Agricultural Price Inflation.

rainfall and average temperature in the last growing period are non-linear.

The semiparametric model accounts for 66.0% of the variations in the growth of German agricultural prices. Weather effects account for 20.5% of the observed variations of agricultural price inflation. The range of weather effects on agricultural price inflation is –4.0% to +6.0% in Germany[14] (see Fig. 8) significantly higher than the estimates for Britain. Comparing the agro-weather output and price effects suggests that in Germany not only was the effect range larger on prices but the output and price effects are of comparable proportions: weather shocks explain about one fifth of the variations of German agricultural output (Solomou & Wu, 1999).[15] A similar proportion is reported here for prices. In contrast, in the case of Britain, weather variations explain over half the variations in agricultural output but only approximately one sixth of variation in price inflation.

3. WEATHER EFFECTS ON AGGREGATE INFLATION

During the period 1870–1913 weather shocks were important to the observed fluctuations of agricultural price inflation. The impact of these sector-specific effects on the macroeconomy will depend on the magnitude of the sector-specific inflationary effect and secondly, the relative weight of the sector in the macroeconomy (and, implicitly, changes in the sectoral shares over time). In this section we consider the aggregate effect of weather shocks by weighting the estimated effect using the sector's share in GDP, as a way of quantifying the impact of weather shocks on the GDP price deflator.

The sectoral shares in GDP are plotted in Fig. 9. In the case of Britain a combination of a relatively small weather effect and a relatively small (and declining) share for the sector in GDP suggests that the effect of weather shocks on aggregate price inflation was small. The range of weather effects on aggregate inflation during 1870–1913 was around –0.2% to +0.66% (see Fig. 10). For most of the period between 1880 and 1913 the effect range was around ±0.2%. Since the standard deviation of the inflation rate of the GDP deflator during 1870–1913 was 2.39%, the sector accounts for a relatively small proportion of aggregate domestic inflation.

In the case of Germany a very different picture emerges. The relatively large effect range of weather shocks on sectoral inflation and the large weight of the agricultural sector in GDP, result in a large effect on aggregate inflation. The inflation rate of the German GDP deflator ranged between –6.3% and +7.8%; the standard deviation of the inflation rate being 3.0%. The range of the weather effect on agricultural price inflation was –1.5% to +1.8%; the standard deviation

