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ON THE PRODUCTION ECONOMICS OF CATTLE

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by

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Introduction

Two empirical regularities in the beef-cattle sector have been observed for a long time. First, the time-series for cattle stock exhibits strong cyclicity with a period of several years. Second, beef supply seems to be negatively related to price.

Following Jarvis (1969), the key to the explanation of the dynamics of this sector is the observation that cattle is both capital and consumption good. Optimal allocation of the present stock between current and future consumption has to satisfy an arbitrage condition that equates the current price with the expected price for the next period, where the latter reflects the present expectation of future supply and demand. Shocks cause differences between expected and realized prices and production decisions are taken accordingly.

As noted by Rosen Murphy and Scheinkman (1994), (RMS, 1994), the cattle model differs from the storage model in that the building up of depleted stocks is a gradual process due to the biological constraint. This constraint reflects technological parameters that determine the relationship between the size and composition of the breeding herd and output, Chavas and Klemme (1973), Whipple and Menkhaus (1989), Foster and Burt (1991). The technology also determines, together with the demand, the parameters of the arbitrage condition and thereby it affects the quantity slaughtered and the price.

In spite of the importance of technology, there is no empirical model that fully captures the role that it plays in determining the dynamics of the sector. In this paper we

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want to gain insight on this issue by analyzing data for three countries with different technologies: Argentina, Uruguay and the United States. We do it by studying the behavior of four series: slaughter (or current consumption), price (of slaughtered cattle), stock of cows of breeding age (hereon cows) and stock of total herd (hereon herd).

The starting point is similar to earlier studies, an attempt to summarize the biological constraint in terms of an empirical production function. The outcome is not very informative because an accurate description of the process requires to include in the production function more lagged values of cows than the data can support. We therefore shift to a less demanding approach based on binary measures of autocorrelations and cross-correlations of the four series. This provides a good description of the time series properties of the data. Also, we explore the cyclical behavior of cattle by peak analysis of spectral density. Finally, the strong emphasis on demography raises the question on the role of prices in supply decisions. We evaluate this question empirically.

It is striking that in spite of the wide differences in technologies, key cyclical properties for the United States and Argentina are almost identical, and those for Uruguay are not much different. Another important result is that the smoothing of consumption in response to shocks carried out through stock adjustment does not preclude the cyclical behavior of consumption to the extent that the cycle of slaughter conforms to that of stocks. This is in contrast to the common case in other sectors where consumption smoothing eliminates or greatly reduces the cycles in this variable.

We begin with a short literature review that brings up the main issues in the study of the cattle sector. The rest of the paper concentrates on an empirical examination of the biological constraint, its reflection in the time-series properties of the data, the strength of the spectrum as a criterion for evaluating the quality of a model, the role of prices and the question of the supply response. The discussion is then used to propose an approach for the analysis.

Literature review

The existence of cycles in beef and hog prices and quantities is documented in the works of Brenner (1876), Thomsen (1936), Coase and Fowles (1937) and Lorie (1947). The problem was perceived as an expectation problem, thus Ezekiel (1938) formulated a dynamic system where the lagged price is the predictor for current price. His cobweb model predicts cycles of lower length than those actually observed. Thinking of the problem as that of price expectation led to modifications, and in fact improvements, in the formulation of expectations formation, which eventually resulted in Muth (1961) rational expectations. However, with all the virtues of rational expectations, it remains yet to be demonstrated the extent to which it helps to understand the cattle cycle.

The concern with negative supply response is more recent. It has been connected to an important attribute of livestock production that cows constitute both a capital good and a consumption good. Jarvis (1969, 1974) was first to formulate the decision to slaughter within the framework of capital theory. He was concerned with the sensitivity of the optimal weight to prices as a key to the understanding of the negative supply response. "...the immediate response of both heifer slaughter and calf slaughter to an increase in the price of beef is negative. A higher price, or lower feed costs, makes it profitable to feed heifers to heavier weights and to retain cows for calf production." (Jarvis, 1986, p. 10). He differentiates between a transitory and long run price effect and between production response and supply response. However, he does not take a full account of the arbitrage conditions. As we shall see below, the supply analysis should explain not only the slaughter but also the changes in inventory. Such an empirical analysis by Reutlinger (1966) had preceded the theoretical development.[2]

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[2] "A property of the heifer and cow components of beef supply is that they slaughtered for consumption or retained as investment to build up inventories" Reutlinger (1966, p. 909).

Viewing cattle as a capital good shifted attention to the role of stocks and population dynamics and their effect on empirical analysis. Carvalho (1972) and Nerlove, Grether and Carvalho (1979) used a dynamic programming framework to derive inventory demand and supply functions for producers who maximize the expected discounted value of profits over time. The importance of the biological constraints in the determination of the cattle cycle is emphasized by Rucker, Burt and LaFrance (1984).[3] Chavas and Klemme (1986) illustrates the importance of demography.[4]

Rosen (1987) formulated a compact model that emphasizes the core of the problem: changes in supply that occur through changes in the number of cows slaughtered determined by market equilibrium under rational expectation. An important result of his analysis is that the effect of a demand shock depends on how it is perceived by producers. If they perceived it as transitory, they will respond by increasing the number of slaughtered cattle, whereas if it is perceived to be permanent, they will do better by building up their stock of breeding cows first and take advantage of the shift in demand in the future. He differs from Jarvis (1974) in that the response is in the number of slaughtered cows, and not in the age of slaughter.

Favaro (1989) also questions the flexibility that farmers, as a whole, have in postponing the slaughter age in response to market conditions and supports this position with empirical evidence. He applies and extends the Rosen framework by introducing

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[3] "The persistence and regularity of the "cattle cycle" is apparently rooted in producer responses under biological constraints on production, particularly in conjunction with changing age distribution in the herd caused by recent perturbation in economic variables" (Ibid. p.132)

[4] Additional studies: Maki (1962, 1963), Lattimore and Schuh (1979) for Brazil, Sapelli (1985) for Uruguay. Fisher and Murno (1983) show a positive relationship between desired inventories and expected prices. Rucker et al. (1984) obtained a positive response of inventories to prices for the United States. See also Paarsch (1985), Trapp (1986), Whipple and Menkhaus (1989).

population dynamics that takes an explicit account of the age distribution of the stock of cows as an essential ingredient for generating cycles, to develop a dynamic model of the Uruguayan cattle sector. He also adds feed constraint to the model and deals with the optimal use pasture by cattle and sheep.

RMS (1994) further develop Rosen (1987) by incorporating the biological constraint and summarize the dynamic of the system in two difference equations, the arbitrage condition and the biological constraint. In summarizing their paper they state that "The low fertility rate of cows and substantial lags and future feedbacks between fertility and consumption decisions cause the demographic structure of the herd to respond cyclically to exogenous shocks in demand and production costs" (p.468).[5] This is a rather rich set of factors and it remains to be unveiled what is the partial qualitative and quantitative effect of each of these factors.

Foster and Burt (1992) examine the sequential decisions and biological constraints for the United States and suggest that "...the greatest response from an increment to price in period t occurs on January 1 of period t+2 rather than t+1 because a replacement of heifer is typically between one and two years old." (p.422). They then go on to explain the pattern of the lagged response. Their analysis, based only on the supply side, suggests a 12-13 year cycle but they say that this result is obtained without taking demand into account.

An upshot of the current work is that when more cows are slaughtered today to meet an unexpected increase in demand, fewer cows are left for tomorrow, implying a reduction of the number of calves born next year and thereby a possible reduction of the capital stock. A reversal of this decision requires time. This tradeoff between consumption and the build up of the capital stock is not commonly observed in other

[5] The reference to the low fertility rate as a factor is inconsistent with the quotation from Jarvis that appears below.

sectors and in this sense the cattle sector is different. However, interestingly, the same feature exists for the (closed) economy as a whole where there is a tradeoff between investment and consumption. The analogy stops when it comes to the source of the variability. The shocks in agriculture come mainly from the supply generated by weather conditions, and it is this assumption that drives the storage model, (Williams and Wright, 1991). On the other hand, demand shocks play an important role in non agriculture.

Technology and environment

Beef is produced by beef cattle as well as a by product of dairy production. We deal here with beef cattle. The fact that there is another source of supply is important when matching the demand and supply, because the net demand for beef from the beef cattle depends on the supply from the dairy cattle. In the beef herd, male calves are raised for the market except for a small fraction that are kept for breeding purpose. Females calves are raised for breeding purpose as a replacement to cows and for herd expansion when needed. The rest are prepared for the market.

In principle, the technology is quite simple, but the numerical values of the parameters in question are not well defined as can be seen by reviewing the literature. Two facts stand out: first, there is a great deal of variability within a country, reflecting dependence on exogenous factors such as weather; and second there has been technological and management changes over time that changed the values of the parameters

In the United States, production is divided between pasture-based breeding herd and between fattening mainly in feedlots. "In general, cattle are nearly two years old when they bear their first offspring. The heifers replacement data, however, reflect a mixture of one- and two-year-old animals, .."(Foster and Burt, 1992, p. 420). The fertility rate is about .9 (Trapp, 1986, p. 693), a cow is reproductively viable for a period of eight to ten years. An animal reaches a slaughter weight in 18 months after birth.

In Argentina, "Cattle are raised chiefly on natural or seeded pasture, forage crops, and some byproducts of grain production. Cattle are rarely fattened on harvested grains. ... 80 percent of Argentine's cattle production and 90 percent of the traditional field crop production takes place in the Pampas,..." Jarvis (1986, p. 1). The rest of the beef is produced mostly in provinces bordering Uruguay under similar conditions to those in Uruguay. "The quality of the Argentine cattle herd is superb: ... Nevertheless... Compared to the United States, the calving rate is lower, animal disease and mortality rates are higher, natural pasture are used more frequently than seeded one, there is almost no feeding lots,...This reduces the efficiency and therefore, the level of production and slaughter which might otherwise achieved." (Op cit. p. 2)

"Female calves have a distinctly bimodal optimal slaughter age because *more female calves are born than needed for replacement purposes in the breeding herd* (the italics is introduced by the authors). As a result some female animals are slaughtered as fattened heifers, ..., before they bear calves and some are slaughtered only after their value as breeding animals has declined...." (Op cit p. 10).

The fertility rate depends largely on the availability of pasture which in turn depends on the weather conditions. For instance, for the period 1937-1963, Yver (1971, p.73) reports variations in fertility rate for Argentina in the range of .51 to .76. The rate is sensitive to the age distribution of cows which in turn is affected by the prevailing prices. "In short, producer price response altered the age distribution of slaughtered animals ..." (Jarvis 1986, p.24). In constructing a data set he assumed a rate of .72. At the present, the prevailing number is around .8. The productive life of a cow is six to eight years. The supply shocks are important, for instance, "The Argentine droughts in 1950/51 and 1952/53 prompted herd reductions in these years." (Op cit P. 40). This may suggest that it is not the level of the fertility rate but its variability which contributes to the cyclicity.

Production in Uruguay relies completely on natural pastures and there is no supplementary feeding. The area of natural pasture limits the total supply of feeds and determines the seasonal distribution during the year. Absence of pasture during the winter provokes retardation in the process of fattening an animal and extends the length of the period necessary to mature it to completion. It also generates a seasonal pattern in slaughter and the price of cattle. To fully utilize the pasture, cattle is raised jointly with sheep. A cow is reproductively viable for a period of four to five years. An animal reaches a slaughter weight in four to four and a half years. The fertility rate is .6, lower than that of the other two countries.

To sum up, in all three countries the production depends on natural pasture and therefore there is variability in all these attributes. Higher dependence on natural pasture reduces the physical performance of the cattle enterprise, both in terms of level and stability. This is apparent from typical values for the parameters in question:

	U.S	Argentina	Uruguay
Fertility rate	.8-.9	.5-.8	.5-.6
Birth age	1-2	2-3	4
Slaughter age	1.5	2-3	4-4.5
Reproductive life	8-10	6-8	4-5

Thus, the United States is employing the most productive technique as measured by fertility rate, productive life of a cow and time needed to prepare an animal to the market whereas Uruguay is the least productive in all these attributes.

Data[6]

We deal here with four variables: cow - the stock of female animals at breeding age; herd - the total stock; slaughter - the number of animals of all ages slaughtered in a given year, and price - the price of the slaughtered cattle, deflated by a general price index to account for changes in the price level. For the United States we present also the nominal, undeflated, prices. The choice of a deflator is problematic for two reasons. First, Uruguay and Argentina experienced several periods of very high inflation that distorted relative prices. Second, to better represent the relative prices, we need to employ a different deflator for prices that enter the supply and the demand equations. Deflating by the consumer price index is relevant for demand but not necessarily for supply. For supply, it would have been more instructive to deflate the data with the price of the most relevant input, say corn. This is particularly the case for Argentina where about 80 percent of the beef comes from the Pampa region where the pasture is part of a crop rotation with cereals. Thus, the price of corn represents, both the price of an input as well as the price of an important alternative product. This we may want to try to do in future work. The case of Uruguay is somewhat different because there is no supplemental feeding and also the ranch land has no alternative uses in production.

In general, the slaughter data are thought to be most accurate because they are collected in a relatively small number of establishments on a continuous basis. The stock data are based on censuses updated on the basis of slaughtered data and supplementary information that varies from country to country.

Figures 1 to 3 present the raw data for the three countries. The data and the sources appear in the appendix. The United States data show an upward trend in the

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[6] See the Appendix for the data and sources.

level of activity whereas the deflated price shows a positive trend until the early 1950s and a negative trend thereafter. The presence of cycles is very clear both in the stock data as well as in the slaughter series.

The data for Uruguay show only a slight trend in the herd from the early 1970s accompanied with a similar trend in slaughter and a decline of price. The Argentinean data show a slight upward trend until the late 1970s. In 1974 the common market imposed serious restrictions on the import of beef from the two countries. It is possible that Uruguay, not having good alternatives to cattle in agriculture could not adjust well to this restriction and as a result domestic prices decline. A similar decline in prices is observed in Argentina. Like in the United States, there are pronounced cyclical variations in the Argentinean and Uruguayan data.

Counting heads:

Throughout we use the following notations:

ab = age of first breeding

as = slaughter age of steers.

A = maximum age of cows.

sf(t) = number of slaughtered females in year t.

sm(t) = number of slaughtered males in year t.

s(t) =sf(t)+sm(t); number of slaughtered animals in year t.

1-δ = mortality rate, assumed to be the same for all ages.

f(a,t) = number of females of age a in year t.

F(t) = number of cows of breeding age; $F(t) \equiv \sum_a f(a,t)$; $ab \leq a < A$

g = fertility rate.

m(a,t) = number of males of age a in year t.

The number of calves born in year t is given by gF(t-1). We assume equal number of male and female calves. Most of the births take place in the winter and early spring and as such may fall in two adjacent calendar years.[7] When dealing with annual data, calves born in the same season may be classified to be of different ages depending on whether they were born before or after January first for the United States and July 1 for the southern hemisphere. Those born in January (July for the south) of year t-1 will appear to be of age zero in our head count at the end of year t-1 but may be bred late in t, which in our annual count will appear to be of age one. This heterogeneity is important for the empirical evaluation as will become clear below. We now do the arithmetic by assuming homogeneity for each **ab** and then consider the consequences of convolution of groups with different **ab.**

As the breeding age differs between, as well as within, countries, we consider three possible values: one, two and three years. One year is the norm today in the dairy herds and not uncommon in advanced herds. Thus the number of heifers entering maturity in year t is given by:

ab=1: $f(0, t-1) = .5gF(t-2)$.

ab=2: $f(1, t-1) = .5gF(t-3)\delta$

ab=3: $f(2, t-1) = .5gF(t-4)\delta^2$

and generally by:

$$f(ab-1, t-1) = .5gF(t-ab-1)\delta^{ab-1} \qquad (1)$$

where d is the survival rate, assumed to be the same for all ages.

The tradeoff between consumption and investment is determined by the biological constraint:

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[7] In Argentina most of the births take place between August and November, but there is a monthly distribution that covers almost the whole year, (Jarvis, 1986, p.25). A similar pattern is expected for Uruguay.

$$sf(t) + F(t) = \delta[F(t-1) + f(ab-1, t-1)], \tag{2}$$

using (1),

$$sf(t) + F(t) = \delta[F(t-1) + .5gF(t-ab-1)\delta^{ab-1}] \tag{3}$$

This is a difference equation of order **ab**. For a given **ab**, there are two lagged terms on the right hand side. If the population is not homogenous in the sense indicated above, there will be more lags and the order will be determined by the highest **ab**.

Turning to males, the number of slaughtered steers is determined by:

$$sm(t) = .5gF(t-as-1)\delta^{as-1}. \tag{4}$$

Most of the male yearlings are marketed at full weight which differs somewhat among breeds and techniques. However, some yearlings are sold young and this again introduces heterogeneity to the population. As a result, sm(t) is determined by a difference equation containing possibly more than one lagged value of F.

We now combine **sm** and **sf** to obtain total slaughter, **s**. The biological constraint on **s** is referred to here as the production function for cattle:[8]

$$s(t) + F(t) = \delta F(t-1) + .5g[F(t-as-1)\delta^{as-1} + F(t-ab-1)\delta^{ab-1}]. \tag{5}$$

When the breeding and slaughter age are the same, **as=ab≡a**, the expression simplifies to:

$$s(t) + F(t) = F(t-1)\delta + gF(t-a-1)\delta^{a-1}. \tag{6}$$

To illustrate, consider the assumptions made by RMS (1994): **ab=as**=2 and no mortality in the young stock to obtain their equation (3), written in our notations:

$$F(t) = \delta\, F(t-1) + gF(t-3) - s(t)$$

The present discussion complicates this formulation in two ways: First, it accommodates coexistence of techniques, which in turn affects the number of lags that appear in the

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[8] This is not an accurate term because the function does not include feeds and labor. The terminology however emphasizes the important feature that the current stock determines the sum of the investment and consumption through the biological process.

difference equation of any given country and second it accommodates cross-country differences in technologies.

