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by

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Abstract

Among prominent recognized features of the industrialization of animal production over the past half century are growth in the stock of inflexible, or use-dedicated capital, as an input in production, and growth in productivity. Less recognized is a trend toward aseasonal production. We record the deseasonalization of animal production in the US and European countries over the past 70 years. We also suggest that A) lower seasonality can precede or Granger-cause increased productivity due to increased capital intensity, and B) productivity improvements can Granger-cause lower seasonality. Process A) should be more likely earlier in the industrialization process. For US dairy production, our empirical tests find some evidence that process A) operated early in the 20th Century while process B) operated in more recent times.

Keywords: Capital Intensity, Causality, Dairy, Regional Production Systems

Seasonality, Capital Inflexibility, and the Industrialization of Animal Production

Agriculture has become more capital intensive in most of the world during the latter part of the 20th Century. This capital deepening has occurred largely in the machinery, irrigation, and buildings categories (Larson, Butzer, Mundlak, and Crego). The structural effects have been particularly notable in animal agriculture in the developed world, where the phrases 'factory farming' and 'industrialized agriculture' correctly depict an animal production process for hogs, chickens, turkeys, and laying eggs that is broadly similar to the prototypical manufacture of widgets. These large farms have increasingly automated production processes, and most workers are employees with routinized tasks.

Field crop agriculture on the other hand, though greatly affected by mechanization and other technological innovations, does not yet resemble an industrialized process. Allen and Lueck argue convincingly that randomness due to weather is primarily responsible because it confounds monitoring in the principal-agent relation, and it requires managerial focus when organizing many mundane production activities. Strengthening control over animal agriculture has involved largely strengthening the control of nature in the production process. Animals have been confined, while seasonal aspects of biological behavior have been suppressed through breeding or physiological interventions. Consequences have been the homogenization of the production process and the growing affordability of cheap animal protein in much of the world.

Notwithstanding attention from several academic fields, the process of industrialization at the sector level is not well-understood. This is so in agriculture and in other sectors. Most economic studies on industrialization assume agriculture to be the reference non-industrial sector, and their insights concerning the details of agriculture are limited. Technology in agriculture is seen to matter because it frees up resources for other uses (Jorgenson; Scitovsky). Kuznets does emphasize co-dependency, through spillover effects, between technical change in agriculture and other sectors. This view sees agriculture developing along with other sectors so that all sectors are comparably industrial. A facet of this viewpoint arises in the induced innovation argument of Hayami and Ruttan. If the price of agricultural labor rises due to increased demand from other sectors, then labor-saving innovations should be induced in response over time.

Studies in economic history have shown evidence that interactions between agricultural seasonality, non-agricultural industrialization, and productivity outside agriculture are likely adverse because industrial plants are most efficient when labor supply is constant (Sokoloff and Dollar; Sokoloff and Tchakerian; Anderson). Our interest is not in the role of agricultural seasonality on external industries, but in its role on agriculture itself.

As to what industrialization is, it has many features involving firm behavior, industry structure, the creation of new subsectors and change in the nature of sector products. We refer the reader to Meeker, to Boehlje, or to Drabenstott on characterizations, and qualify the components that we are interested in as primarily firm-level and industry-level behavior regarding technologies used. The technologies should emphasize the control, systemization, and routinization of processes in order to be more assured of product volume and quality at low cost given the larger capital investment necessary for an industrial approach. Regarding the efficiency effects of capital deepening, Chandler (p. 24) has written

> “These potential cost advantages could not be fully realized unless a constant flow of materials through the plant or factory was maintained to assure effective capital utilization. If the realized volume of flow fell below capacity, then actual costs per unit rose rapidly. They did so because fixed costs remained much higher and “sunk costs” (the original capital investment) were also much higher than in the more labor-intensive industries.”

How industrialization arises is largely a question of structural dynamics because the process is not instantaneous and there is no guarantee it will continue to the point where a sector or economy is recognized as being industrialized. Some inquiries into the path taken suggest the possibility of multiple equilibria (Murphy, Shleifer, and Vishny; Matsuyama; Gans, 1997; Chen and Shimomura; Ciccone) so that the economy needs a ‘big push’ to industrialize. As Gans (1998) has pointed out, the existence of multiple equilibria relies on the assumption that firms face two technology choices where one is increasing returns and the other is a constant returns reference technology. This 'big push' literature leads naturally to policy proposals on engineering an equilibrium, typically a more industrial equilibrium given the increasing returns to scale that are present. Due to its macro-economy nature, this area of work has little to say about how the particulars of any given industry affect the industrialization process. Our interest is focused on animal agriculture, and we intend to show that sector detail can provide insights on the process.