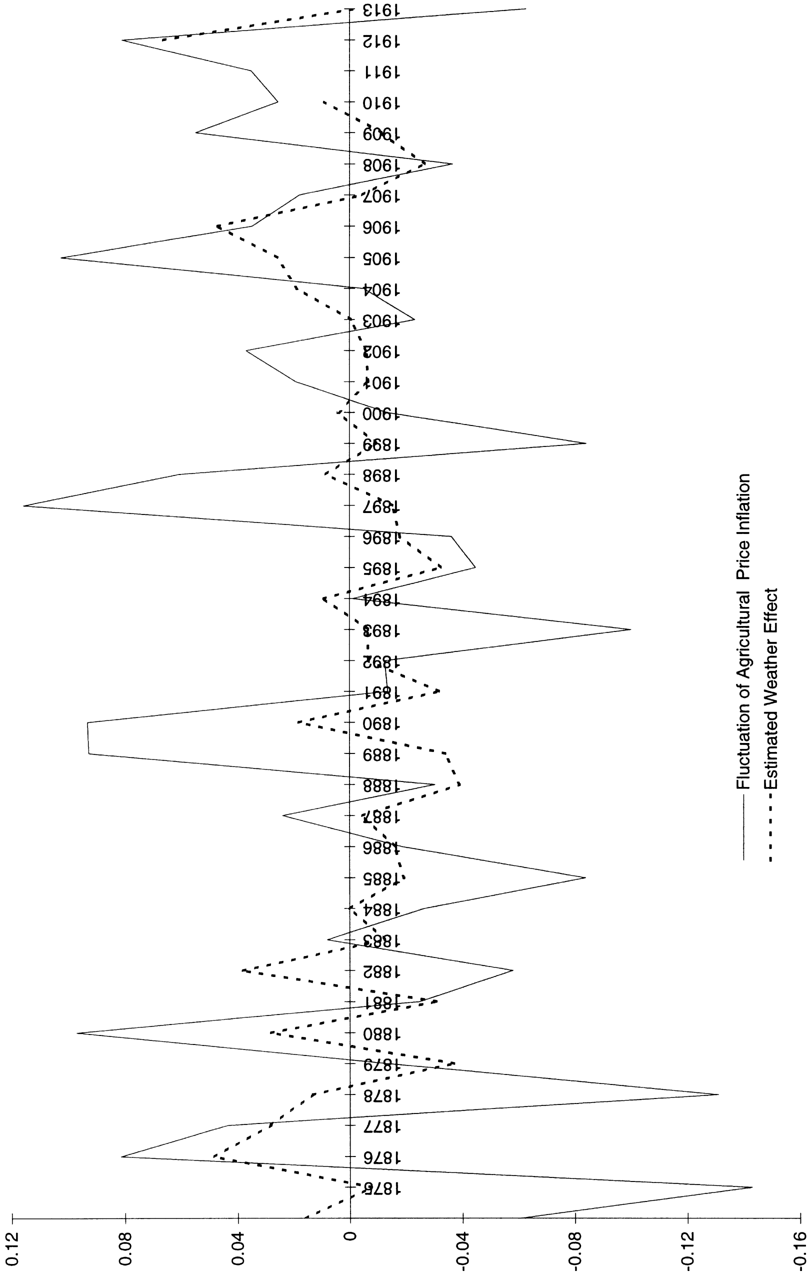

Fig. 8. Fluctuation of German Agricultural Price Inflation and Estimated Weather Effect.