In addition to the production function in a level form we also examine the production function in flow form where the dependent variable is slaughter plus the change in stock, $\Delta F(t)=F(t)-F(t-1)$. In what follows, we define this sum as output. This function is:

$$sf(t) + \Delta F(t) = (1-\delta)F(t-1) + .5gF(t-ab-1)\delta^{ab-1} \tag{8}$$

EMPIRICAL ANALYSIS

Technology

To gain some insight on the production technologies, we begin examining the static relationships in the data. Under a steady state economy, the production function (5) can be written as: $s/F \equiv \lambda(g,\delta,ab,as,A)$, where **s** and **F** are the steady state values and the multiplier λ represents technology. For instance, for the case of **as=ab≡b** considered above, we have: $s/F = [g\delta^{a-1} - (1-\delta)]$: $g\delta^{a-1} - (1-\delta) > 0$. When the technological parameters change, so does λ. An indication of the order of magnitude of λ can be obtained from the data as a ratio of the sample means, $\bar{s}/\bar{F}$. The values for the three countries are: .77 for the United States, .54 for Argentina and .44 for Uruguay. The order reflects differences in productivity. Estimates of annual values of λ change slowly over time, they show an increase in Argentina and a decline in the United States. We think that this decline reflects the increase in the relative importance of dairy cows in the stock figure. The ratio of mean *output* is similar to that obtained with *slaughter* but its annual values are more stable than those for slaughter. This is simply an indication of the tradeoff between slaughter and stock buildup.

Turning to dynamic analysis, we want to determine empirically the number of lags that enter the production function and their relative importance. To do so, we estimate the function in two forms: levels where the dependent variable is s(t)+F(t), and flows where the dependent variable is output, s(t)+ΔF(t). The coefficient of F(t-1) in the flow equation should equal that in the level equation minus one. This is indeed the case for all three countries for various lag structures, except that the fit for the level version is much higher. The calculations are done with actual data and with filtered data - obtained by eliminating the trend components as explained below. The results are similar for the two data forms and therefore we present in Table 1 only results for the actual data in flow form.

1. In general, the data do not sustain more than two lagged values for F.
2. As more lags are added, the coefficients change but their sum is robust.
3. The foregoing discussion suggests that there should be two dominating lags. However, the numerical values of the coefficients are not consistent with our prior guesses of the values of g and δ. For instance, for the United States the first two lags seem to dominate. It is likely that our priors cannot be rejected but this is of little comfort because in that case the confidence regions are too big to be meaningful for our analysis.
4. The output, s(t)+ΔF(t), coefficient (or sum of coefficients) is about .56 for the United States, .5 for Argentina and .26 for Uruguay. This suggests that the techniques used in the United States and Argentina are quite similar, in this respect, but are more productive than those used in Uruguay.
5. The country ranking of the output coefficient is the same as the ranking of the ratio of means of slaughter to cows.

RMS (1994) compute a regression of F(t)+s(t) on F(t-1), F(t-2) and F(t-3) to test their assumptions about the biological parameters. They find that the second lag is not significant, but "... the coefficient on x_{t-4} (our F(t-4)) is statistically significant (all larger lags are insignificant), indicating that the model's intertemporal specification is not strictly accurate" (p. 481). The relevance of the fourth lag suggests that there is a fraction of the herd with low intensity technique involving higher maturity age or a higher slaughter age. Alternatively, it may suggest that a specification that does not take full account of the age distribution, such as in ... , is not sufficiently rich to capture accurately the dynamics.

The inability to determine empirically the lag structure in the production function may be attributed to the strong multicollinearity among the lagged values of the cow stock (see equation). However, we did not succeed to resolve the problem by running the regression using a principal components technique. The possibility that the "actual" structure may contain long lags (for instance, 10 or 12 periods, see below) further worsens the multicollinearity problem. In the following sections we turn to non-parametric analysis of the data, especially the second moments and power spectra. They are based on binary measures where it is not required to allocate the variability in the dependent variable between several explanatory variables. This is in the spirit of resorting to non-parametric estimation.

Time series properties

To study the cycles, we have to concentrate on the short term variations and to do so we eliminate the trend. The trend is particularly pronounced for the United States, but it exists also for Uruguay and Argentina. The detrending is done using the Hodrick-Prescott method (see Prescott).[9] To avoid the question of the ideal price deflator, we

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[9] The trend is obtained by:

$$\min_{y(t)} \sum \left([y(t) - x(t)]^2 + \alpha[y(t-1) + y(t+1) - y(t)]^2\right)$$

where x(t) is the original series and y(t) is the smoothed one. Note that the y(t) is selected by least squares with a penalty for deviation from a straight line. In the algorithm we used α=1000.

detrend the actual, rather than the deflated, price for the United States. We did not do it for Argentina and Uruguay because of the dramatic changes in the price levels there. The detrended, or filtered, data are presented in Figures 5-7 where the cycles are now more obvious. The shocks left in the filtered data are of short run duration and are probably dominated by supply shocks because the pasture conditions are influenced by the weather whereas the demand is more stable in the short run. Indeed, it seen that for all countries the filtered data show a negative relationships between slaughter and the current price.

We now turn to a less demanding approach to study the time-series properties of the data using a binary measure that does not require to differentiate between the net contribution of the various lags. Specifically, we examine the autocorrelation and cross-correlation coefficients of the various variables. The autocorrelation coefficients for the actual data are presented in figures 8-10. It is seen that the first order coefficient for the stocks are quite high, .9 and above. These coefficients for the United States decline as the lag increases and show no cyclical variations. Those for Argentina behave similarly in herd, but show some cyclical variations in cows and more so for slaughter and price. The most cyclical values are obtained for slaughter in Uruguay.

The plots for the filtered data in figures 11-13 show a distinct 10-year cycle in stocks and slaughter in the United States. The price is also cyclical but it shows a somewhat different pattern. The Argentinean plots also show a 10-year cycle in the stock and slaughter and a distinct 6-year cycle in price. The pattern is somewhat different in Uruguay where the cycle seems to be of six year duration.

The conformity of the cyclical behavior of the various variables is also reflected in the cross-correlations for the filtered data, as presented in figures 14-16. The plots are drawn in such a way that the first variable in the title is held fix whereas the second varies with time, progresses to the right and lags to the left. For instance, for the United States, the panel of 'slaughter cow' should be read as follows: at t, the correlation coefficient of slaughter and cow is .6. The coefficient between slaughter at t and cow at t-1 is higher, about .7 whereas the coefficient between slaughter at t and cow at t+1 is lower, it continues to decline with time until it reaches its lowest value of -.5 at t+4.

The upper panel of Figure 15 shows that the cow in t-4 to t are positively correlated with slaughter at t but slaughter at t is negatively correlated with cows in t+1 to t+5. The higher is cow in the near past, the higher is the slaughter today. The higher is the slaughter today, the smaller is the herd in the near future. The second panel shows a negative correlation between contemporaneous slaughter and price. The correlation turns positive between current slaughter and price in t+3 or t-3. The correlation between slaughter and cow and slaughter and price is reflected in the correlation between price at t and cow at different dates. Price is negatively correlated with current cow because cow is positively correlated with slaughter and the latter is negatively correlated with current price.

The pattern of the slaughter-cow coefficient is similar to that of the autocorrelation of cow. To examine this pattern, we refer to equation (6) above, use the same notations for deviations from the means as for the variables and label the correlation coefficient between x(t - i) and y(t - j), $r_{xy}(i,j)$, to write for $j \geq i$:

$$r_{xy}(i, j) \equiv \frac{1}{T-j} \sum_{t-j}^{T} \frac{x(t-i)}{\sigma_x} \frac{y(t-j)}{\sigma_y}$$

where the σ's are the standard deviations. Then, the cross-correlalogram between slaughter at t and cow at t-j, $r_{sf}(0,j)$, can be expressed as:[10]

[10] From (6), counting F(t-j) = F(j), etc, $s(t) = - F(t) + F(t-1)\delta + gF(t-a-1)\delta^{a-1}$, becomes:

$$r_{sf}(0,j) \approx \frac{\sigma_f}{\sigma_s}[(d-1) + g d^{a-1} r_{ff}(0, a+1-j)] \qquad \textbf{(9)}$$

This cross correlation is determined by the autocorrelation of the stock and the technological parameters as well as the variability in **s** and **F**. For given variances, the correlation decreases with **a** and increases with **δ** and **g** and as such it is expected to be higher the more advanced the techniques are. This is confirmed by the data. From Figures 14-16 we read the contemporaneous cross correlation for slaughter and cow to be approximately .62, .38 and .1 for the United States, Argentina and Uruguay respectively.

$s(0) = -\ F(0) + \delta F(1) + gF(a+1)\delta^{a-1}$

$F(j)s(0) = -F(j)F(0) + \delta F(j)F(1) + g\delta^{a-1} F(j)F(a+1)$; and for j=1

$F(1)s(0) = -F(1)F(0) + \delta F(1)F(1) + g\ \delta^{a-1} F(1)F(a+1)$

Assuming that the variance of $F(j) = \sigma_{ff}$, is independent of j, then

$$r_{sf}(0,j) = \frac{1}{(T-j)\sigma_s \sigma_{f_j}} \sum [-F(j)F(0) + \delta F(j)F(1) + g\delta^{a-1} F(j)F(a+1)]$$

$$r_{sf}(0,j) = \frac{\sigma_f}{\sigma_s}[-r_{ff}(j) + \delta r_{ff}(j-1) + g\delta^{a-1} r_{ff}(j-a-1)]$$

and for j=0,

$$r_{sf}(0,0) = \frac{\sigma_f}{\sigma_s}[-1 + \delta r_{ff}(1) + g\delta^{a-1} r_{ff}(a+1)]$$

The sample values of ratios of the standard deviations of cow to slaughter (σ_f/σ_s) are 1.03, .88 and .95 for the United States, Argentina and Uruguay respectively. Dividing the correlation coefficient by the ratio of standard deviation we obtain the bracketed term of (9). The outcome is about .6 for the United States .4 for Argentina and .1 for Uruguay. The ranking of these values is indicative of the advancement of the techniques used in the three countries.

On the basis of (9) we expect the cross-correlation of slaughter and cow to follow closely that of the autocorrelation of cow. This suggests that we can expect conformity in the cycles of the two variables, slaughter and cow. This is indeed the case as we show below and in this respect our results differ from RMS (1994) who claim cycles in cows but not in slaughter (consumption in their terminology). The difference raises the question: given the technology, what could weaken the relationship between slaughter and cow and thereby the similarity in their cyclical movement? A partial answer, based on (9), is a decline in the ratio σ_f / σ_s. The values for the sample show a higher variance of cow than of slaughter for the United States and Uruguay. This is to be expected because the essence of the arbitrage condition calls for the stabilization of consumption through stock variations. Thus, the work of the arbitrage condition in fact strengthen the tie between consumption and stock.

The interpretation of the autocorrelation indicates that their pattern summarizes the outcome of the decisions made under uncertainty given the constraints and the technology of the sector. It is therefore suggested that any model will be judged by its ability to reproduce the correlation patterns. This is a more stable criterion than that of a multiple regression. To apply this criterion, it would be necessary to simulate the model given the assumed distribution of the shocks and estimate the autocorrelation paths.

The spectrum

Alternatively, the time-series properties of the data can be analyzed in the frequency domain by studying their spectra. The spectrum decomposes variations of the data series at different frequencies, or given the relationship between frequency and periodicity, at different periods. This approach is particularly powerful in cycle analysis. A cycle in the data series is simply represented in the frequency domain by a distinctive peak in the spectrum around the frequency that corresponds to the length of the cycle. Often, when the data is generated by more than one force, each of which has different cycle, it may not be reflected in analysis in the time domain, but it will be shown in the frequency domain as several distinctive peaks.

We used nonparametric estimate of spectra for all time-series using the modified Bartlett kernel, (Hamilton, pp. 165-167). Specifically, let $\hat{r}_j$ be the sample value of the j-lag autocorrelation, we the calculate

$$\hat{S}(\omega) = \frac{1}{2\pi}[1 + 2\sum_{j=1}^{q} (1 - \frac{j}{q+1})\hat{r}_j \cos(\omega)]$$

where (1 - j /(q+1), j=1,...,q, is the kernel and q is the bandwidth parameter, chosen by trial and error.[11]

The results for the filtered data are presented in figures 17-19. The period of the cycle is obtained by the ratio of 2π to the frequency at the peak. For the United States, there is a peak at a frequency of slightly above .6, indicating a 10-year cycle as was already observed above. A similar cycle is observed for all the variables. There is some concentration at a lower frequency (often referred to as "typical spectral shape") that

[11] Theoretically, q should be chosen as q(T), where T is the length of the series, such that when $T \to \infty$, $q \to \infty$ but $q/T \to 0$.

represents a long term drift that was not smoothed out. The cycle in Argentina is basically identical to that in the United States except for the prices. Here again, there is a presence of a long term drift as indicated by some concentration for low frequencies. The plots for Uruguay show two cycles, 6 and 12 years. Dividing the data to two sub-periods before and after 1971 shows that the 12-year cycle comes from the first subperiod and the six-year cycle comes from the second subperiod. At the present, we have no explanation for this result.

The spectra of price show somewhat more variability in the higher frequency than the other three variables, especially for Argentina and Uruguay. This may be related to two independent factors. First, there is trade in slaughter. Argentina and Uruguay are traditional exporters and the United States has also been engaged in trade. At times, about one third of the production in Uruguay was exported. Uruguay accounted for 13.8 percent of the world beef trade in the late 1920s and this share has come down to 1.6 percent. (Favaro, 1989). As such, the domestic prices are likely to be affected by world prices. Favaro (1989) examined the relationships between the world price and the domestic price in Uruguay and concludes that "Although the data appears to be consistent with the existence of a strong influence of the price of beef exports upon the price of cattle a substantial portion of the variance of the latter remains to be explained. Thus the hypothesis that the price of cattle is determined in the domestic market appears to be more consistent with the empirical evidence than its alternative." (p.17). This is indicative of some relationships between the domestic and world price. We calculated the cross-correlation of prices between Argentina and Uruguay and obtain a value of .6 for contemporaneous correlation and a pattern for the lagged values similar to that of the autocorrelation of prices in the individual countries.[12] A similar calculation for Argentina

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[12]To avoid too many graphs, the results are not shown here.

and Uruguay with the United States shows a weak contemporaneous tie but stronger ties with lagged values. Second, in Argentina and Uruguay the prices are deflated, and as such a stochastic element unrelated to the cattle sector is introduced.

To conclude, it is interesting that in spite of big differences in technology, the three countries display somewhat similar spectra. This suggests that the key to understanding the dynamics of the sector lie in a variable which does not differ much for the three countries. This is the orientation that we take in our present search.

Arbitrage, consumption and cyclicity

The arbitrage condition leads to the stabilization of consumption through stock variations. This point is stressed by RMS who find support in the observation that cycles exist in cows but not in slaughter (consumption in their terminology). As shown above, the consumption cycles conform to the stock cycles in all the three countries and in this respect our results differ from theirs. This result calls for a closer examination of the relationship between consumption smoothing and cyclicity.

The effect of the arbitrage condition in consumption smoothing through stock variation reduces σ_s, increases σ_f and thereby increases the ratio σ_f / σ_s. It follows from (9) that as this ratio increases, the pattern of cross-correlation of slaughter and cow is expected to follow more closely that of the autocorrelation of cow and thereby strengthen the conformity of the cycles of the two variables, slaughter and cow. Thus a distinction is drawn between consumption smoothing and cyclicity, smoothing does not eliminate cyclicity. This result reflects the nature technology. Unlike in manufacturing, in the case of cattle it is impossible to operate a plant for an extra shift when a shock generates an excess demand.

The role of prices

The relationships between slaughter and cows or herd reflect the technology but by itself it provides no information on the economic behavior of producers. That brings up the following question: what is the role of prices in cattle production? To answer this question, it is instructive to draw analogy to the storage model. A common element to the two models is the arbitrage condition. The two models differ in the details of the stock constraint or the production function. In its simplest version, the storage model has one state variable, availability, defined as the sum of carry-in stocks and current production. Given the demand function and the availability, the arbitrage rule determines the allocation between current consumption and carry over. The price, as well as consumption, are determined by the model and as such are endogenous, a point emphasized by Williams and Wright (1991).

The availability in the cattle case is the herd and its composition. The current price is endogenous and is determined jointly with the slaughter and the amount of carry over. There is an important difference between the two models related to the computation of the expected price, or simply the computation of the arbitrage condition, but this is not as much a conceptual problem as a technical one.

Thus, the response to shocks takes two forms, quantity slaughtered and changes in stock. Traditional supply analysis relates output to price. But as just indicated, this means relating variables that are jointly determined. This is similar to the text book case of introducing simultaneous equations. The result of a regression of quantity on price will give a mixture of the supply and demand parameters. The resulting slope will be negative if the supply shocks dominate the demand shocks. It is for this reason that we qualify supply by quotation marks in the heading of Table 2 . Keeping this in mind, we can now examine the meaning of such a "supply" analysis with slaughter as dependent variable. Table 2 presents results for the filtered data for the three countries and with the actual data for the United States. The results are summarized as follows:

Filtered data:

1. For all countries, the coefficients of current and one-year-lagged price are negative. This is consistent with the situation where the supply shocks dominate demand shocks and as such trace the demand function.

2. The coefficients of higher lagged prices are insignificant and the results are not reported here.

3. The data sustain three lagged values for cow for the United States and Uruguay and only one lag for Argentina. Again, this is a indication that this type of analysis can not provide precise results on the lag structure of cows.

4. The results for Uruguay and Argentina with actual data are not different in substance from those of the filtered data and therefore are not reported here.

5. For the actual United States data, cow lagged two years is the only relevant stock value. This is in contrast to two or three lags sustained by the filtered data. The difference simply reflects the strong trend in the data. Once the trend is filtered out, the composition of the herd plays a role. The current-price coefficient is negative. The price lagged two years is positive but insignificant.