The formal literature on explaining the agricultural industrialization process is quite sparse. In one sense this is not surprising because the set of events presents somewhat of a conundrum. Agricultural produce is largely commodity in character, while market size is both large and stable. Management of on-farm processes does not require intensive formal training. These technology attributes make the production of food quite like cloth or pin manufacture, and so an explanation on the critical distinctions are warranted.

One theory is that agricultural industrialization is demand-led, through increasing demand by consumers and food retailers for product and process information (Barkema; Drabenstott; Kinsey). While likely a facet of the subject, for industrialized agriculture can deliver higher quality and more information, demand-side ideas have thus far explained little about the process. The demand-side story is best at explaining changes in control and increasing vertical coordination across much of the food sector. Consumers (or, more likely, their agents) want to peer inside the farm in order to verify quality and caretaking behavior (Hennessy). Processors seek knowledge on product attributes in order to better satisfy consumers. Demand-side arguments do not explain why crop agriculture is not industrial. Nor does it explain common features in the technologies that tend to accompany industrialization. Part of the answer must lie in the nature of the process and product.

Allen and Lueck, in extending insights by Becker and Murphy on the importance of information in coordinating activities, hold that noise and other irregularities in the production process are a reason that crop agriculture has not industrialized. Hennessy, Miranowski, and Babcock go further to suggest that biotechnology innovations can promote three features of industrialization. These are demand for tight control over the production environment, strong productivity growth, and an increasingly differentiated product. Motivated by Chandler, in this paper we consider two other features of agricultural industrialization; the roles of low variability in throughput and enterprise-dedicated capital in enhancing productivity.[1]

Briefly our problem is as follows. Animal production has tended to be seasonal due largely to the biology of the animals themselves and the plants they are fed on. Seasonal production had faced the problem of perishability, together with the unpleasant consequences of storage technologies (e.g., salting). Refrigeration, ease of transportation, and growing international trade have largely solved these problems, though at a modest cost (Goodwin, Grennes, and Craig). These, by themselves, should promote the extent of production seasonality and yet we will show that animal production seasonality has declined in recent decades. The resolution of the conundrum lies, we believe, partly in the inflexible nature of capital investments. Unlike labor and the versatile tractor, most other investments in animal agriculture tend to be inflexible in adapting efficiently to seasonality because machines are often dedicated to a particular use.

The intent of this paper is threefold. We will complement earlier work by Erdogdu on the United States by recording the deseasonalization of animal production using time series and statistical trends available for pork, beef, and (mostly) milk production in the Northern Hemisphere during the latter part of the 20th century. We will propose a theory on the origins of this deseasonalization, and on what it means for the industrialization of agriculture. We will also test this theory.

Our analysis is structured as follows. After this introduction, we focus on dairying to review some of the most important trends in animal production in the developed world during the last 50

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[1] Jovanovic and Rousseau provide evidence in favor of growth in enterprise-dedicated capital used by US corporations to motivate a theory on trends in the division of surplus.

years. Based on monthly production data for dairy, beef and pork in various countries, we present and discuss seasonality indicators. We then develop a brief causal model of diminishing seasonality. Hypotheses emerge concerning causal relationships between capital intensity and seasonality indices, and we test for evidence on these hypotheses.

The Seasonal Dimension: Dairying

While we see no reason that our theory would not apply to other animal products, we focus attention on dairying for two reasons. First, data on monthly production is readily available and interpretable across several countries. Second, the issue is topical in the dairy sector because traditional systems of more seasonal production remain viable whereas poultry meats, eggs, and hogs are now produced overwhelmingly in non-seasonal systems.