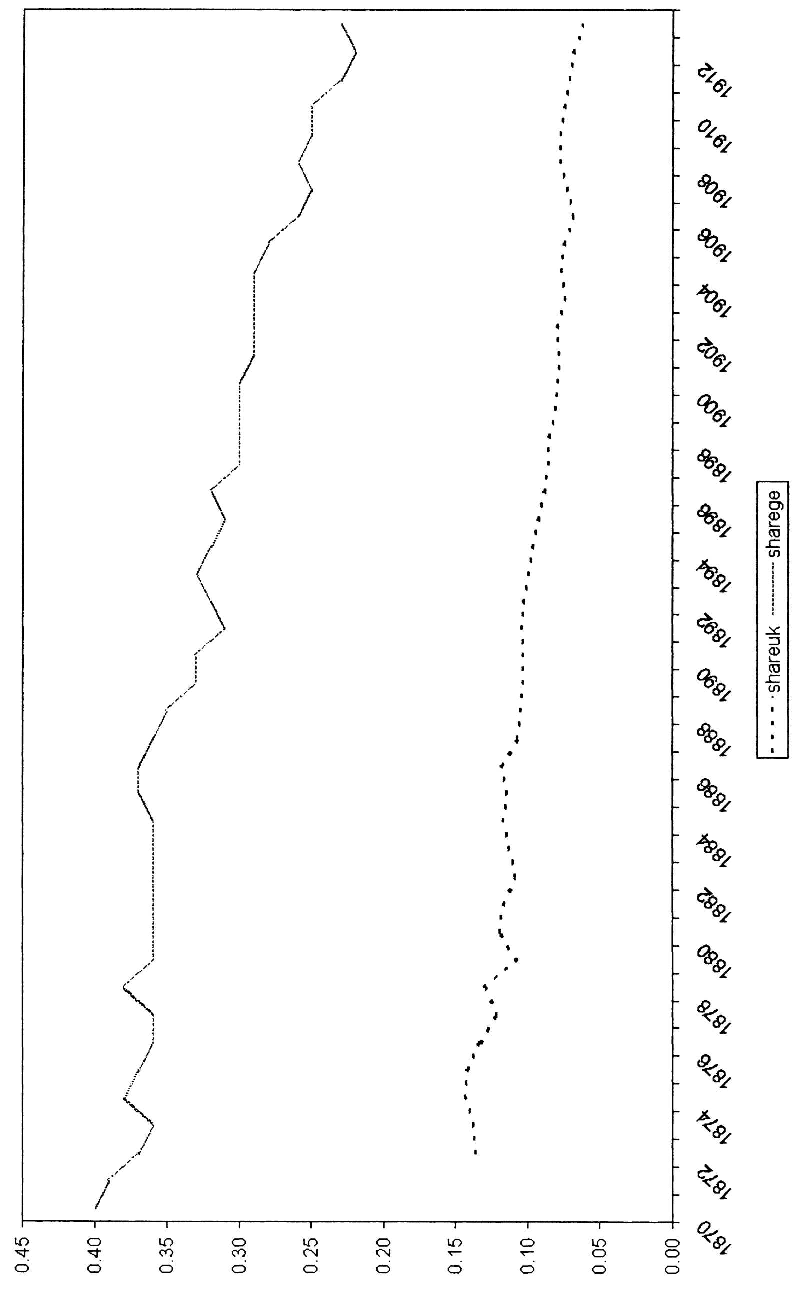

Fig. 9. Share of Agriculture in GDP.