Relationships of stocks to prices were examined by Reutlinger (1966), Rucker, Burt and LaFrance (1989) and Foster and Burt (1991) among others. In interpreting this relation, we note that in order to restore the arbitrage condition in response to a shock, an adjustment is made in the number of cows slaughtered as well as in the stock of cows kept for future production. The relevant prices for such a decision are the expected prices to prevail in the future. Expected prices are unobservable but the arbitrage equation relates those prices to the current price. If the current price declines and the arbitrage condition is maintained, we can infer that the expected price also declines. Keeping this interpretation in mind, we turn now to Table 3 for estimates of the regression of cows on their lagged values and on prices, including the current price. Some combinations of variables are not reported here because their results are similar to those in the table.

The price coefficients for the United States are similar for the two data forms and are quite robust. The coefficient of current price is on the whole not significantly different from zero. The coefficients of the lagged prices alternate signs, the price in t-1 has a positive coefficient whereas that of t-2 is negative. The observed pattern is consistent with the following story: assume a shock today that calls for down sizing the stock initially carried over for next period. The adjustment to the shocks is made by increasing the current slaughter, thereby causing the current price to decline along with the stock carried over for next year. Hence next year stock is positively correlated with this year price. The decline in next year stock will result in a decline in slaughter the year after, which in turn will cause a price increase and hence the negative sign of the coefficient of the price lagged two years. This pattern is repeated for higher lags but with declining magnitude and significance. This interpretation suggests a supply response of a somewhat complex pattern which can not be captured by a simple formulation.

The systematic pattern of the signs of the price coefficients observed for the United States is not repeated in Argentina and Uruguay where on the whole the effect of price is weaker than in the United States. In the two countries the current price has a positive coefficient and marginally significant. Lagged prices are on the whole positive in Argentina whereas in Uruguay the sign of the one-year-lag is negative, the opposite pattern from that observed for the United States. This may reflect the influence of export mentioned earlier. However, Jarvis (1986) analyzes inventory demand for different animal types and find a positive response. This suggests that the present analysis may be too crude to detect the exact pattern of price effects. Also, it is likely to reflect the influence of export mentioned earlier.

Turning to the stock coefficients, there is a difference between the results for the actual and the filtered data. For the United States filtered data, the coefficient for one-year lag is about .76, indicating scope for adjustment to prices and other shocks. With two-year lag, the first coefficient is positive and near 1 and the second is negative. Their sum is slightly smaller than the coefficient of the one-year lag-stock. The results in Table 1 show that an increase in the stock in t-2 results in an increase in slaughter two years later, whereas the results in Table 3 show a corresponding decline in the stock at t. This is consistent with the story outlined above about the adjustment to shocks that intend to preserve the arbitrage condition. A similar pattern of the effect of the lagged stocks is observed also in Argentina and Uruguay.

The coefficient of the stock in the regressions with actual data are larger than those for the filtered data. This difference is due to an upward trend in demand, attributed to population and income growth, that was unmatched by a corresponding increase in productivity. This difference is observed also in Uruguay but it is considerably smaller in Argentina.

A model

In formulating the model we note that the cattle stock and its age distribution determine the sell-hold decision at any point in time.[13] The decision depends on the product demand, feed supply, the discount rate and the parameters of the production function. The quantity slaughtered will determine the current price whereas the stock carried over for next year affects the expected future price.

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[13] We should not rule out also adjustments in the weight and age of the slaughtered animals. Those are not included because the problem is complex enough without it. Ignoring these adjustments is of secondary importance.

To simulate a competitive conditions we assume an optimization problem where the objective function is the sum of the consumer and producer surpluses. As we are trying to explain filtered data, income effect is eliminated and therefore the integration of the demand function gives an exact measure of the consumer surplus. For simplicity we assume a linear demand function. Let, $q = \alpha_0 - \alpha_1 p$ and derive the consumer surplus: $C \equiv \int_{p}^{\bar{p}} [\alpha_0 - \alpha_1 q(p)]\, dp$. Integrating and simplifying, $C = q^2/2\alpha_1$.

The producer surplus is the revenue less cost. The cost is largely cost of feeds but the formulation is general and covers other costs such as fencing, veterinarian service, work and so on. We allow for the unit cost of feed, w, to increase with the amount of feeds used:

$$w(t) = \gamma_0 + \gamma_1 v(t). \tag{10}$$

In the case of perfectly elastic feed supply, as assumed by RMS (1989), α_1 is zero. For Uruguay, Favaro (1989) assumed a feed constraint. This assumption is replaced with a steep supply function where γ_1 is set at a high level and γ_0 is set near the level of the constraint.

The feed demand is determined by the herd size and composition, described by a vector h(t), assuming fixed coefficient for each age group. This results in a linear combination of the herd composition:

$$v(t) = \eta' h(t). \tag{11}$$

Thus, the producer's surplus (PS) is $pq - [\gamma_0 + \gamma_1 v(t)]v(t)$, substituting the demand:

$$PS = \alpha_0/\alpha_1\, q - 1/\alpha_1\, q^2 - [\gamma_0 + \gamma_1 v(t)]v(t). \tag{12}$$

The present value of the stream of total surplus is:

$$TS = E_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{\alpha_0}{\alpha_1} q(t) - \frac{1}{2\alpha_1} q(t)^2 - \gamma_0 v(t) - \gamma v(t)^2 \right) \tag{13}$$

We now assume that all the slaughter is for domestic consumption, so that we can set s(t)=q(t). The problem is to chose q(t) according to:

maximize $2\alpha_1$TS, subject to:

The biological constraint, as in (5), with a shock added:

$$q(t) + F(t) = \delta F(t-1) + .5g[F(t-as-1)\delta^{as-1} + F(t-ab-1)\delta^{ab-1}] + e_d(t) \tag{14}$$

The feed, or input, demand, as in (11) with a shock added:

$$v(t) = \eta' h(t) + e_v(t) \tag{15}$$

The biological transition identities:

$$y(0,t) = gF(t-1) \tag{16}$$

$$y(1,t) = gF(t-2)\delta \tag{17}$$

$$y(2,t) = gF(t-2)\delta^2 \tag{18}$$

$$m(3,t) = .5gF(t-3)\delta^3 \tag{19}$$

where y(a,t) is the number of young animals, of either sex, of age **a**. Basically, (16)-(18) give the calves and yearlings which are not in the breeding herd but require feeds and (19) gives the steers to be marketed in t. The exact age distribution should be calibrated for the technology used in the particular country. These values are added to the cows to obtain the herd which enters in (15).

Numerical solution of this problem are obtained by using the Hansen-Sargent (1994) framework. A detailed specification includes assumptions on the distribution of the shocks introduced in (14) and (15). The framework is broadened by allowing also the slopes of the demand and feed supply equations to be subject to shocks.

The problem is that we do not know the feed supply and the demand equations, nor do we know the parameters of the probability distribution of the various shocks and what pattern do they follow; are they subject to autocorrelation? if yes, of what order? Thus, there is a problem of fitting a rather complicated model with little initial information. We do it by iteration where we try to select a model that will fit well the autocorrelations and cross correlations observed in the sample. We consider this to be a good summary of the time series properties of the model and if we can come close to the data, then we have a story that is consistent with the data in a meaningful way. The procedure is:

1. Select initial values for all the parameters in question, including the parameters of the probability distribution of the shocks.
2. Run a large number of Monte-Carlo simulations and compute for each one the autocorrelations and cross correlations and average them. These coefficients are functions of the initial parameters.
3. Compute the squared differences between the values of the correlation coefficients in 2 above and the actual ones. Define a function which gives declining weights to these differences according to the length of the lag. Also differentiate between autocorrelations and cross correlations.
4. Compute the weighted sum of the squared differences between the actual and computed coefficients. This gives a loss function.
5. Minimize the loss function by altering the values of the parameters in question.

Summary

The dynamics of the sector depends on the production function that relates the output to the lag structure of the stock of cows and on the arbitrage condition that relates the current price to the expected future price . The parameters of these functions reflect the biological process. Knowledge of the production function can be used to estimate the cyclical behavior of output.

These two functions are relatively simple, yet hard to estimate. We were unable to estimate the lag structure of the production function with sufficient precision, nor are we aware of any other study that does it. The reason is thought to be rooted in the high autocorrelation of the stock. To avoid this problem, we divert attention to binary measures, the sequence of autocorrelation and cross correlation coefficients, for summarizing the time series properties of cattle production and through this measure to determine the relevant underlying structure.

The autocorrelation coefficients computed from detrended data show distinct cycles. For each country, the cycles are of the same length for all quantities - cows, total herd and slaughter. The cycles in prices deviate somewhat from those in quantities. The cycles are more apparent when displayed by the spectrum in the frequency domain. It is striking that in spite of the wide differences in technologies, key cyclical properties for the United States and Argentina are almost identical, and those for Uruguay are not much different. This finding should help to search for the common factor that makes this behavior so similar in spite of wide differences in technology, economic and physical environment. Another important result is that the smoothing of consumption in response to shocks carried out through stock adjustment does not preclude the cyclical behavior of consumption to the extent that the cycle of slaughter conforms to that of stocks. This is in contrast to the common case in other sectors where consumption smoothing eliminates or greatly reduces the cycles in this variable.

The role of prices in cattle production is interpreted in light of the arbitrage condition. The stock plus current production are allocated between sales, or slaughter, and carry over stock. The quantity slaughtered and the demand determine the current price. The carry in stock reflects past expected prices, which due to the arbitrage conditions, reflects past prices.

This complex pattern of response to changes in the environment limits the information that can be drawn directly from empirical analysis. We thus outline a model that intends to imitate the main decisions and evaluate it through simulations in order to sort out the effects of the various pertinent variables.

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Table 1--The Relationship of Output to Stock of Cows

R^2	Cow at				
	t-1	t-2	t-3	t-4	sum
			USA		
0.958	.573 (36.3)				
0.961	.274 (2.1)	.292 (2.3)			
0.96	.236 (1.7)	.431 (2.0)	.105 (.8)		0.562
0.959	.227 (1.63)	.415 (1.9)	-.005 (.021)	-.078 (.6)	0.559
			Argentina		
0.193	.428 (3.6)				0.428
0.263	-.215 (.8)	.665 (2.6)			0.45
0.347	.013 (.05)	-.245 (.6)	.743 (2.9)		0.511
0.379	-.062 (.2)	.021 (.05)	.080 (.2)	.511 (2.0)	0.55
			Uruguay		
0.108	.194 (2.8)				0.194
0.335	-.484 (3.1)	.736 (4.7)			0.252
0.374	-.443 (2.9)	.449 (2.0)	.275 (1.8)		0.281
0.384	-.419 (2.6)	.414 (4.4)	.439 (2.0)	-.164 (1.02)	0.271

Notes: The dependent variable is output = slaughter + change in stocks. The numbers in parentheses are t-ratios. Sum is the sum of coefficients. R^2 is the adjusted R^2.

Table 2 -- "Supply" Analysis

R^2	Cows			Prices		
	t-1	t-2	t-3	t	t-1	t-2
Filtered data						
USA						
.769	.14 (1.5)	.533 (5.2)		-1.65 (4.0)	-.93 (2.3)	
.787	.21 (2.0)	.38 (2.8)	.17 (1.7)	-1.68 (4.1)	-.77 (1.9)	
Argentina						
.672	-.03 (.2)	.19 (1.4)		-5.78 (4.7)	-5.23 (4.3)	
.703	.11 (.8)	-.08 (.4)	.33 (2.2)	-5.51 (4.6)	-4.71 (3.9)	
Uruguay						
.513	-.34 (2.8)	.80 (6.5)		-3.7 (2.6)	-2.27 (1.6)	
.538	-.29 (2.3)	.65 (4.4)	.22 (1.8)	-3.6 (2.5)	-2.02 (1.4)	
Actual data - USA						
.960	.59 (36)			-.891 (2.4)		
.971	.03 (.3)	.547 (4.6)		-.676 (2.0)		
.973	~.0 (~0)	.579 (4.7)		-.401 (.6)	-1.26 (1.5)	1.16 (1.9)

Notes: The dependent variable is slaughter. The numbers in parentheses are t-ratios. R^2 is the adjusted R^2.

Table 3 - Cow stock at the end of year t; USA

	Cow		Price					
R2	t-1	t-2	t	t-1	t-2	t-3	t-4	t-5
Filtered data								
.609	.753b		-12	96a				
.632	.783b		-46	195b	-119a	7		
.677	.763b		-61a	211b	-159b	81a	-52	-73a
.646	.983b	-.306b	-17	78a				
.686	1.079b	-.385b	-62a	212b	-188b	59a		
.725	1.062b	-.370b	-71a	225b	-231b	150a	-86a	-38
Actual data								
.987	.983b		-.846b					
.988	.980b		-.04	1.04a				
.988	.995b		.27a	1.83b	-1.1a	.81	-.78a	
.988	1.24b	-.25b	.71b					
.989	1.25b	-.25a	.30	1.76b	-1.56a	1.08a	-.83a	

Table 3 -- Cow stock at the end of year t; Argentina

R2	Cow		Price					
	t-1	t-2	t	t-1	t-2	t-3	t-4	t-5
Filtered data								
.474	.731b		2.07a					
.499b	.709b		1.08	1.98a				
.501	.710b		1.02	1.64	.45	-.64		
.499	.713b		1.06	1.63	.51	-.72	.14	
.559	.979b	-.416b	.86					
.565	.943b	-.383b	.46	.99				
Actual data								
.814	.8b		2.1b					
.817	.8b		1.2	1.5a				
.788	.8b		1.0	1.4	.2	-1.2		
.818	1.1b	-.3b	1.9b					
.820	1.1b	-.3b	1.3a	.9				
.805	1b	-.3a	1.1	1.1	-.2	-.6		
.766	1.1b	-.3a	1.	1.2	.1	.8	.2	.5

Table 3 -- Cow stock at the end of year t; Uruguay

R2	Cow		Price					
	t-1	t-2	t	t-1	t-2	t-3	t-4	t-5
				Filtered data				
.402	.621b		2.05a					
.403	.627b		2.23a	-.54				
.439	.630b		1.37	-.74	-.21	-2.39a		
.445	.647b		1.78	-.69	.16	-2.64a	1.03	
.430	.754b	-.212a	1.68a					
.433	.763b	-.216a	1.90a	-.71				
.435	.762b	-.210a	-1.64a	-.38	-.74			
				Actual data				
.860	.916b		2.17a					
.860	.921b		2.64a	-.79				
.872	.919		2.71a	-.93	.58	-2.51a	2.77a	

Notes to Table 3:
The dependent variable is the stock of cows at the end of year t, the explanatory variables are the stock of cows at the end of t-1 and t-2 as well as beef prices as indicated.
a: t-ratio is between 1 and 2
b: t-ratio above 2, coefficients not marked with a or b have t-ratios below 1.

The actual price for the U.S is scaled differently from the filtered data and hence the difference in the order of magnitude of the price coefficients by a factor of 100. This of course does not affect the statistics.