In the traditional United States dairy areas of the Upper Midwest, New England and New York, cows were grazed outdoors during the warmer half of the year. This approach took advantage of cheap in-situ grass while surplus grass and other crops made for cheap fodder during the winter when cows were confined. Cows tended to be calved in Spring to match lactation with grass growth. In part because of the perishability of liquid milk and in part because of milk marketing regulations, other regions also produced milk. Dairy farms in some of these regions, especially California, tended to be very different. Scale of production tended to be larger, output was less seasonal and cows were largely confined, i.e., in dry-lot. During the period 1950-2000, production in the West has expanded at the expense of the traditional regions and the expanding farms have tended to be more industrial in format.[2]

Table 1 provides an overview of some of the main innovations in United States on-farm dairy production over the last Century. We categorize them as pro-seasonal, neutral, or anti-seasonal. The pro-seasonal innovations are provided in the first column. Electric fencing has greatly improved efficiency of in-situ grazing, while irrigation technologies have assisted in reducing the weather risk of an outdoor production system. Forage preservation techniques have improved grass utilization efficiency and have helped to maintain the contribution of grass products to the dairy cow diet. These innovations have acted to alter seasonal costs. Final product storage innovations, P4, on the other hand, separate the timing of production from consumption and so allow for more intensive production in low-cost seasons.

Concerning entries in the seasonality neutral column, genetic innovations have increased dramatically the milking cow's productivity. The consequences for seasonality are not readily apparent beyond making two points. The cow's dry period at end of lactation has declined and this is a very direct way in which increased productivity can cause deseasonalization. There is also reason to believe that high yielding cows are less robust to weather and disease. They are increasingly bred with a constitution that favors an indoor life, but that may be a consequence of deseasonalization and not a cause. Antibiotics, N2, are a substitute for sanitation, N3. While the confined cow is easier to monitor and maintain a health regime for, cleanliness can be a problem and communicable disease can also be transmitted more quickly. Fertilization technologies have reduced the costs of concentrate feed, forage, and in-situ grazing. In the absence of further information, we place it in the seasonality neutral column. Finally, the tractor has proved to be just as versatile around the farmyard as in the field and so the effect on the decision to confine cows is not immediate.

The third column lists what we contend are anti-seasonal innovations. Artificial insemination and housing innovations have diminished the roles of nature in animal production and must be important components of sector industrialization. Entries A3 through A9 are of particular interest to this paper, and involve the growing capitalization of animal agriculture. In all cases the equipment put in place is dedicated and is inelastic with respect to inter-season

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[2] Blayney provides detailed perspectives on US production patterns in recent times.

substitution.[3] As we will show, this inflexibility should be important in determining the rate of deseasonalization. On A10, manure is spread as fertilizer but it is an inconvenient form of plant nutrition. While all dairy production systems produce manure due to animal confinement, the problem is most severe for a completely confined production system and so innovations in that area have been most beneficial for non-seasonal production.

United States farms have become increasingly specialized in the outputs they produce, see Gardner (p. 61). This likely means there are fewer other on-farm uses of dairy farm labor during the low output season. Transportation innovations are also likely to have been anti-seasonal, if only because feed and forage input markets have become more integrated and so less subject to regional effects.

The direct importance of these developments for agricultural productivity has been studied elsewhere in the literature. Of interest to us are their effects on seasonal structure in animal production. In the next section we will provide statistical evidence on the nature of change in animal production seasonality over time.

Documenting Seasonal Patterns in Agriculture

Table 2 reports the monthly production data series we have used from US, Canada (CAN), UK, and German (DE) sources. The series have been transformed to take account of the different length of the months in a year. That is, monthly production has been divided by the actual number of days to yield average daily production and then normalized to a thirty-day month.

Seasonality of production has been measured by two concentration indices. Following Erdogdu, who investigated animal production seasonality at US state level for hogs, milk and

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[3] For readers not familiar with modern capital intensive dairy farming and processing we reference Tamime and Law, where the extent and variety of commercial dairy mechanization and automation applications is documented. For on-farm US agriculture in general, real net (of depreciation) on-farm investment was positive for most years between 1945 and 1980. A decline in real capital investment occurred only with the farm crises of the 1980s (for data see p. 263 in Gardner, 2002).

beef, we use the Herfindahl index (H) and the maximum entropy index (E). Denoting month *m* share, $m = 1$ for January and $m = 12$ for December, in annual production in year *t* as $s_{m,t}$, $\sum_{m=1}^{12} s_{m,t} = 1$, the year *t* value of H is calculated as $\mathsf{H}_t = \sum_{m=1}^{12} (s_{m,t} \times 100)^2$. Year *t* entropy is $\mathsf{E}_t = -\sum_{m=1}^{12} s_{m,t} \ln(s_{m,t})$. Because $(s_{m,t})^2$ is convex whereas $-s_{m,t} \ln(s_{m,t})$ is concave, an increase in dispersion among monthly shares should be identified by a lower H and higher E. In fact, for monthly production shares, E reaches a maximum of ln(12) = 2.4849 when an equal share of 1/12 is produced in each month whereas H has value 833.33 in this case.