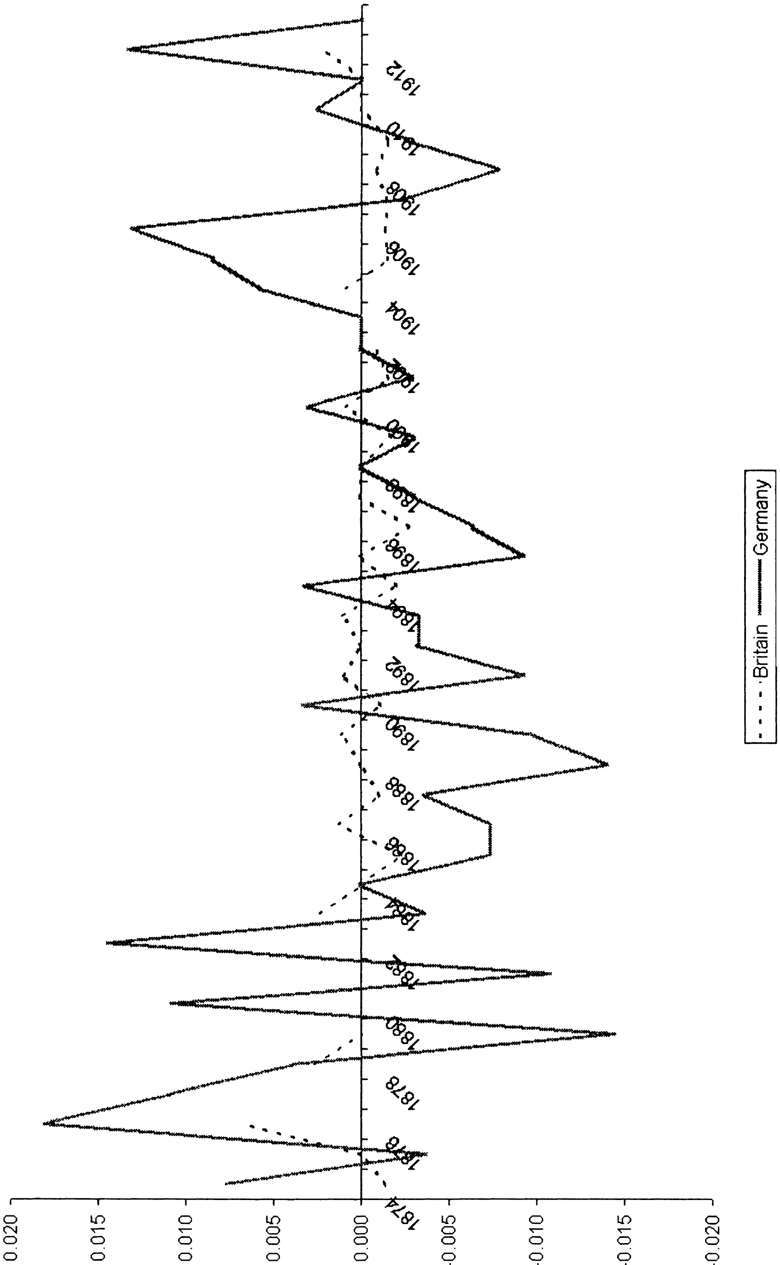

Fig. 10. Weighted Effect of Weather Shocks on GDP Price Deflator.

of the weather effect on aggregate inflation being 0.8%. Thus, weather shocks to agriculture can account for approximately one quarter of the variations in aggregate domestic inflation.[16]

CONCLUSIONS

Sectoral Inflation Rates and the Agro-weather Relationship

The agro-weather production relationship had significant effects on agricultural price inflation. In an era when aggregate inflation rates were low the agricultural sector saw larger variations, partly induced by weather effects and partly by large variations in import prices.

Agro-weather Effects are Cyclical

A number of processes added cyclical effects on agricultural price inflation. First, weather follows a cyclical path. Hence, the agro-weather linkages will generate cyclical effects on the sector. Secondly, weather has both a contemporaneous and lagged effect on agricultural prices, affecting the propagation mechanism of shocks.

The Macroeconomic Effects of Weather on Aggregate Prices

The two country comparisons reported in this paper illustrate that the macro effects of weather shocks remained large during the period 1870 to 1913. Britain was exceptional in that its economic structure differed from that of Europe; a very small agricultural sector and a free trade stance implied that domestic agricultural prices were mainly being determined by import prices. The results reported for Germany are likely to be more representative for the European economies, with large agricultural sectors and agricultural protection. The contrasting policy and economic structures for Britain and Germany also offer interesting insights into the agro-weather relationship of modern day developing economies. The results for late 19th Century Germany will be replicated in a similar way in modern day relatively closed developing economies.

NOTES

1. Because the rainfall data during this period are available only at a monthly frequency, we define the growing period for both countries as the duration May–August. In practice there will be some differences, which can only be captured with higher frequency data.
2. We also considered models allowing for more macroeconomic information, such as the money supply. However, such models were not co-integrated.

3. On theoretical grounds we assume that import prices are exogenous to domestic agricultural prices.

4. Britain was on the gold standard throughout 1870–1913 and Germany during 1879–1913.

5. Import prices are treated as an exogenous variable. The cointegration model was one of unrestricted intercepts and no trend in the VAR. Order of VAR = 1.

6. Agricultural import prices and agricultural tariffs are treated as exogenous variables. The cointegration model was one of unrestricted intercepts and no trend in the VAR. Order of VAR = 1.

7. We also considered the lagged weather effects using annual weather data. In the case of Britain only the lagged growing period weather information proved significant.

8. The statistical methodology we employ is within a general to specific framework. The initial models allowed for a wider set of economic and weather variables. The final reported results are based on model selection using the AIC (Akaike Information Criterion.

9. All three variables are retained because they jointly improve the fit of the semi-parametric model.

10. The sample excludes four observations with extreme annual rainfall larger than 1140mm or rainfall over last growing period larger than 460mm.

11. British agricultural price inflation rates range from –11.1% to +8.5% around the average.

12. The average agricultural tariff rate in Germany follows a step function. We therefore assume that the tariff has a long run impact on the price level rather than the inflation rate. Any effect on agricultural price inflation will be via the error correction component.