FIGURES

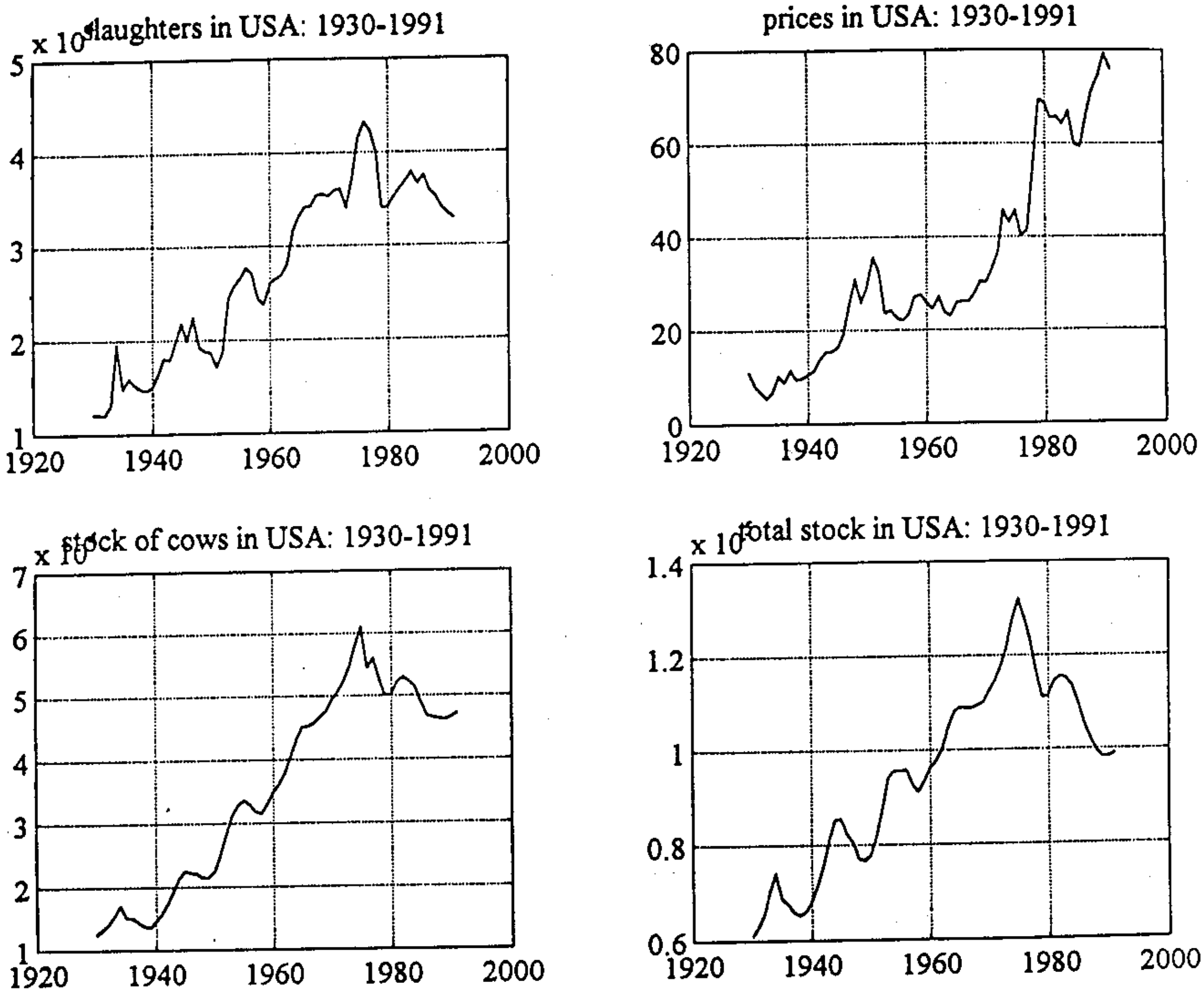
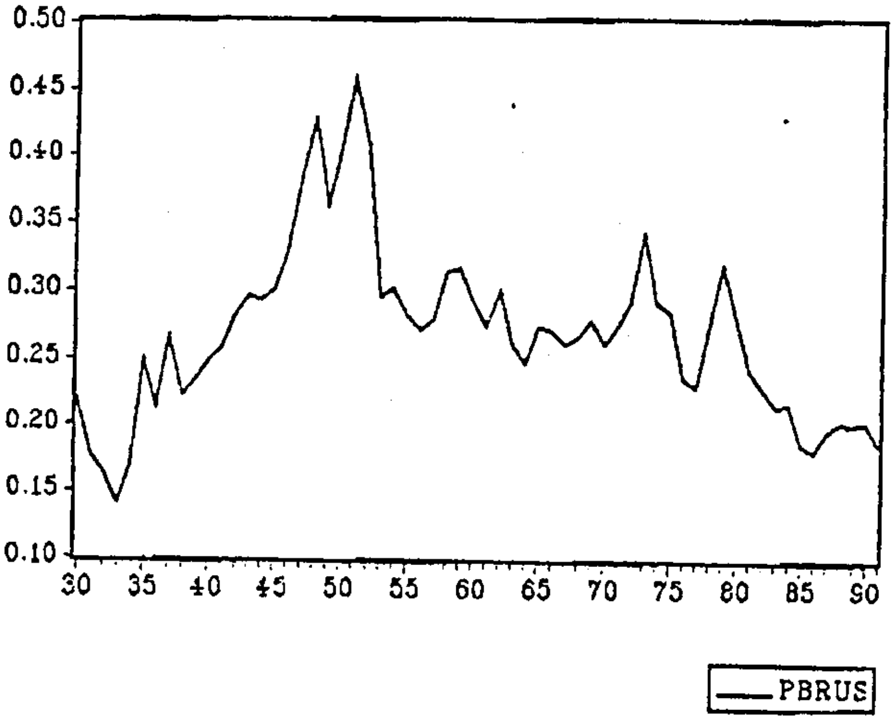