For ease of interpretation we also report the peak-trough ratio of monthly production. In a given year it is calculated as the ratio of production in the month where production is maximum, $s_{\max,t}$, to production in the month where production is minimum, $s_{\min,t}$. The peak-trough ratio is $\mathsf{R}_t = s_{\max,t} / s_{\min,t}$. By definition, R values are limited to no less than unity and a value of one would indicate constant production across months in a year. Note also that the peak and trough months may differ across states and years. All analyses to follow have been performed on both H and E indices but results are very similar and we conserve space by only reporting results using E. Descriptive statistics in the following tables are provided for R and E as the former lends itself most readily to intuitive interpretation.

Table 3a reports the calculated indices at the national level. It is obvious that seasonality has declined over time. The most marked decline is in dairy production. Canada, in particular, changed from a strongly seasonal to an essentially non-seasonal system over the period 1950-2000. A similar trend, but to a lesser extent, is observable for pork. For beef, no clear trend toward more or less seasonality is discernable. Table 3b reports the seasonal indices for 14 major US milk producing states, where monthly data were available from 1950 onwards.[4] The decline over time in seasonal dispersion is quite uniform across states.

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[4] States were selected on the availability of continuous monthly production data over 1950-2002.

An understanding of the table's regional dimension requires some background on the significance of states in the US dairy industry. Table 4 shows that Wisconsin and California were the two most important milk production states in 2002. These states have had very different production systems, Wisconsin having smaller herds and more pronounced production seasonality.[5] Since 1950, California had quadrupled production share to move from fourth to first in production. Wisconsin's production share grew from 12.7% to beyond 17% in 1980 before declining back toward 13%. The less significant Midwestern states have lost production uniformly since 1950, Minnesota and Wisconsin being the exceptions and Minnesota's relative decline commenced circa 1970. The significant Eastern states of New York and Pennsylvania saw a growth in national share before a relative decline set in over the twenty years commencing about 1980. Southern states, small producers to begin with, have largely contracted while the parched Western and Mountain states have expanded.

To understand the dynamics behind the decline in seasonality as reported in tables 3a and 3b, we test the hypothesis that E is converging to a non-seasonal system. If deseasonalization follows a geometric convergence process, then it can be modeled as $\bar{E} - E_t = a_1(\bar{E} - E_{t-1})$, $\bar{E} = \ln(12)$. This is equivalent to an autoregressive order 1 (AR1) process:

$$(1) \qquad E_t = a_0 + a_1 E_{t-1},$$

with the restriction on the constant that $a_0 = (1 - a_1)\bar{E}$. In this process, a_1 is the convergence rate: the higher its value, the faster E converges to $\bar{E}$.

The results are given in tables 5 and 6. These tables also provide test statistics for the hypothesis H_0: $a_0 = (1 - a_1)\bar{E}$, i.e., whether constant geometric convergence to the non-seasonal system is an appropriate model. Looking at the results for the different countries in table 5, the

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The chosen states represented 63% of US production in 1950 and 75% of production in 2000.

[5] An interesting comparison of structural divergence between California and Wisconsin systems over 1950-1982 is provided in Gilbert and Akor, who show that the systems have diverged markedly in farm structure and input usage patterns.

hypothesis of geometric convergence is rejected in all cases except for milk in Canada and the US. The convergence rates for milk vary between 0.842 in the UK and 0.975 in Canada. Convergence rates are considerably lower, but still significant, for pork where they vary between 0.176 in Germany and 0.672 in the US. They are insignificantly different from zero for beef in Germany and in the US. Table 6 reports similar results for the 14 US dairy states. Convergence to a completely aseasonal system is rejected at the 5% significance level except for Minnesota. Nonetheless significant convergence rates are observed, varying between 0.775 and 0.929. Overall convergence rates in these states are lower than for the US as a whole. For both tables, the estimated convergence parameters are sufficiently large to suggest the existence of a unit root and we will formally test for unit roots at a later juncture.

As will be explained shortly, changes in animal productivity are important in our inquiry into the nature of deseasonalization. Here we only have reliable indicators for milk in the US, Canada, Germany and the UK, and for pork in the US. Milk yield per cow in liters or gallons is used as the productivity indicator in dairying. Measures of hog productivity in the growing phase are more difficult to obtain and we use the breeding phase indicator of farrowing sow average litter size.