13. The sample excludes one observation with annual average temperature larger than 9.6 °C.

14. Over the period, the inflation rate of German agricultural prices is more volatile than the British rate, ranging from –14.3% to +11.6% around the average.

15. Using decomposed weather data the effect of weather shocks and cycles increases to one third of output variations. However, the limited degrees of freedom prevented us from using decomposed weather data in the estimated price models. Hence we compare the results from untransformed weather data.

16. Aggregate models of weather and inflation give similar results to this sectoral accounting methodology (results are available on request).

17. A specific agricultural import price index is not available. We use the total import price index on the assumption that the largest component of British imports was food and raw materials.

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APPENDIX 1

Semi-parametric Modelling the Effects of Weather on Agricultural Prices

The semiparametric approach relaxes the assumptions behind classical regression models and offers a useful methodology for modelling non-linear relationships. The presentation here draws on the work of Engle et al. (1986). Let,

$$y = \mathbf{x}\,\beta + g\,(z) + \varepsilon \tag{1}$$

where y is the dependent variable; $\mathbf{x}$ is the $p \times 1$ vector of linear explanatory variables; β is the coefficient matrix; $g\,(z)$ is the nonparametric function allowing for a non-linear relationship between y and z; and ε is an iid disturbance term.

Denote y_t as log of agricultural prices, $\mathbf{x}_t$ as the vector of economic variables, β as the corresponding parameter vector for $\mathbf{x}_t$, and $\mathbf{z}_t$ as the vector of weather variables. Then, we can rewrite (1) as:

$$\begin{aligned} y_t &= y_t^e + y_t^w \\ y_t^e &= \mathbf{x}_t\,\beta + \eta_t^e \\ y_t^w &= g\,(\mathbf{z}_t) + \eta_t^w \end{aligned} \tag{2}$$

where y_t^e and y_t^w are the effects of the economic and weather variables respectively.

An important property of a smoother is its nonparametric nature: it does not assume a rigid form for the dependence of the response on the explanatory variable(s). With a set of observations, a possible criterion of ‘fit’ for the curve is the sum of squared residuals,

$$\sum_i \left[y_i^w - g\,(\mathbf{z})\right]^2 \tag{3}$$

where $g(\mathbf{z})$ is unconstrained. This measure is zero if $g(\mathbf{z})$ interpolates the data. However, such a curve will be too ‘wiggly’ to be consistent with priors on the shape of the function. As a way of deriving a smoother relationship we can add a term to (3) to penalise for the lack of smoothness. There are many different ways of measuring how ‘rough’ the curve g is. If g is twice differentiable, an intuitively appealing way is to calculate its integrated squared second derivative on its definition interval. The cubic spline is defined for the case where the roughness penalty is the integral of the squared second derivatives of $g(\mathbf{z})$. In this case the penalised least squares estimator is to minimise the cost function

$$S(g) = \sum_i [y_i^w - g(\mathbf{z})]^2 + \lambda \int [g''(\mathbf{z})]^2 \tag{4}$$

Thus, the cost $S(g)$ of a particular curve is determined not only by its goodness-of-fit to the data as quantified by the residual sum of squares but also by its roughness measurement. Such smoothness priors represent information that the unknown function does not change slope abruptly. λ represents the 'rate of exchange' between residual error and smoothness. If λ is zero (i.e. no smoothness penalty) the solution is any interpolating set of functions whose evaluations satisfy (3) above. On the other hand, if l goes to infinity, the penalty term goes to infinity unless the second derivative is zero (i.e. unless each g is linear, allowing estimation using standard linear least squares).

A linear model is additive in the predictor effects. Hence, once we have fitted a linear model we can examine the predictor effects separately, in the absence of interactions. For analytical convenience we assume that y_t^w is estimated using a general additive model (GAM), which retains the additive feature for non-linear predictors. Thus, the effect of weather, generalising to a number of weather variables, can be presented as

$$y_t^w = \sum_k g_k(z_{kt}) + \eta_t^w \tag{5}$$

where the g_k is a univariate function for each predictor variable.