Figure 1
USA: data

Fig 1.e Price of Beef in the USA Deflated by CPI



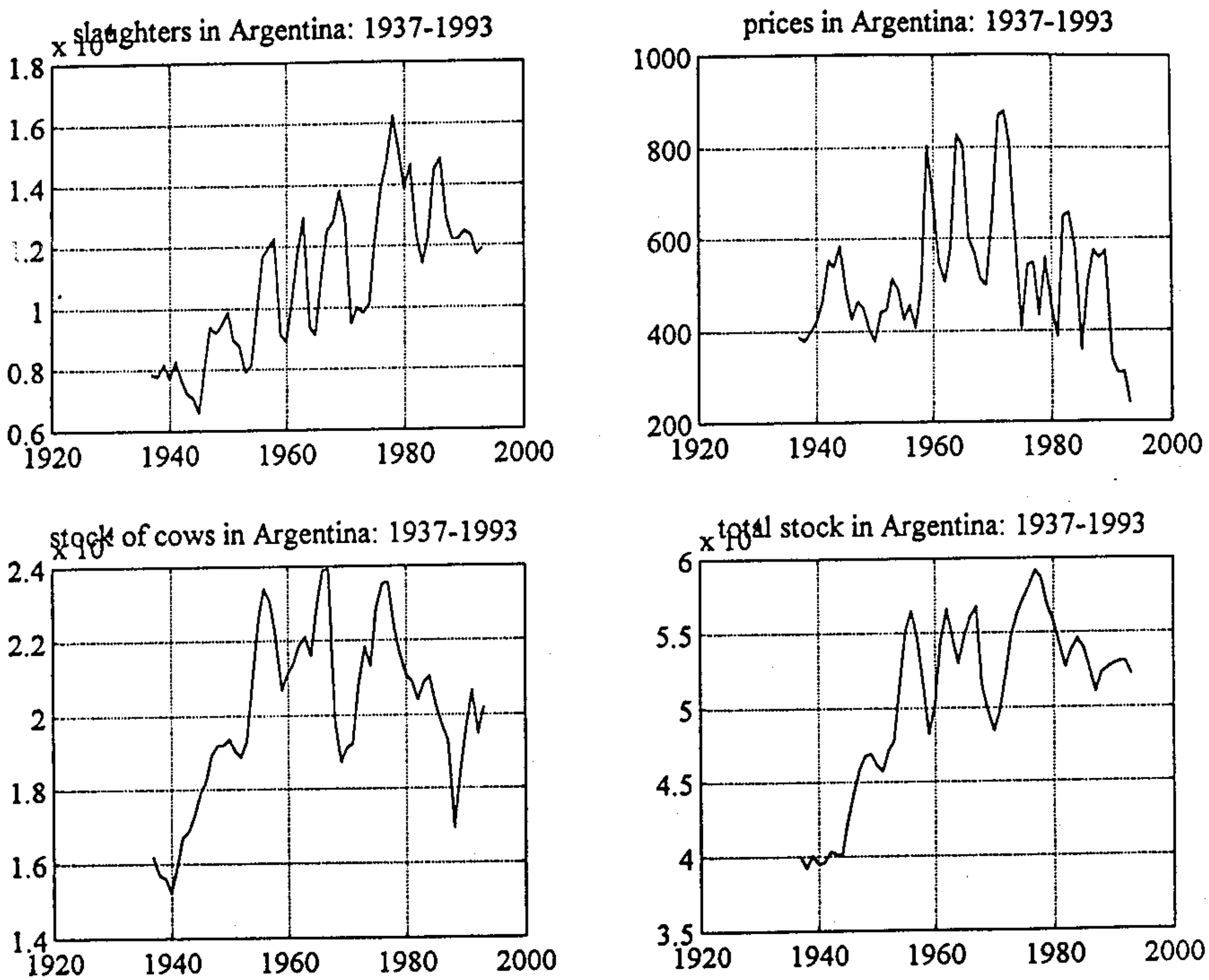


Figure 2

Argentine: data

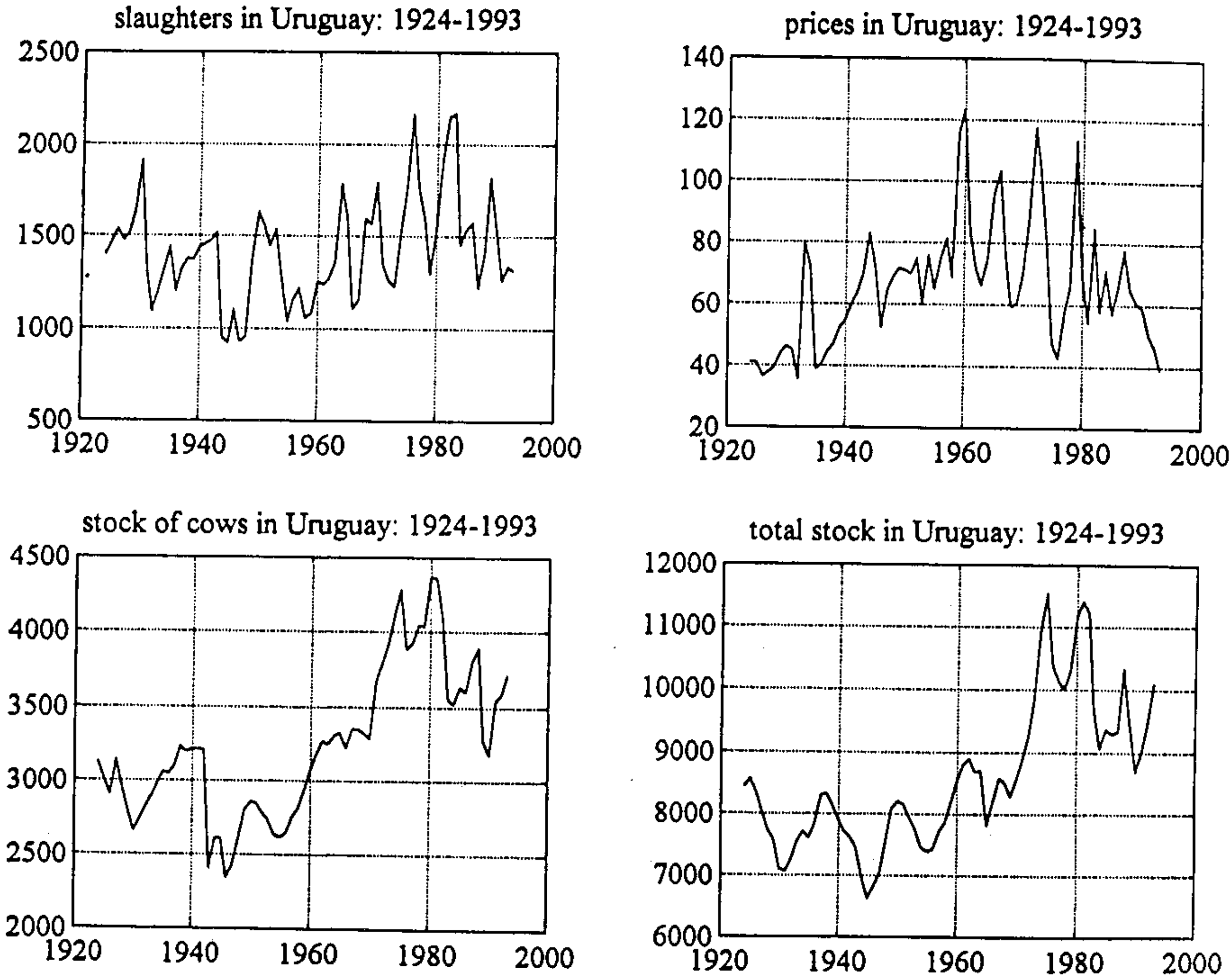


Figure 3
Uruguay: data

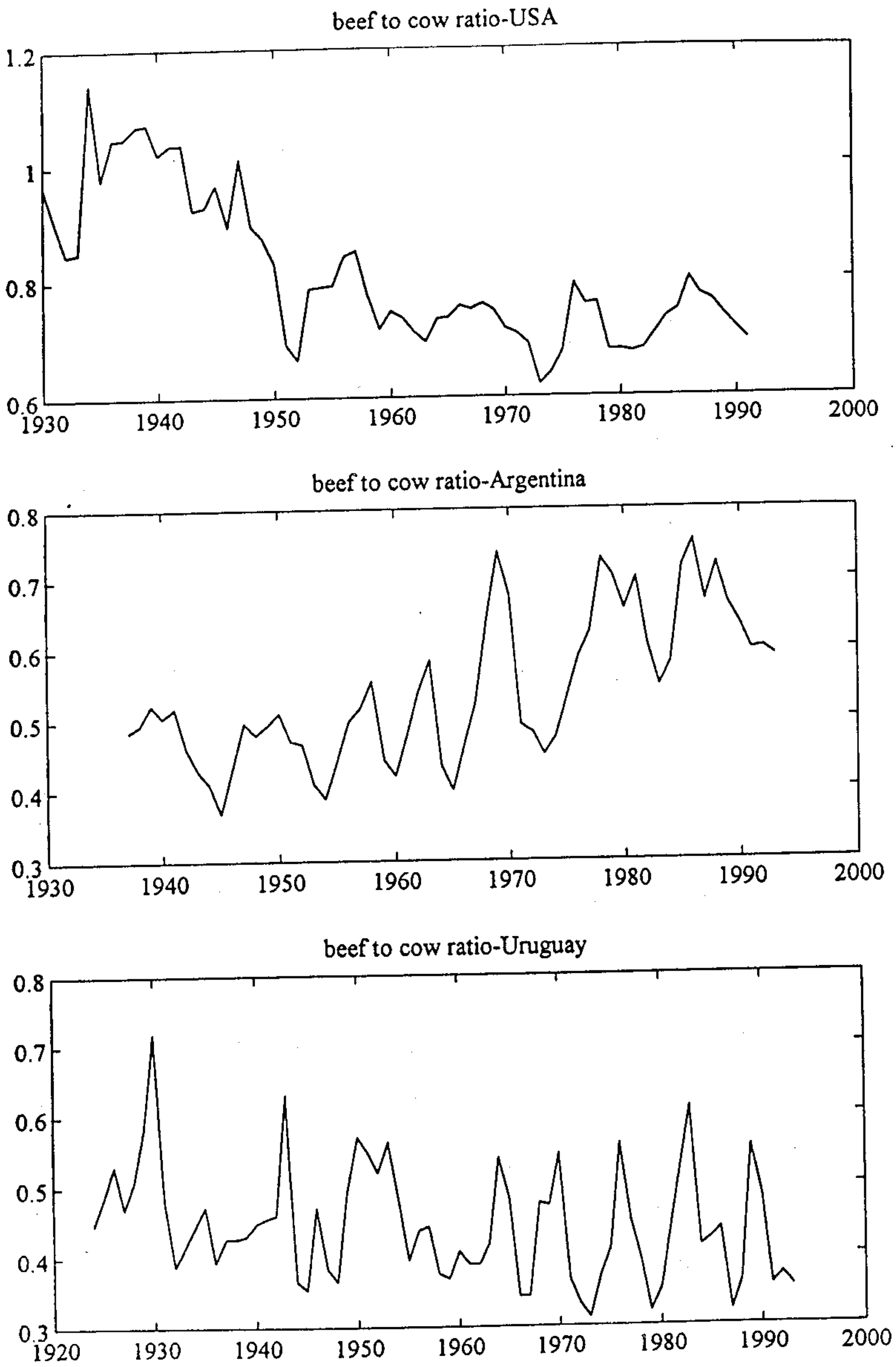


Figure 4
beef to cow ratio

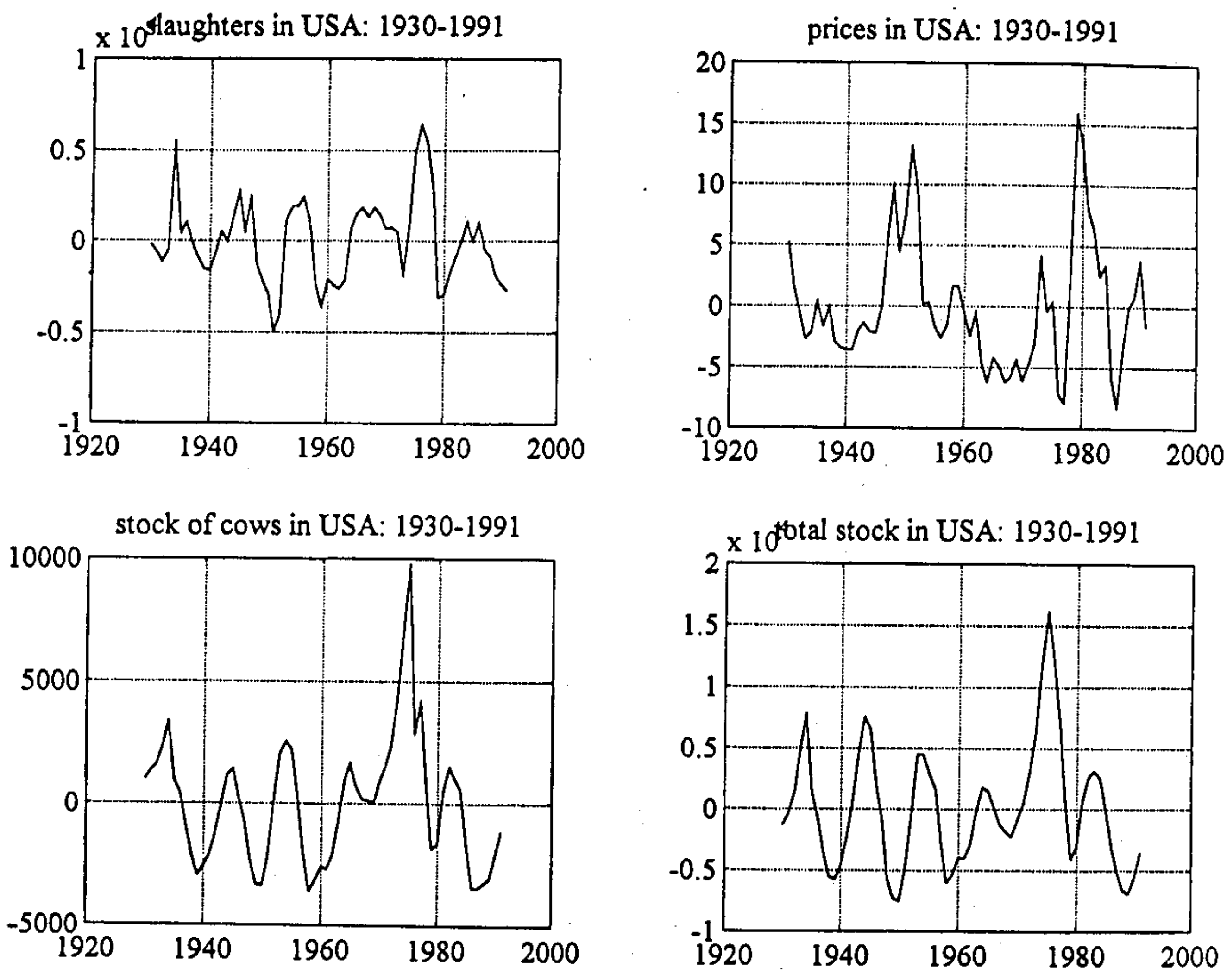


Figure 5
USA: filtered data

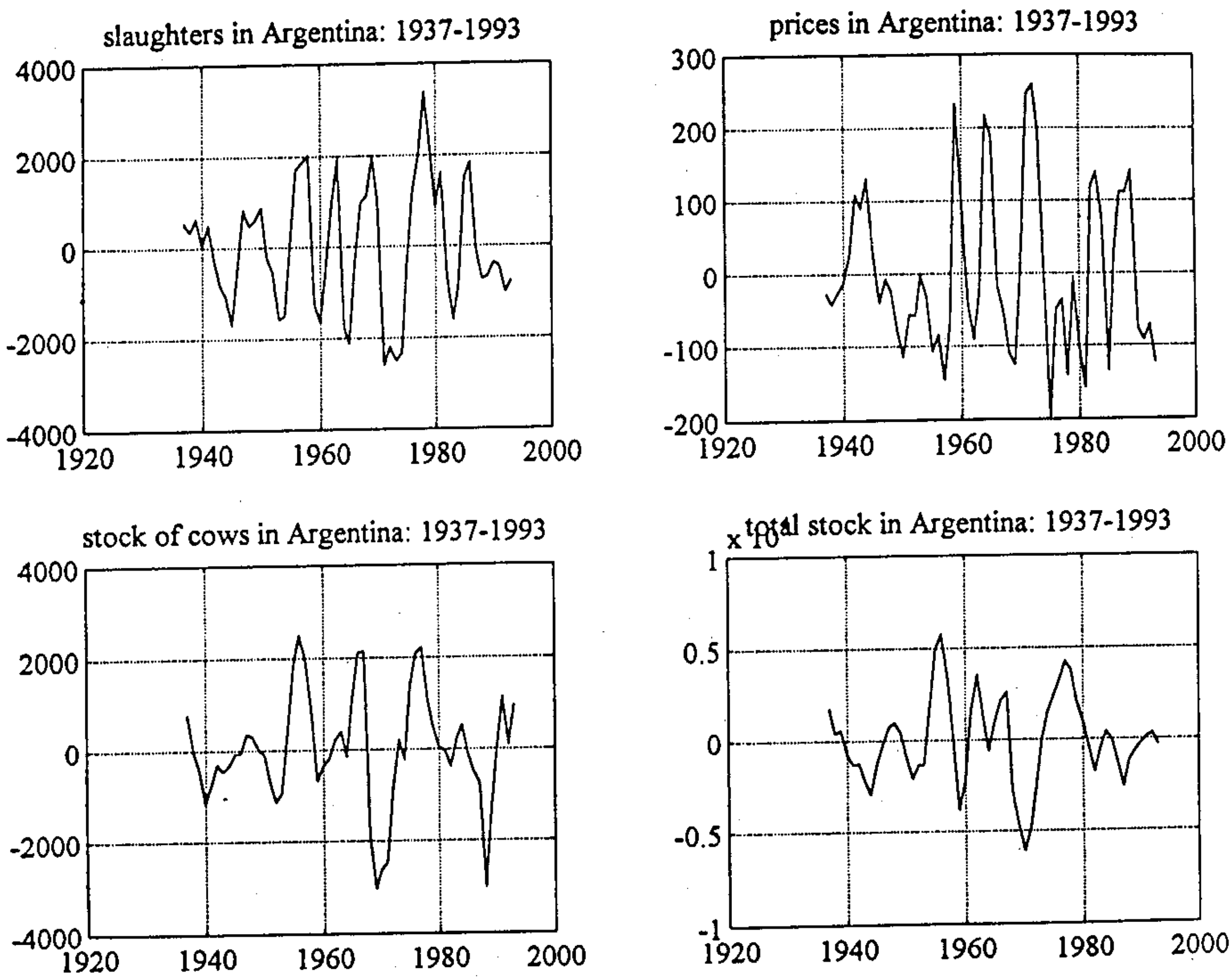


Figure 6
Argentine: filtered data

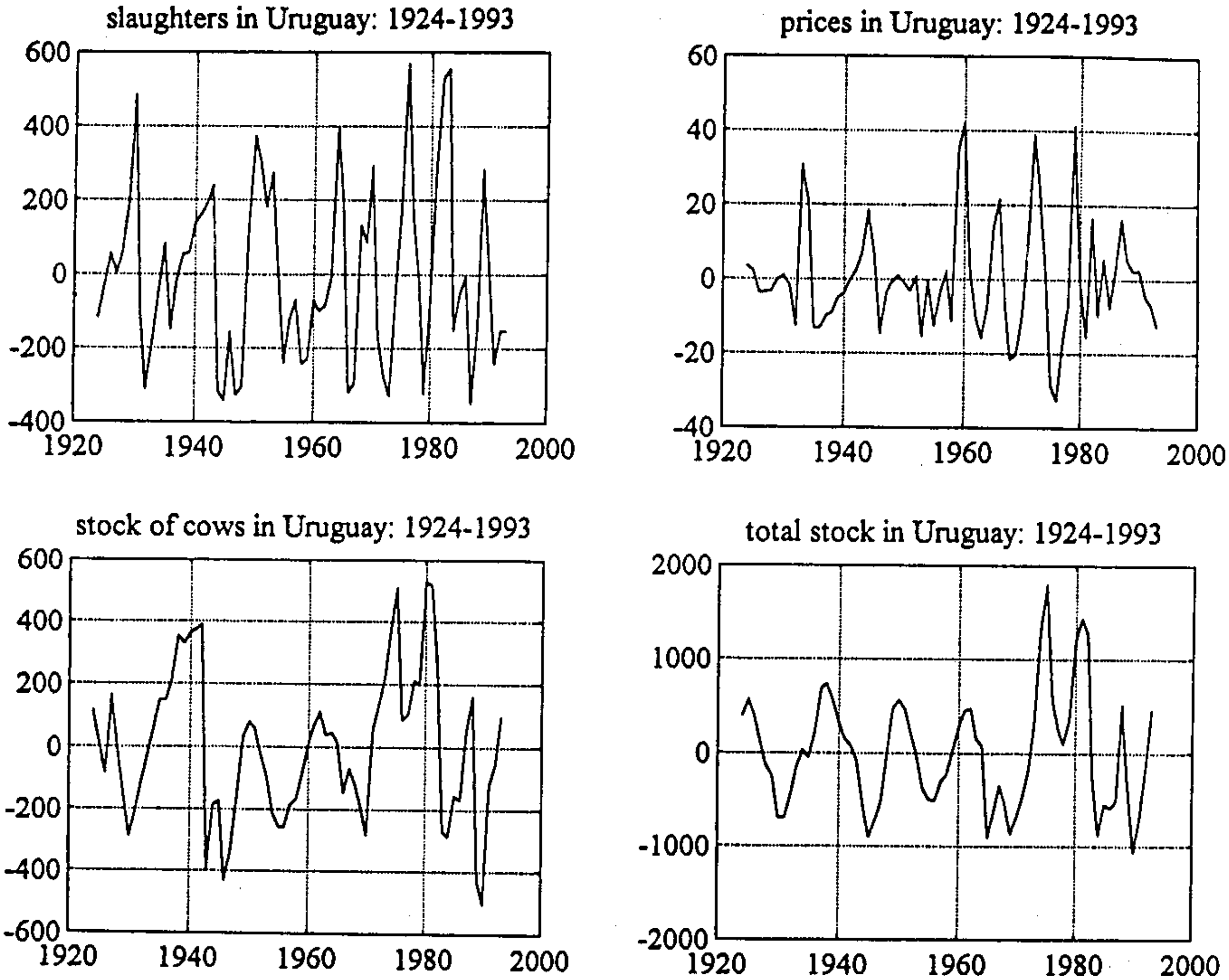


Figure 7
Uruguay: filtered data