Theoretical Motivation

Our intention is to explore interactions between productivity and seasonality. Equipped with these indicators and considering the dynamics of the seasonal structure of the dairy industry in the US, table 7 shows correlations between seasonality, productivity, and production shares for the 14 US dairy states listed in table 6. These correlations were calculated based on 1950 data for the fourteen states, and again on 2000 data. In 1950, when the high seasonality systems of the upper Midwest had the large shares in US total production, a negative correlation existed between production shares (Shares) and aseasonality. This negative relationship turned into a positive one in 2000 because by then the aseasonal western state production systems had large shares in US production.

The relation between productivity and production shares is, as expected, positive in both periods but it declined slightly from 0.459 in 1950 to 0.402 in 2000. This decline indicates that other factors are important. We look next at motivating the closeness in relation between aseasonality and productivity in the lower right part of the table. The relationship has always been positive for the data periods covered but has become much stronger over the last 50 years, increasing from 0.194 in 1950 to 0.358 in 2000.

Model

A representative farm produces animal output in two seasons; season A is high-cost while B is low-cost. Outputs q_A and q_B are produced in seasons A and B, respectively. There are four types of costs. There are seasonal unit costs labeled as c_A and c_B, respectively, where $c_A > c_B$ and these costs amount to $c_A q_A + c_B q_B$ per annum. There is a season-dependent convex cost function $C(q_A, q_B)$ that capture decreasing returns to scale. This cost function is also symmetric, $C(q_A = \hat{q}_A, q_B = \hat{q}_B) \equiv C(q_A = \hat{q}_B, q_B = \hat{q}_A)$. There are season invariant unit costs labeled as $\overline{c}$, and this unit cost parameter will change as a result of technical innovations. These costs amount to $\overline{c} q_A + \overline{c} q_B$ per annum. Finally, there are per annum peak-load unit capital costs amounting to $F \max[q_A, q_B]$. As with $\overline{c}$, parameter F can change as a result of technical innovations.

The price-taking firm obtains season invariant market price P per unit sold where the assumption has been made that product is storable at zero cost. Firm annual profit is then

$$(2) \qquad \pi = (P - \overline{c}) \times (q_A + q_B) - c_A q_A - c_B q_B - C(q_A, q_B) - F \max[q_A, q_B].$$

Denote the optimal output choices as q_A^* and q_B^*. The symmetry of $C(q_A, q_B)$ allows us to readily conclude that optimum outputs satisfy $(c_A - c_B)(q_A^* - q_B^*) \le 0$, and so that $q_A^* \le q_B^*$. We characterize capital intensive innovations as follows. They increase unit peak load capital cost F while also decreasing unit season-invariant cost $\overline{c}$. The sorts of innovations considered here include items A2 through A9 in table 1. The innovation will be adopted if the trade-off between costs is sufficiently favorable. Using the envelope theorem on (2), profit increasing innovations are ones that satisfy $\partial\overline{c}/\partial F \leq -q_B^*/(q_A^*+q_B^*)$.

Characterize the distribution of trade-offs on available innovations $x=\partial\overline{c}/\partial F$ as discrete measure $\mu(X):(-\infty,0]\rightarrow[0,1]$ where X is a set of form $(-\infty,x], x\in-\overline{\Re}_+$, $\overline{\Re}_+$ the non-negative reals. The normalization to $[0,1]$ is a convenience, and the most profitable among available innovations to adopt are those with low x values. They reduce costs $\overline{c}q_A+\overline{c}q_B$ by most relative to the cost increase arising from the required increase in F. Firms adopt innovations with trade-offs up to the critical trade-off ratio $-q_B^*/(q_A^*+q_B^*)$ so that set of adopted capital intensive innovations among those available has measure $\mu((-\infty,-q_B^*/(q_A^*+q_B^*)])$. This measure is largest, at $\mu((-\infty,0.5])$, when the seasonality peak-trough ratio q_B^*/q_A^* is smallest.

PROPOSITION 1. *As seasonality decreases, i.e., the peak-trough ratio decreases, then the rate of adoption of capital intensive innovations increases.*

The proposition can be interpreted in two ways. Suppose some multi-use innovation with a barnyard application (e.g., electricity or vacuum tubes) is commercialized. If it so happens that the innovation has an anti-seasonal bias, so that seasonality decreases, then one should see a pick-up in the adoption of capital intense innovations that are already available to dairy producers. Alternatively, viewing table 3b, one can take a regional perspective to conclude the Wisconsin and Minnesota seasonal production systems should be less capital intensive than the California system.