Within the GAM framework, there are a total of $p + q$ explanatory variables: a p-vector of linear variables and a q-vector of splined variables. Thus, the cost function of the partial spline can be rewritten as

$$\begin{aligned} S(\beta, g) &= (\mathbf{y} - \mathbf{X}\beta - \sum_k \mathbf{g}_k)^T \mathbf{W}(\mathbf{y} - \mathbf{X}\beta - \sum_k \mathbf{g}_k) + \sum_k \lambda_k \int g_k''^2 \\ &= (\mathbf{y} - \mathbf{X}\beta - \sum_k \mathbf{g}_k)^T \mathbf{W}(\mathbf{y} - \mathbf{X}\beta - \sum_k \mathbf{g}_k) + \sum_k \lambda_k \mathbf{g}_k^T \mathbf{K}_k \mathbf{g}_k \end{aligned} \tag{6}$$

where, having T observations, $\mathbf{y}$ is the $T \times 1$ vector of y, $\mathbf{g}_k$ is the $T \times 1$ vector of g_k, $\mathbf{K}_k$ is a quadratic penalty matrix for corresponding predictor z_k. Each function is penalised by a separate constant λ_k. This function is easily minimised to give the estimates of the parameters β and the vector g. To select the optimal λ, Engle et al. (1986) suggest a generalised cross-validation (GCV) criterion:

$$GCV = \frac{RSS_\lambda}{(1 - K/T)^2} \tag{7}$$

where RSS_λ is the residual sum of squares for the given λ, K is the equivalent number of parameters $\mathrm{tr}(\mathbf{A}(\lambda))$, and T is the number of observations.

APPENDIX 2: DATA SOURCES

Britain

The weather data relate to daily central England temperatures (Parker et al., 1992) and monthly central England rainfall (Wigley et al., 1984). The following economic series were used:

(a) The agricultural price index is the Sauerbeck Price index reported in Mitchell (1962);
(b) Import prices are from Feinstein[17] (1972, Table 64);
(c) The money supply, M3, from Capie and Webber (1985).

Germany

The temperature series is calculated from available station records in the file ADVANCE-10K, downloaded from the homepage of the Climate Research Unit at the University of East Anglia. The ADVANCE-10K contains the station emperature data for the E.U. research project "Analysis of Dendrochronological Variability and Associated Natural Climates in Eurasia – the last 10,000 years" (ref. no. ENV4-CT95-0127). The following stations are included: Leipzig, Dresden, Jena, Erfurt/Bindersleben, Kiel, Hannover, Berlin, Frankfurt a Main, Darmstadt, Bayreuth, Karlsruhe, München/Riem, Friedrichshafen and Hohenpeissenberg.

The rainfall series are calculated from the available records of the following German stations: Bamberg, Berlin-Dahlem, Emden-Hafen, Gutersloh, Halle, Husum, Kalkar, Lingelbach, Loningen, Mergentheim, Regensburg and Trier-Petrisberg (source: CD-ROM "World Climate Disc: Global Climate Change Data" by the Climate Research Unit at the University of East Anglia).

The Following economic data were used:

(a) Agricultural prices are from Weber (1973);
(b) Money supply figures are from Mitchell (1992). An aggregate series is constructed as the sum of the three components: Banknote Circulation, Deposits in Commercial Banks and Deposits in Savings Banks;

(c) Agricultural import prices are calculated from Desai (1968, Table A24). The index is constructed as the average of the import price of food grains and the import price of other food, drink and tobacco. The weights used are taken from Desai, 1968, Table C.1;

(d) Agricultural tariff rates are the average tariff rates on pigs and crops. This is calculated using Webb (1982).