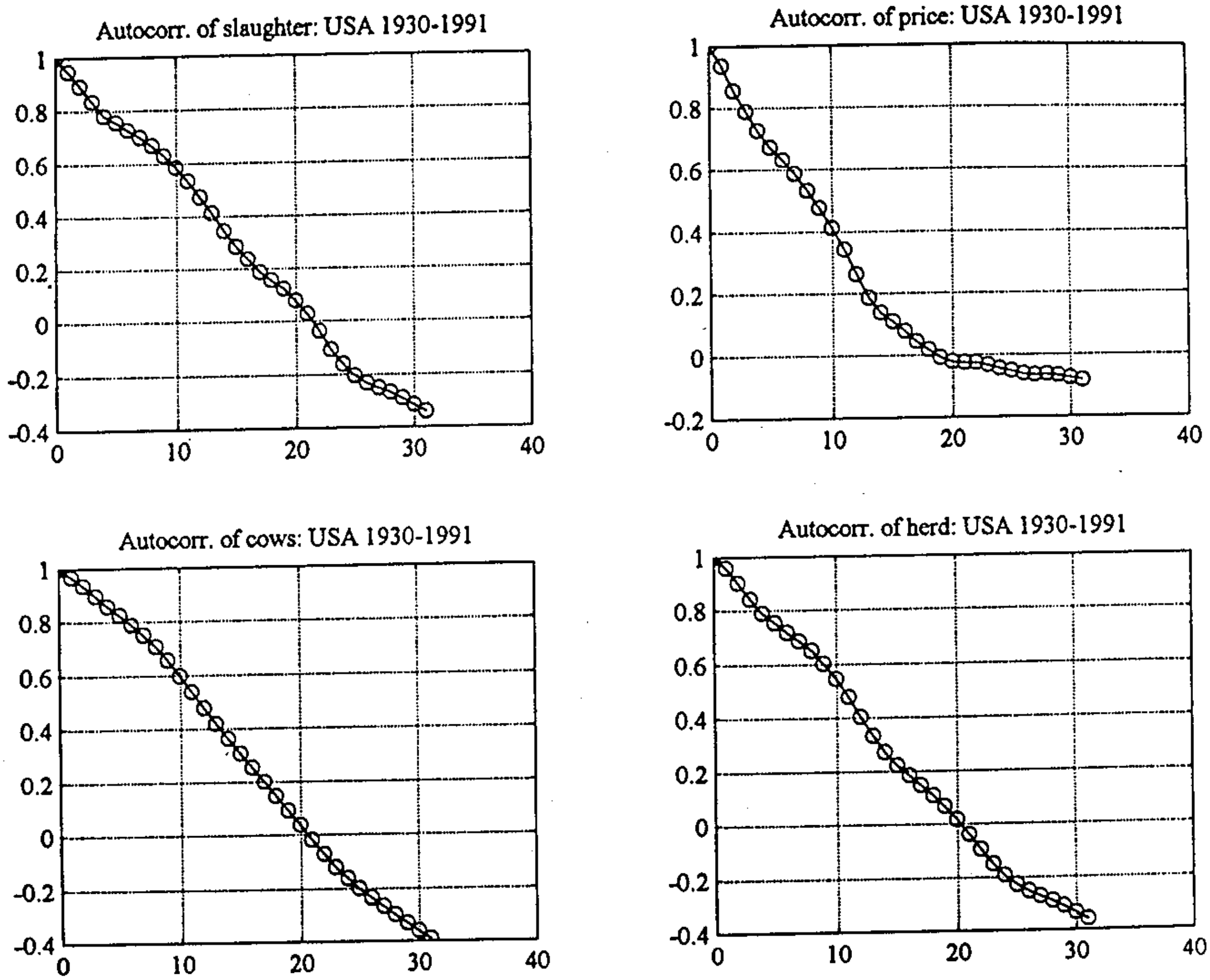


Figure 8
USA: autocorrelation

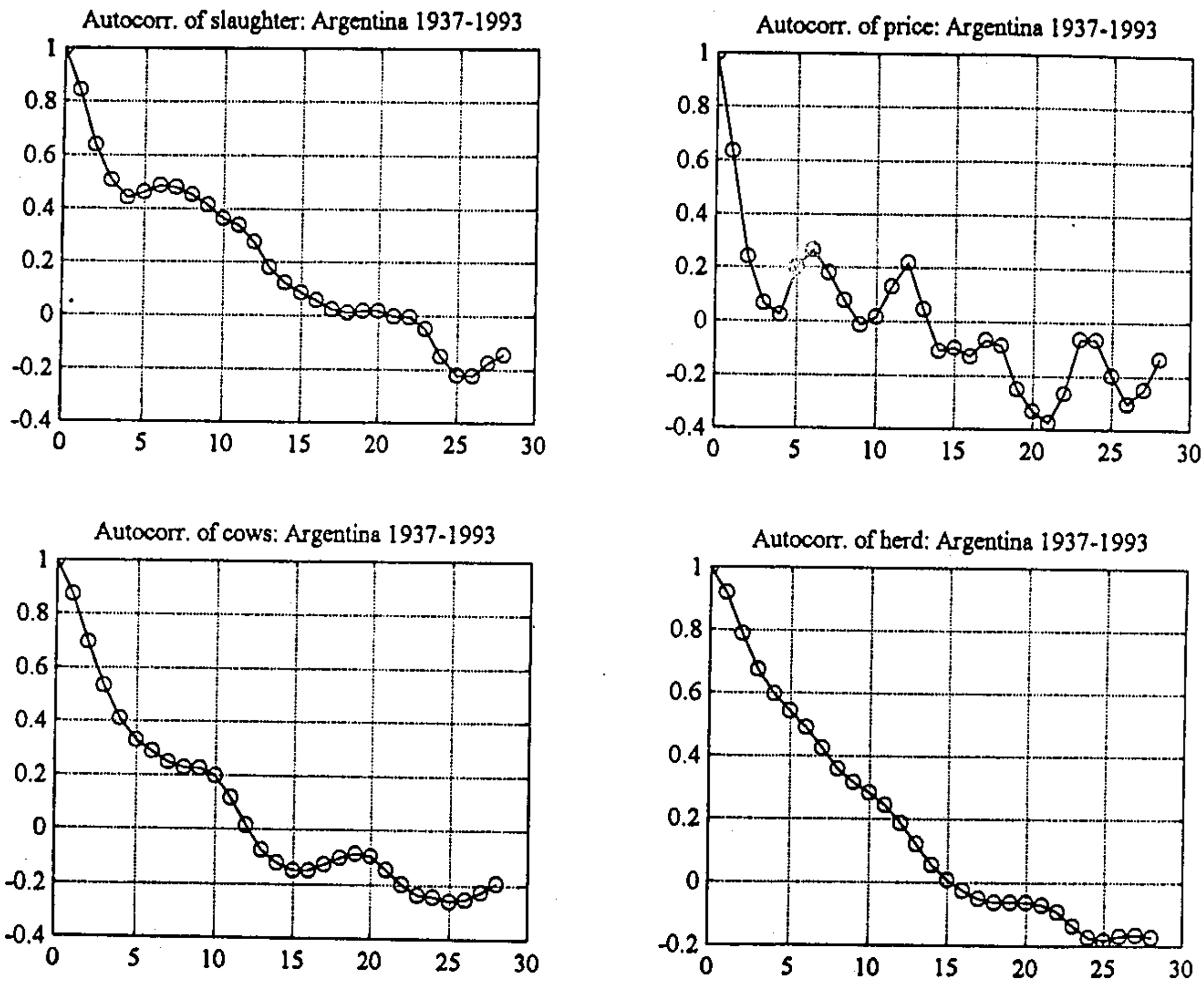


Figure 9
Argentine: autocorrelation

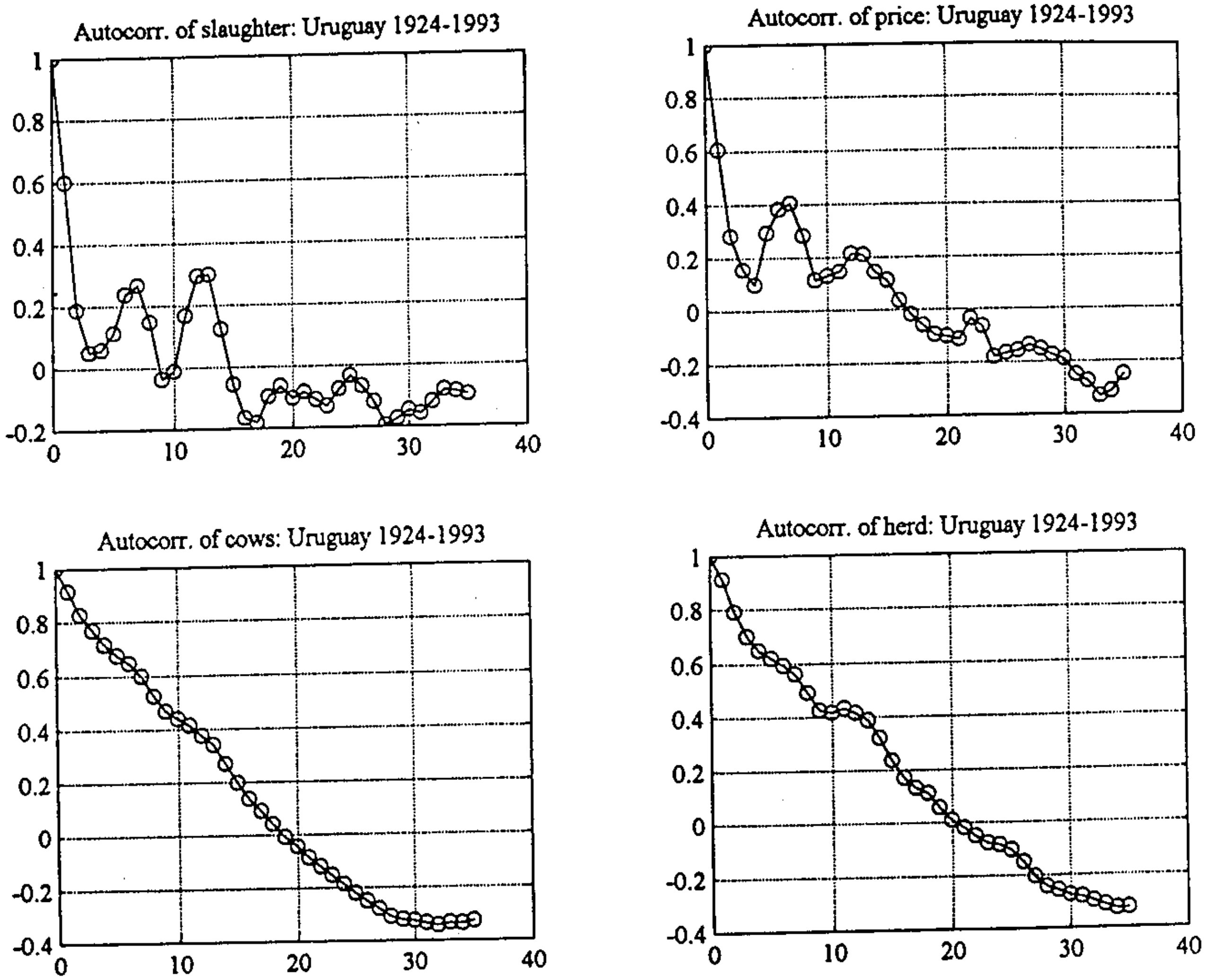


Figure 10

Uruguay: autocorrelation

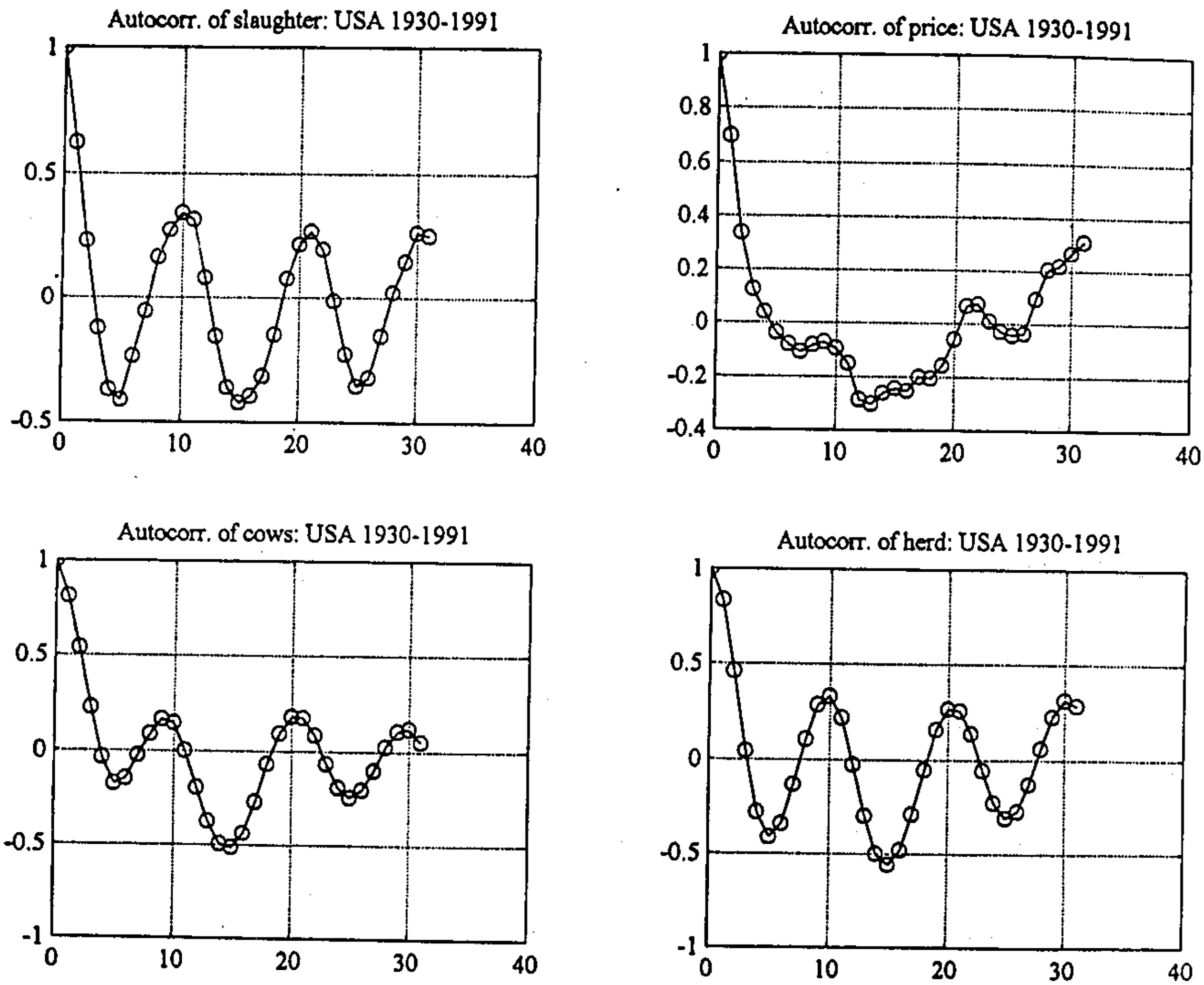


Figure 11

USA: autocorrelation - filtered data

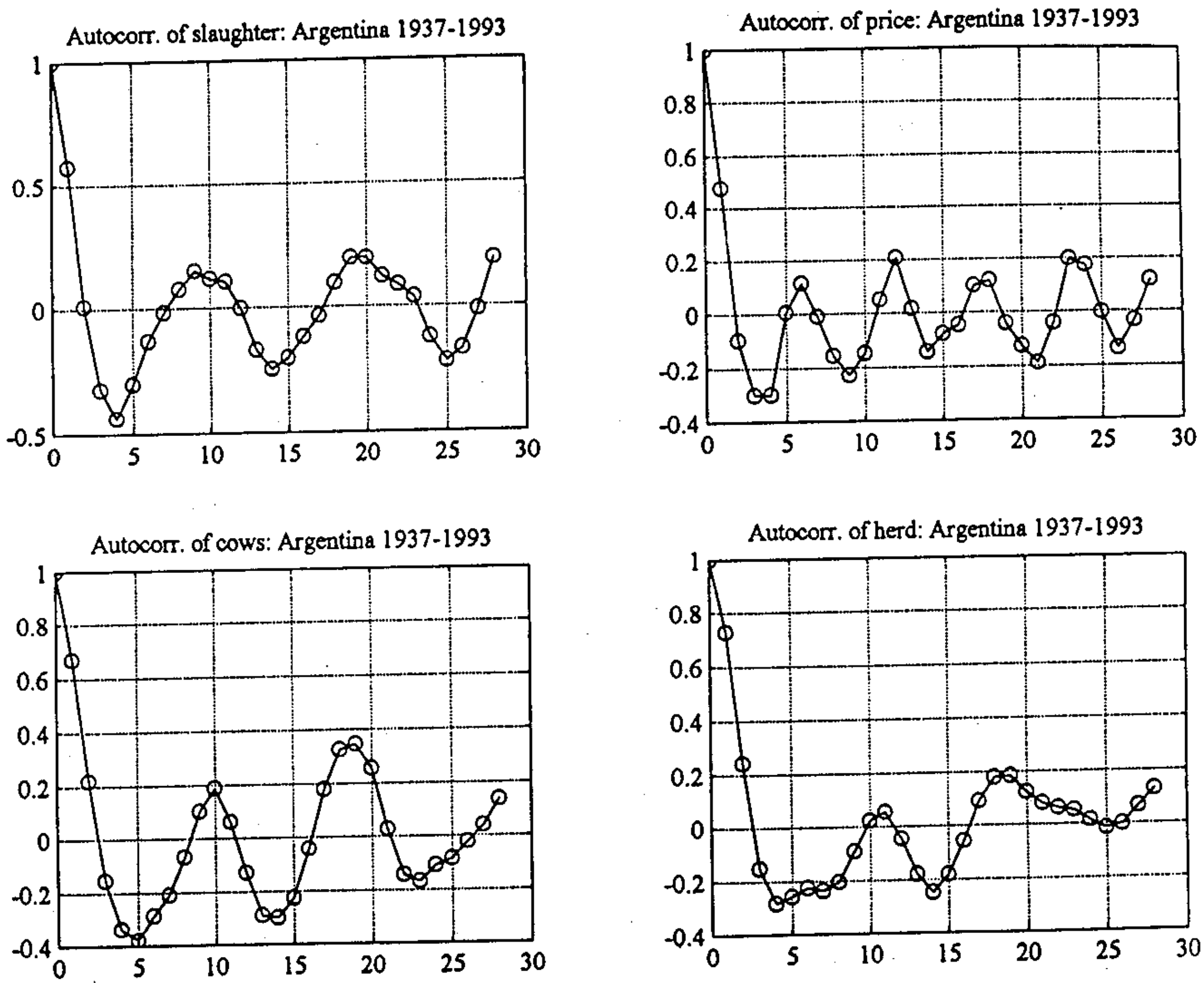


Figure 12

Argentine: autocorrelation - filtered data

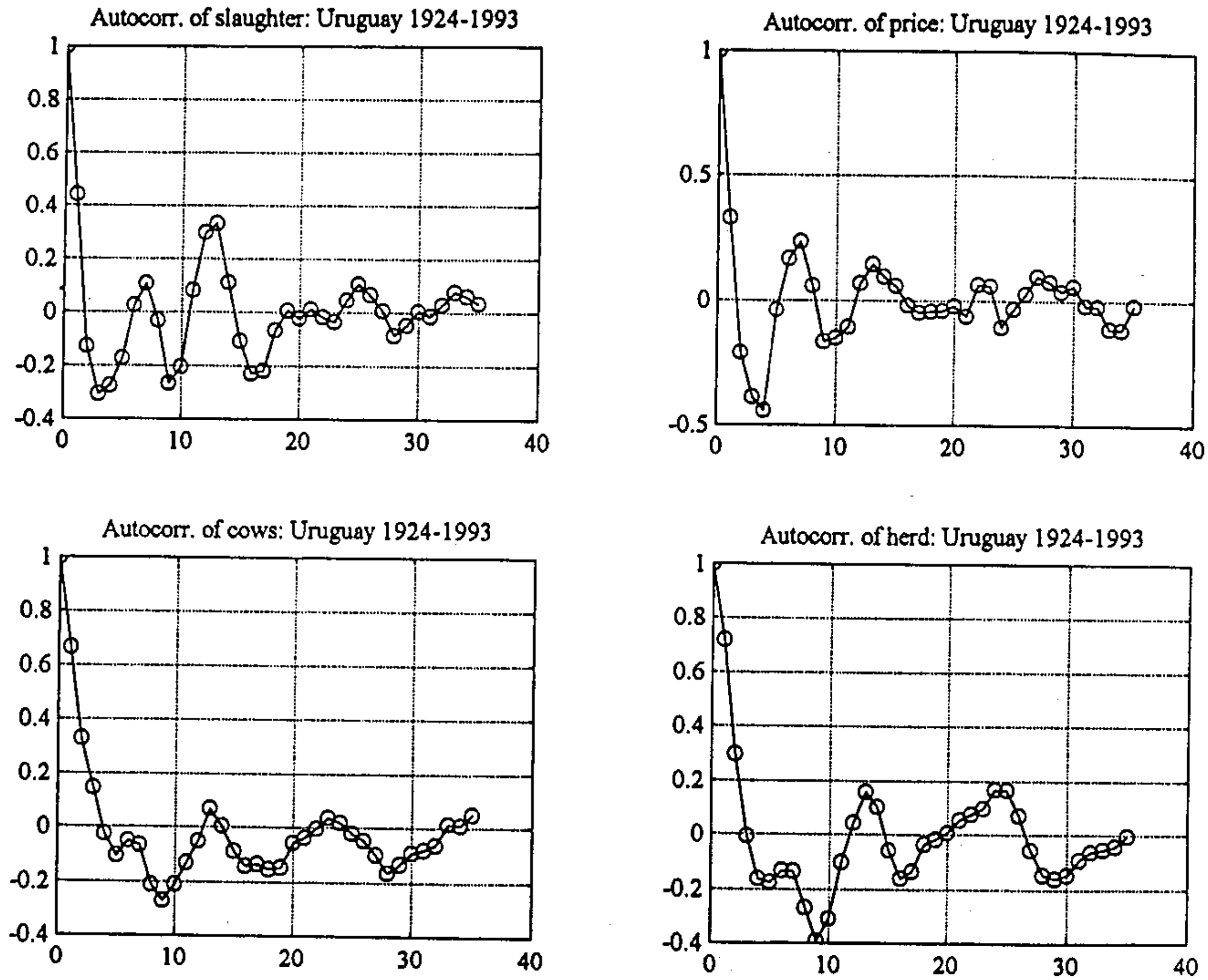
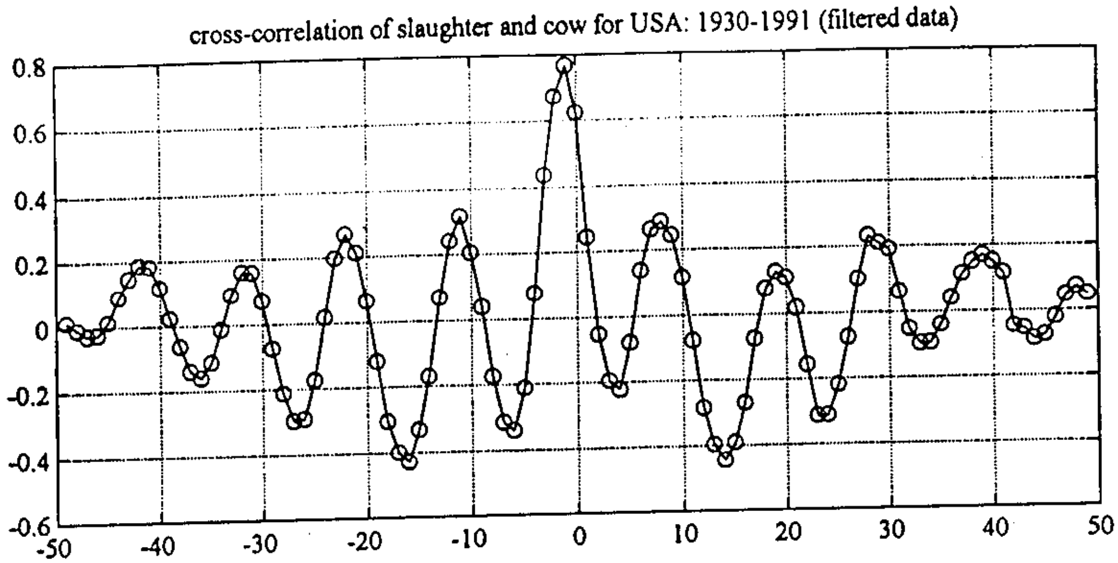
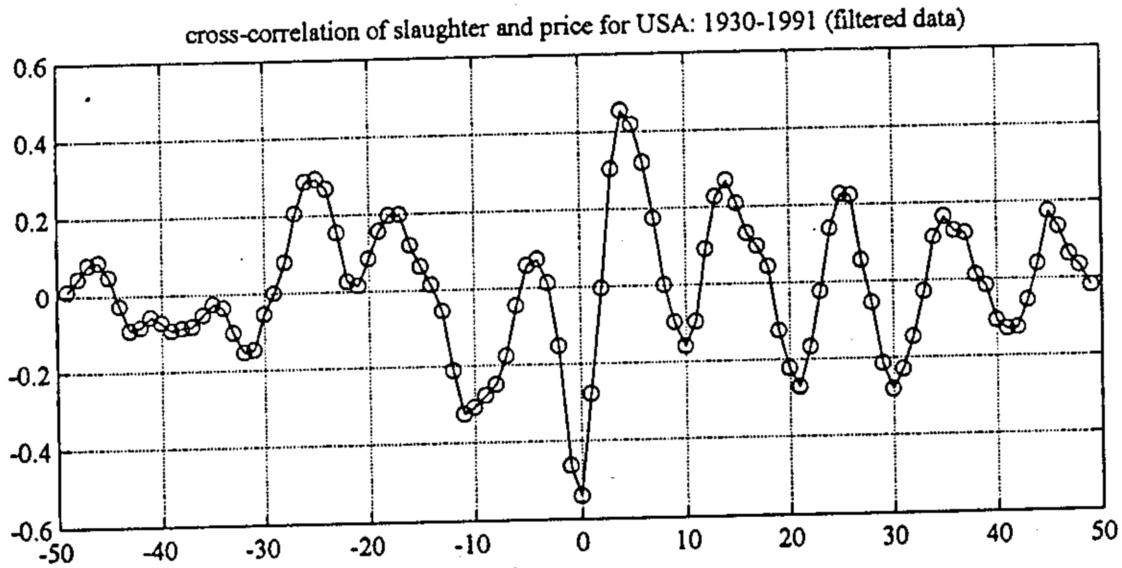