This proposition would, by itself, suggest that deseasonalization should precede productivity growth when productivity growth is primarily in the form of season-inflexible capital. However, the peak-load capital cost has another effect. Suppose that $C(q_A,q_B)$ takes the homothetic constant elasticity of substitution form $C(q_A,q_B)=\hat{C}[(q_A^\rho+q_B^\rho)^{1/\rho}], \rho>1$. The optimality condition for an interior solution with $q_B^* > q_A^*$ is

$$(3) \qquad \frac{q_B^*}{q_A^*} = \left(\frac{P - \overline{c} - c_B - F}{P - \overline{c} - c_A} \right)^{1/(\rho-1)},$$

and, given $c_A > c_B$, consistency requires that $c_A > c_B + F$. If instead $c_A \leq c_B + F$ then the farm would not produce more in season B than in season A because the marginal cost of season B production would (weakly) exceed that of season A production. Nor would the farm produce more in season A because $c_B < c_A + F$. So $q_A^* = q_B^*$ when $c_A \leq c_B + F$.

Differentiate (3) with respect to F, taking into account the associated change in $\overline{c}$, $d\overline{c}/dF$ < 0, to obtain

$$(4) \qquad \frac{d(q_B^*/q_A^*)}{dF}\Big|_{\overline{c}\ changes} = \frac{1}{\rho - 1} \left(\frac{P - \overline{c} - c_B - F}{P - \overline{c} - c_A} \right)^{(2-\rho)/(\rho-1)} \frac{c_A + \overline{c} - P + (c_A - c_B - F) d\overline{c}/dF}{(P - \overline{c} - c_A)^2}.$$

The number is negative when $c_A > c_B + F$, and so more capital intensity decreases the peak-trough ratio. When $c_A \leq c_B + F$, then $q_A^* = q_B^*$ remains valid under the higher F value.

PROPOSITION 2. *Let* $C(q_A, q_B) = \hat{C}[(q_A^\rho + q_B^\rho)^{1/\rho}], \rho > 1$, *with* $c_A > c_B$. *Let capital intensity increase, i.e.,* F *increases and* $\overline{c}$ *decreases by a sufficient amount that the new cost structure is adopted. Then production seasonality, as represented by peak-trough ratio* q_B^*/q_A^*, *decreases if greater than unity and does not change if equal to unity.*

This proposition would suggest that capital intensity induced productivity growth should precede deseasonalization. It is not a contradiction of proposition 1 because causality between series can be two-way, each re-enforcing the other. Note though that it is only when there is a base of capital intensive innovations, i.e., $F > 0$, that the model suggests productivity growth should precede deseasonalization. When F is low, one should expect to see deseasonalization before capital intensity induced productivity growth in order to establish a capital base in the production system.

CLAIM 3. *For low capital intensity farms, deseasonalization should precede capital intensity induced productivity growth. For high capital intensity farms, capital intensity induced productivity growth should precede deseasonalization.*

Empirical Relationships between Productivity and Seasonality

We have just identified conditions under which an increase in productivity can induce a reduction in seasonality and under which the reversed causal relationship can pertain. From this perspective, $\text{Cov}(\mathsf{E},\mathsf{P})$ in table 7 warrants further scrutiny. We test for causal pathways in Northern hemisphere milk production data.

Since the work of Yule, the danger of spurious regressions in testing for causality among time series has been recognized. Evaluating the relationship of economic time-series data often results in highly autocorrelated residuals and may bias conventional hypothesis tests (Granger and Newbold). To circumvent this problem, it has become common practice to first test for cointegration among the series. If series are known to be integrated of order one, denoted by I(1), but not cointegrated, the practice is to estimate a vector autoregressive regression (VAR) model on differences. Alternatively, if the series are known to be cointegrated then causality can be determined using an error-correction model. Since the procedure will depend on the result of the pretest, we adopt a procedure proposed by Dolado and Lütkepohl. This procedure is robust to the degree of cointegration and so avoids possible problems with pretesting. Nonetheless, we will first test for unit roots and cointegration.