Figure 13

Uruguay: autocorrelation - filtered data





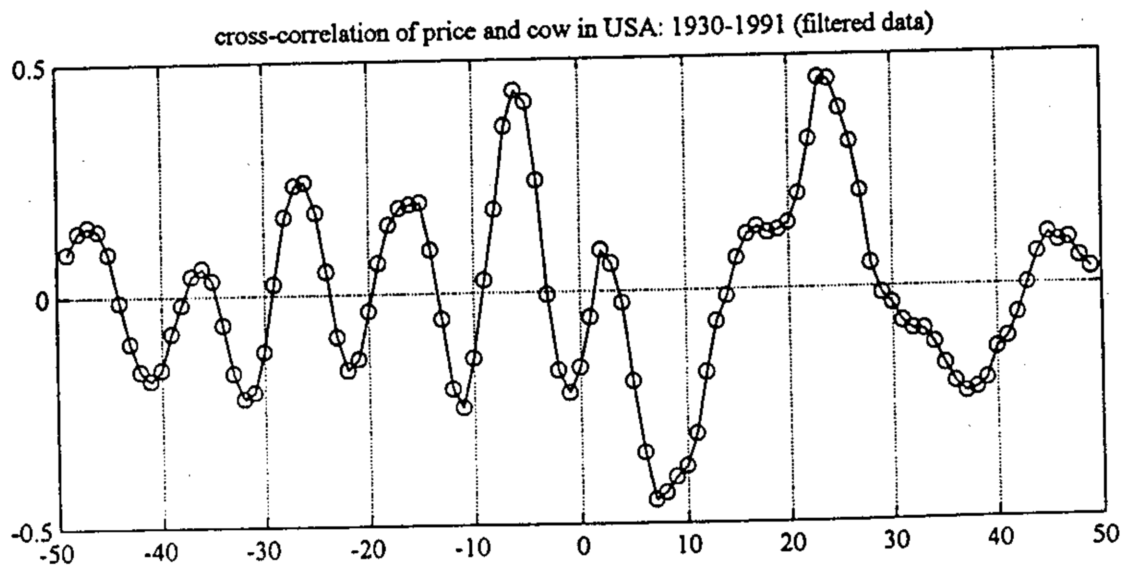


Figure 14
USA: cross correlation

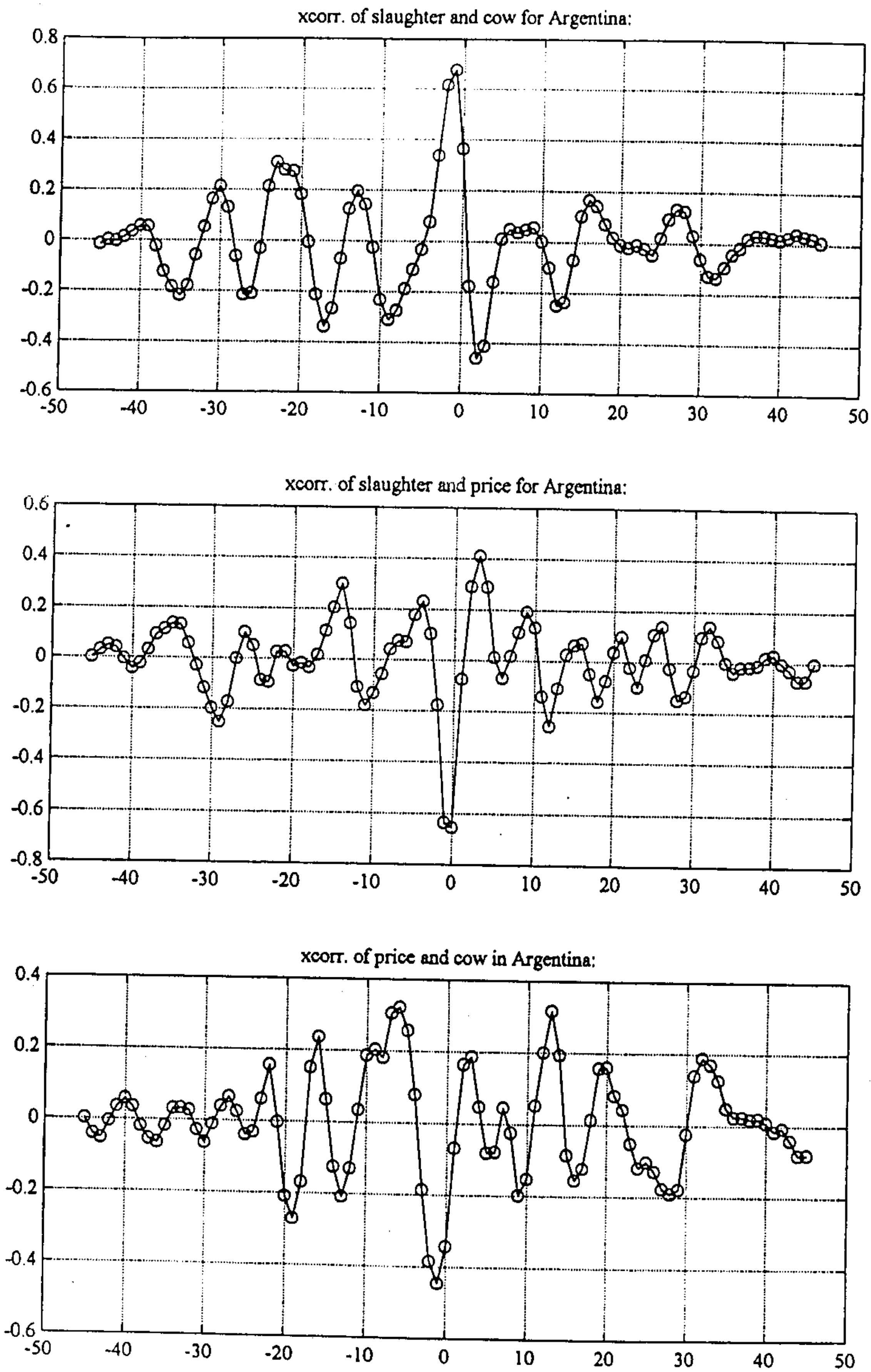
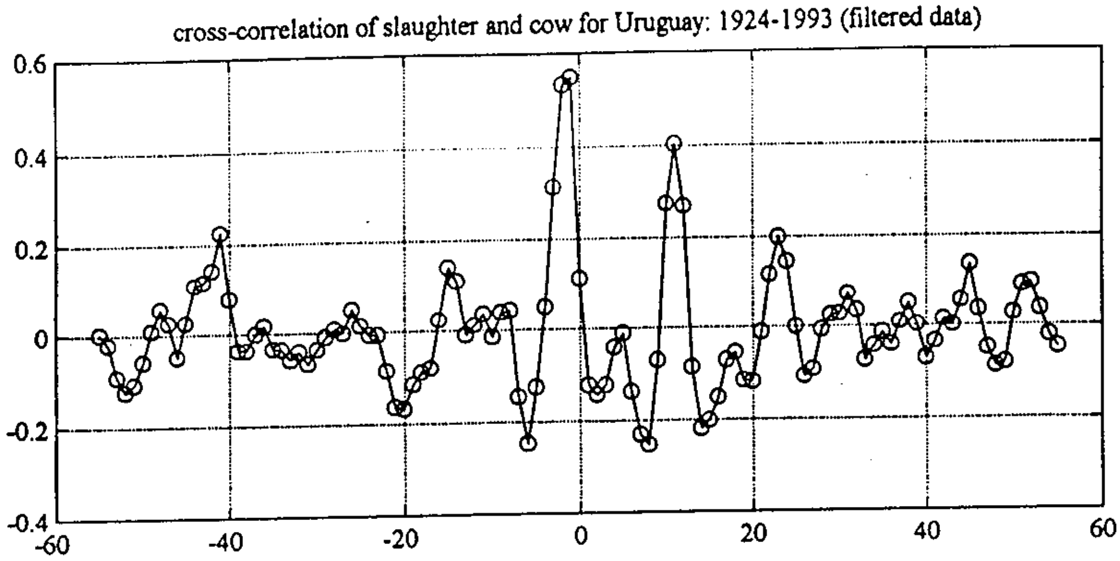
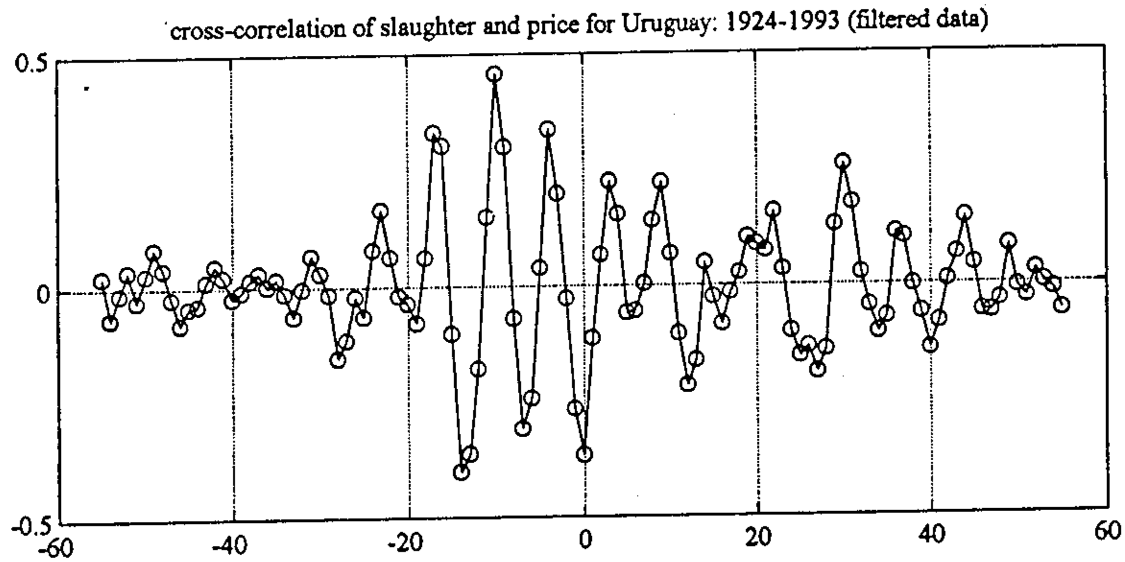


Figure 15
Argentine: cross correlation





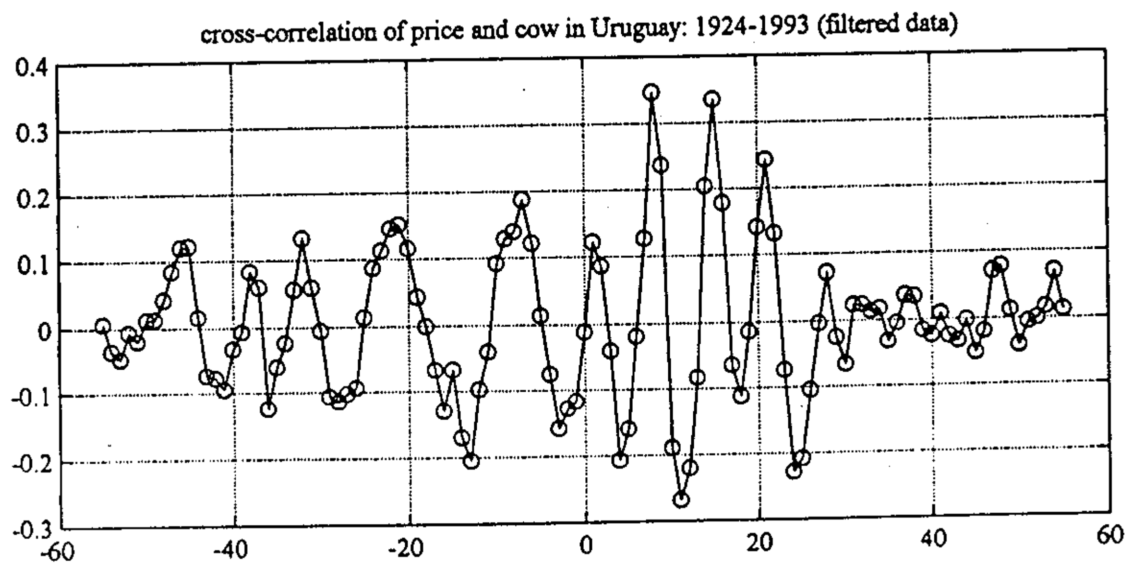


Figure 16
Uruguay: cross correlation

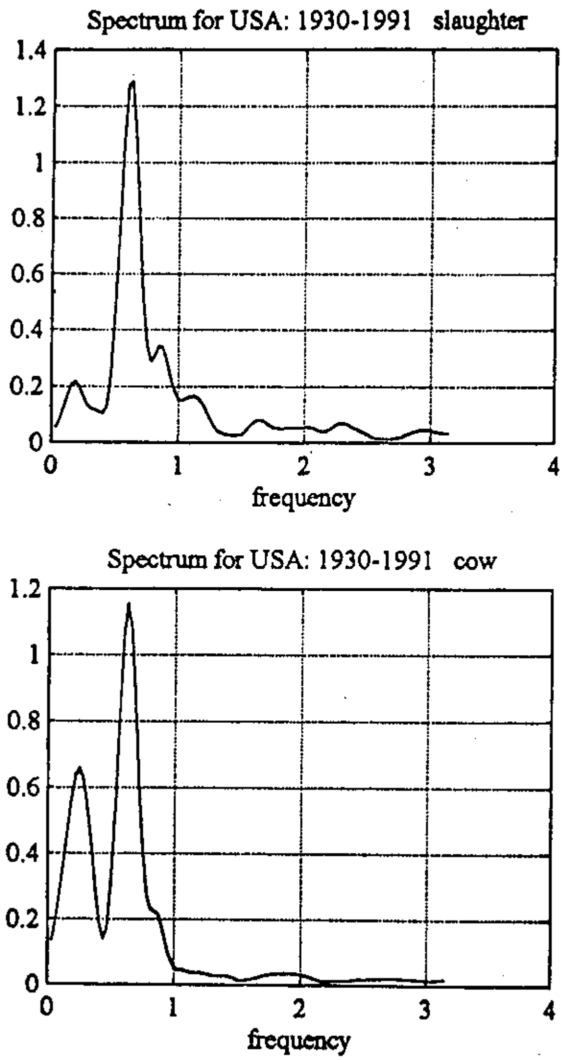


Figure 17
USA: spectrum

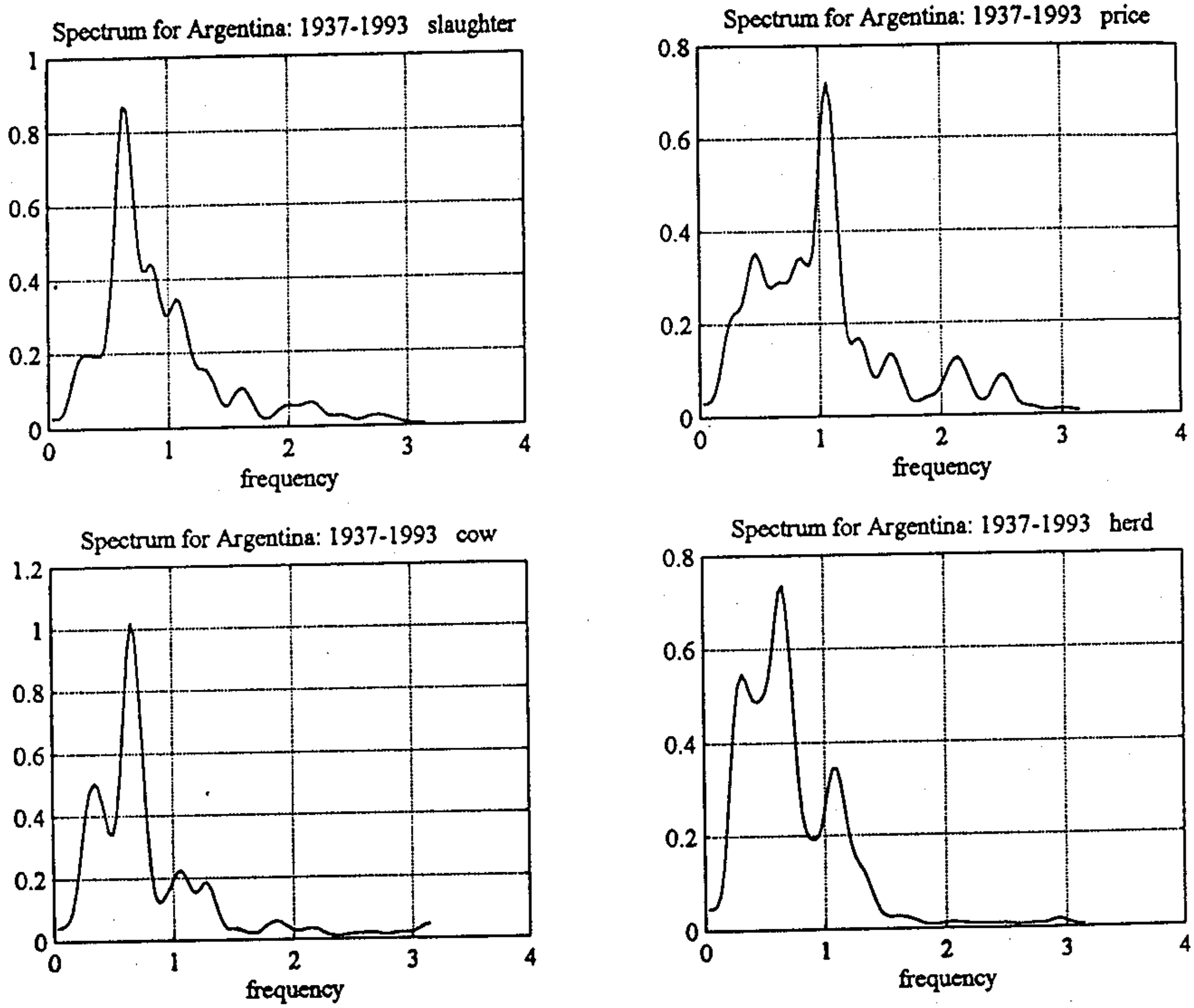


Figure 18
Argentine: spectrum

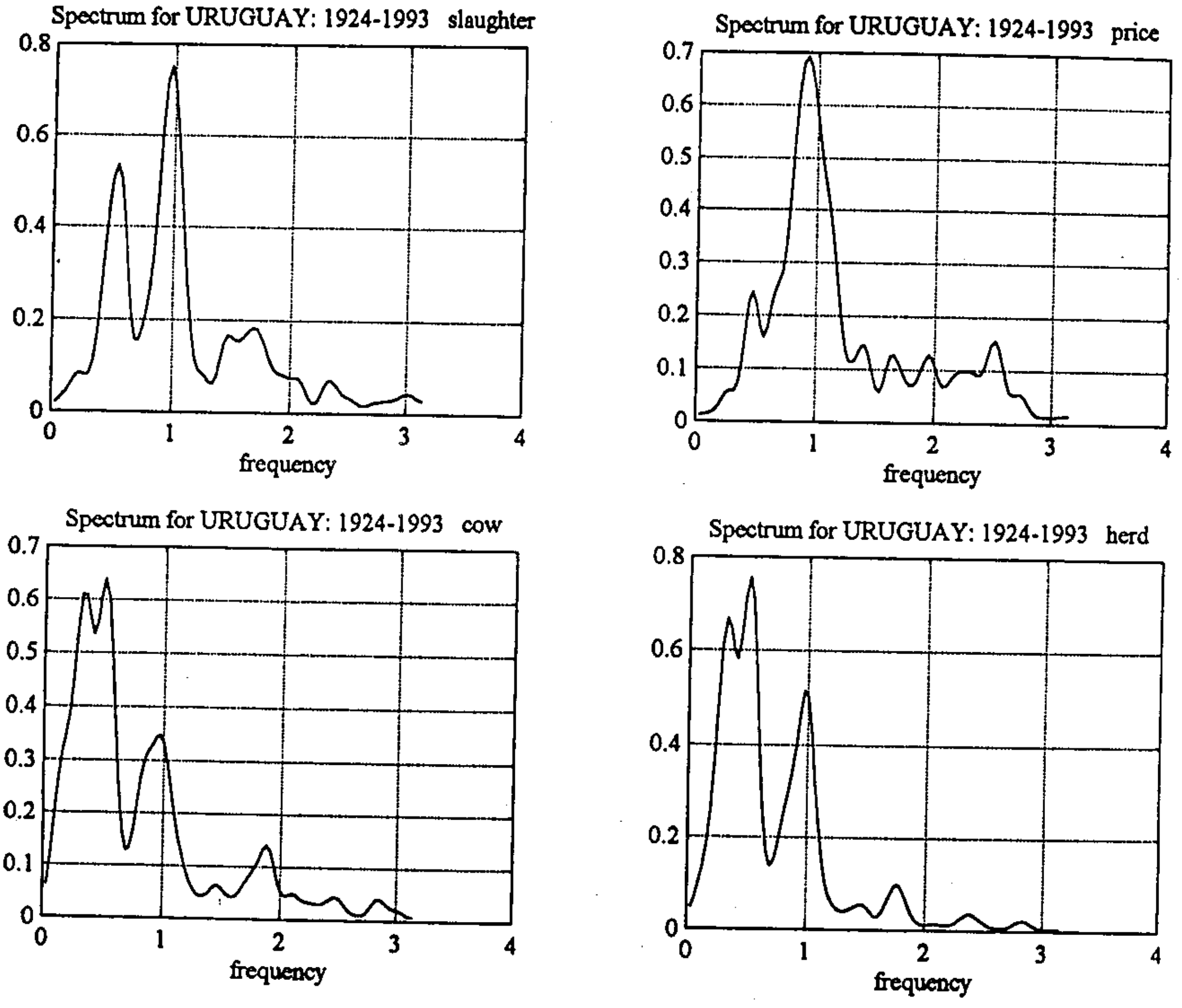


Figure 19
Uruguay: spectrum

APPENDIX: COUNTRY DATA

Table 4 -- Argentina data

YEAR	Price of Steer	Price of Steer (deflated)	Slaughtered Cattle	Cow Herd (1)	Cow Herd (2)	Cattle Stock	Cattle Herd
					(in thousand units)		
1930			6,524.30	13,745		32,212	
1931			5,898.60				
1932			5,857.60				
1933			6,250.50				
1934	0.16	33,926,356	6,578.60				
1935	0.20	38,063,636	7,043.90				
1936	0.22	38,869,892	7,380.60				
1937	0.22	38,576,188	7,848.00	14,377	16,180	33,207	39,898
1938	0.21	37,769,148	7,773.70		15,711		39,259
1939	0.23	39,965,248	8,169.50		15,609		40,091
1940	0.25	41,978,244	7,688.00		15,209		39,467
1941	0.28	46,365,292	8,275.60		15,949		39,592
1942	0.35	55,311,812	7,700.90		16,695		40,339
1943	0.35	53,928,404	7,226.30		16,867		40,150
1944	0.38	58,613,188	7,088.00		17,319		40,036
1945	0.38	48,941,972	6,583.50		17,896		42,366
1946	0.39	42,485,100	7,916.90		18,198		44,214
1947	0.48	46,439,324	9,406.60	16,733	18,932	41,048	45,854
1948	0.53	45,271,024	9,203.30		19,183		46,764
1949	0.62	40,571,544	9,480.30		19,205		46,933
1950	0.72	37,586,136	9,897.90		19,366		46,205
1951	1.15	44,077,768	8,978.00		19,053		45,717
1952	1.62	44,631,060	8,785.70	17,635	18,867	45,750	47,137
1953	1.94	51,294,952	7,896.10	16,850	19,320	41,182	47,724
1954	1.92	49,113,404	8,133.10	17,865	20,943	43,596	51,510
1955	1.87	42,408,688	10,003.90	17,970	22,578	43,978	55,159
1956	2.28	45,665,756	11,664.30	19,191	23,396	46,940	56,484
1957	2.52	40,440,052	11,961.70	17,623	23,080	43,980	54,660
1958	4.04	49,320,784	12,277.70	16,483	22,071	41,327	51,811
1959	14.06	80,303,392	9,148.30	16,374	20,669	41,167	48,220
1960	15.15	68,334,048	8,883.60	17,738	21,125	43,521	50,161
1961	13.78	54,654,128	10,212.30	17,942	21,361	43,520	54,439
1962	16.08	50,564,608	11,790.50	16,991	21,860	42,901	56,581
1963	23.25	58,037,072	12,926.50	15,987	22,101	40,344	54,795
1964	40.51	82,788,696	9,367.60	18,196	21,580		52,919
1965	50.52	80,287,456	9,133.90	20,044	22,892	46,909	54,733
1966	49.94	60,187,816	11,075.80		23,903		56,082
1967	60.71	56,738,316	12,520.50	20,044	23,912	51,277	56,710
1968	64.23	51,384,004	12,802.00	19,860		51,465	
1969	66.84	49,880,592	13,820.90	18,721		49,733	
1970	97.70	64,276,316	12,924.50	19,105		48,419	
1971	178.20	86,926,832	9,467.70	19,227		49,787	
1972	285.50	87,846,152	10,010.10	20,781		52,306	
1973	420.80	80,767,760	9,817.90	21,821		54,770	
1974	391.10	60,448,224	10,114.90	21,309		56,300	
1975	738.10	40,333,332	12,146.00			57,300	
1976	5,404.00	54,267,924	13,868.00	23,525		58,174	
1977	15,061.00	54,795,168	14,748.10	23,565		59,192	
1978	32,823.00	43,345,000	16,250.20	22,316		58,705	
1979	109,651.00	55,797,776	15,224.80	21,625		56,864	
1980	178,414.00	45,221,912	13,830.50	21,068		55,761	
1981	310,724.00	38,517,912	14,650.50	20,876		54,235	
1982	1,386,130	64,893,724	12,362.10	20,385		52,650	
1983	6,230,000	65,717,296	11,425.60	20,866		53,790	
1984	39,910,000	57,932,936	12,221.40	21,025		54,569	
1985	190,000,000	35,714,284	14,509.10	20,236		54,000	
1986	509,999,936	50,435,116	14,848.90	19,700		52,537	
1987	1,344,000,000	57,460,456	12,877.60	19,285		51,000	
1988	5,774,000,128	55,733,592	12,200.00	16,914		52,257	
1989	188,529,999,900	57,223,940	12,210.00			52,602	
1990	2,686,750,032,000	33,782,636	12,467.40			52,845	
1991	6,578,880,119,000	30,449,052	12,344.90			53,011	
1992	8,320,000,197,000	30,830,666	11,712.50	19,455		53,011	
1993	7,169,999,634,000	24,020,300	11,894.90			52,173	

Sources: Price of Steer is the price of steers in the Liniers market. SGAyP Databank.
Price of Steer deflated by the CPI. SGAyP Databank.

Slaughtered Cattle. From 1930 to 1956 DGEA of the MAyG; From 1957 to 1959 JNC; From 1960 to 1993 SGAyP databank.
Cow Herd (1): SGAyP databank.
Cow Herd (2): R.Yver (1971) Pp.73.
Cattle Stock: SGAyP databank.
Cattle Herd : Yver (1971) Pp.73.

Table 5 – U.S.A. data

YEAR	PBUS1\PB (1930-1989)	APC (1930-1991)	SGT (1930-1991)	STT (1930-1991)	STC (1930-1992)
	(in $US)		(in thousand units)		
1930	16.42	0.60	12,056	61,003	12,491
1931	12.61	0.32	12,096	63,030	13,392
1932	10.75	0.32	11,980	65,801	14,152
1933	7.83	0.52	13,107	70,280	15,414
1934	9.95	0.82	19,509	74,369	17,058
1935	14.93	0.66	14,805	68,846	15,156
1936	12.31	1.04	15,901	67,847	15,185
1937	16.71	0.52	15,254	66,098	14,527
1938	13.64	0.49	14,822	65,249	13,856
1939	14.26	0.57	14,621	66,029	13,623
1940	15.12	0.62	14,958	68,309	14,655
1941	16.21	0.75	16,419	71,755	15,826
1942	18.78	0.92	18,033	76,025	17,370
1943	19.40	1.12	17,845	81,024	19,348
1944	18.70	1.03	19,844	85,334	21,400
1945	18.70	1.23	21,694	85,573	22,479
1946	26.24	1.53	19,824	82,235	22,209
1947	39.91	2.16	22,404	80,554	22,164
1948	47.27	1.28	19,177	77,171	21,437
1949	39.97	1.24	18,765	76,830	21,488
1950	43.77	1.52	18,614	77,963	22,449
1951	52.97	1.66	17,084	82,083	24,696
1952	50.06	1.52	18,625	88,072	28,023
1953	37.62	1.48	24,465	94,241	31,147
1954	37.73	1.43	25,889	95,679	32,807
1955	36.92	1.35	26,587	95,592	33,598
1956	35.65	1.29	27,755	95,900	32,976
1957	37.05	1.11	27,068	92,860	31,809
1958	42.39	1.12	24,368	91,176	31,400
1959	42.57	1.05	23,722	93,322	33,072
1960	41.38	1.00	26,026	96,236	34,859
1961	38.67	1.10	26,467	97,700	35,968
1962	43.11	1.12	26,911	100,369	37,738
1963	37.69	1.11	28,070	104,488	40,411
1964	36.48	1.17	31,678	107,903	43,240
1965	40.48	1.16	33,171	109,000	45,080
1966	40.28	1.24	34,171	108,862	45,250
1967	41.01	1.03	34,295	108,783	45,770
1968	43.84	1.08	35,414	109,371	46,700
1969	47.75	1.15	35,574	110,015	47,570
1970	46.82	1.33	35,334	112,369	49,252
1971	52.39	1.06	35,895	114,578	50,655
1972	55.34	1.57	36,083	117,862	52,196
1973	67.41	2.55	34,026	121,539	54,798
1974	67.09	3.02	37,327	127,788	58,227
1975	73.64	2.54	41,464	132,028	61,114
1976	60.96	2.15	43,196	127,980	54,484
1977	62.66	2.02	42,381	122,810	56,018
1978	80.80	2.25	39,970	116,375	52,545
1979	101.72	2.48	34,008	110,864	50,034
1980	104.39	3.12	34,116	111,242	50,181
1981	99.85	2.47	35,265	114,351	52,190
1982	101.68	2.55	36,155	115,444	53,027
1983	97.87	3.21	36,974	115,001	52,241
1984	100.17	2.63	37,892	113,360	51,528
1985	90.68	2.23	36,593	109,582	49,968

Table 5 – U.S.A. data (continued)

YEAR	PBUS1\PB (1930-1989)	APC (1930-1991)	SGT (1930-1991)	STT (1930-1991)	STC (1930-1992)
	(in $US)		(in thousand units)		
1986	89.00	1.50	37,568	105,378	46,872
1987	97.24	1.94	35,890	102,118	46,504
1988	103.07	2.54	35,324	99,622	46,301
1989	107.78	2.36	34,106	98,065	46,114
1990		2.28	33,439	98,162	46,646
1991		2.40	32,885	98,896	47,233
1992				100,110	48,258

Sources: PBUS: US Department of Commerce, Bureau of the Census, Historical Statistics: Colonial Times to 1970 (HSUS), 1899-1970; US Department of Agriculture, Agriculture Statistics (AS) 1977, Table 437, Pp. 314, 1971-1976; and AS 1992, Table 393, Pp. 254.

STTUS and STCUS: AS 1993, Table 371, Pp 229, 1988-91; AS 1987, Table 385, Pp.257, 1972-87; AS 1984, Table 388, Pp.261, 1969-71; AS1976, Table 420, Pp.297, 1960-68; and AS 1972, Table 447, Pp.358, 1930-59.

SGTUS: AS 1993, Table 381, Pp 237, 1987-91; AS 1987, Table 395, Pp.265, 1972-86; AS 1972, Table 460, Pp.371, 1945-71; and HSUS, 1897-1944.

Notes: PBUS: Price of Beef in the US. For 1899 to 1970, the price of beef steers is used; for 1971 to 1991, the average price per 100 pounds choice at Omaha was used; the two series were linked by calculating the average ratio of both series for the ten year period they overlap and use this ratio to transform the Omaha original figures.
STTUS: All cattle and calves.
STCUS: Beef cows that have calved plus beef cow replacements plus other cows.
SGTUS: Cattle slaughtered.

Table 6 – Uruguay data

YEAR	Price of Slaughtered Cattle (deflated)	Slaughtered Cattle	Cows Herd	Cattle Herd
			(in thousand units)	
1920		903	3,034	
1921		829	3,056	
1922		1,320	3,079	
1923		1,658	3,102	
1924		1,396	3,125	8,432
1925		1,467	3,012	8,557
1926		1,539	2,903	8,333
1927		1,475	3,144	8,003
1928		1,513	2,974	7,733
1929		1,636	2,814	7,583
1930	46.50	1,912	2,662	7,096
1931	45.00	1,312	2,737	7,060
1932	35.50	1,090	2,814	7,272
1933	80.00	1,198	2,893	7,542
1934	72.00	1,321	2,975	7,703
1935	39.00	1,442	3,058	7,602
1936	40.50	1,198	3,048	7,858
1937	45.00	1,320	3,100	8,298
1938	47.00	1,376	3,231	8,330
1939	52.50	1,372	3,195	8,136
1940	55.00	1,441	3,217	7,891
1941	60.00	1,458	3,211	7,704
1942	64.00	1,474	3,212	7,613
1943	70.00	1,516	2,407	7,462
1944	83.00	953	2,608	6,993
1945	72.00	922	2,610	6,633
1946	52.33	1,103	2,346	6,821
1947	64.67	930	2,430	7,037
1948	68.67	952	2,610	7,536
1949	71.67	1,381	2,808	8,081
1950	71.00	1,628	2,860	8,205
1951	70.00	1,563	2,852	8,154
1952	75.00	1,444	2,783	7,930
1953	60.00	1,537	2,734	7,765
1954	76.00	1,271	2,638	7,467
1955	65.00	1,034	2,619	7,389
1956	75.00	1,158	2,643	7,433
1957	81.43	1,220	2,753	7,716
1958	68.89	1,057	2,811	7,853
1959	115.83	1,083	2,937	8,177
1960	123.53	1,253	3,075	8,532
1961	83.81	1,239	3,179	8,792
1962	71.67	1,271	3,273	8,900
1963	66.21	1,361	3,251	8,682
1964	74.76	1,785	3,310	8,698
1965	95.85	1,604	3,330	7,813
1966	103.25	1,107	3,224	8,188
1967	75.53	1,151	3,353	8,582
1968	59.40	1,596	3,353	8,512

Table 6 -- Uruguay data (continued)

YEAR	Price of Slaughtered Cattle (deflated)	Slaughtered Cattle	Cows Herd	Cattle Herd
			(in thousand units)	
1969	60.41	1,568	3,324	8,282
1970	69.65	1,791	3,289	8,564
1971	87.54	1,350	3,678	8,882
1972	117.60	1,262	3,798	9,273
1973	103.11	1,224	3,926	9,860
1974	80.81	1,532	4,130	10,672
1975	47.72	1,755	3,002	11,530
1976	42.64	2,163	2,744	10,383
1977	57.35	1,760	2,946	10,111
1978	65.82	1,593	3,051	10,001
1979	113.34	1,295	3,109	10,300
1980	69.87	1,538	3,993	11,173
1981	54.19	1,915	3,484	11,421
1982	84.94	2,148	2,974	11,237
1983	57.68	2,166	2,649	9,704
1984	71.21	1,452	2,841	9,062
1985	56.93	1,540	2,895	9,370
1986	65.94	1,576	2,940	9,300
1987	77.87	1,218		9,345
1988	65.06	1,409		10,333
1989	60.69	1,818		9,447
1990	59.08	1,541		8,692
1991	50.45	1,261		9,001
1992	46.15	1,334		9,508
1993	39.23	1,315		10,093

Sources: Price of Slaughtered Cattle Deflated by the Consumer Price Index. From 1930 to 1984 Favaro (1990); from 1985 to 1993 an annual index was constructed as the average of end of month data on price of steers in US dollars (source is ACG databank), multiplied by the exchange rate (source is IFS databank) divided by the consumer price index (source is IFS databank).

Slaughtered Cattle: For 1930-1934 Barbato de Silva (1977); 1935-1939 Rama (1981); 1940-1973 CERES databank; 1974-1993 DICOSE, Muestra Urgente (several issues), MGAP.

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