Stationarity Tests

Using the Dickey-Fuller procedure we test for the stationarity in the E and P indices. The Dickey-Fuller test is restrictive in that it assumes statistically independent error terms of constant variance. Phillips and Perron have developed a generalization of the Dickey-Fuller procedure that relaxes the assumption on the error terms, but their test is problematic when the true model contains a negative moving average. Because the true model is never known, Enders suggests performing both tests. We do so and the results for P and E are reported in table 8, both at the country and US state level. The table shows the test statistics, followed by the p-value in parentheses and the number of lags used in brackets. We cannot reject a unit root in most cases. For German milk, the null of a unit root in E is rejected according to both augmented Dickey-Fuller and Phillips-Perron tests. For US pork, it is rejected under the augmented Dickey-Fuller test. For all states, evidence is inconclusive on the existence of a unit root in E. While it is rejected according to the augmented Dickey-Fuller (Phillips-Perron) test in CA, IN, MI, NY, OH, WA (ID, MN) it is then accepted in the other test. The existence of a unit root in the productivity series is only rejected at the 10% level in KY under both tests, according to the Phillips-Perron test in CA and TX, and according to the augmented Dickey-Fuller test in WA.

Cointegration

Assuming that unit roots do exist, we proceed with tests of cointegration. We use the Johansen maximum-likelihood method (Johansen; Johansen and Juselius) that is based on a full system approach. Cointegration is tested for based on the trace statistics of the integrating vectors. In addition, the Engle-Granger method is used. The latter is a single equation method and it tests for the unit root in the residual of these cointegrating regressions.

The results are reported in table 9. The results obtained using the Engle-Granger method suggest that the productivity and seasonality series are cointegrated in PA and WA. The outcome of the Johansen method provides even more evidence of the need to accommodate possible cointegration. The trace test rejects the null hypothesis of no cointegration (rank of the characteristic roots equal to zero) for milk in the UK, CA, OH , PA, and WA. As explained below, the way in which causality tests are conducted depends on the presence of integrated and/or cointegrated series.

Causality

Standard Granger-causality tests have nonstandard asymptotic properties if the variables of a VAR are integrated or cointegrated. This complicates the tests for causality because one has to recourse to simulations to determine the critical value in a causality test. The standard approach in this case has been to estimate a VAR in differences if the variables are known to be I(1) but not cointegrated, or to estimate an error-correction model if the variables are known to be cointegrated (Mosconi and Giannini). An alternative is to employ an approach developed by Dolado and Lütkepohl and been employed in, e.g., Tsionas. Dolado and Lütkepohl have shown that if variables are $I(d)$ and the true data-generating process is $\mathrm{VAR}(p)$, then fitting $\mathrm{VAR}(p+d)$ results in the usual asymmmptotics for Wald tests. This works because over-parameterization of the VAR process avoids singularity in the test statistic. As Tsionas explains, in order to test for causality fit a $\mathrm{VAR}(p+d)$ in levels and then apply a standard F-test involving the coefficients of lags 1 to *p*.

The $\mathrm{VAR}(p+d)$ model for the commodity in state *j* is

(5)

$$\begin{pmatrix} \mathsf{E}_{j,t} \\ \mathsf{P}_{j,t} \end{pmatrix} = \begin{pmatrix} a_0 \\ b_0 \end{pmatrix} + \begin{pmatrix} a_{11}^j & \cdots & a_{1p}^j & a_{1p+1}^j & \cdots & a_{1p+d}^j & b_{11}^j & \cdots & b_{1p}^j & b_{1p+1}^j & \cdots & b_{1p+d}^j \\ a_{21}^j & \cdots & a_{2p}^j & a_{2p+1}^j & \cdots & a_{2p+d}^j & b_{21}^j & \cdots & b_{2p}^j & b_{2p+1}^j & \cdots & b_{2p+d}^j \end{pmatrix} \begin{pmatrix} \mathsf{E}_{j,t-1} \\ \vdots \\ \mathsf{E}_{j,t-p} \\ \mathsf{E}_{j,t-p-1} \\ \vdots \\ \mathsf{E}_{j,t-p-d} \\ \mathsf{P}_{j,t-1} \\ \vdots \\ \mathsf{P}_{j,t-p} \\ \mathsf{P}_{j,t-p-1} \\ \vdots \\ \mathsf{P}_{j,t-p-d} \end{pmatrix}$$

where $(\mathsf{P}_{j,t}, \mathsf{P}_{j,t-1}, \dots, \mathsf{P}_{j,t-p-d})$ is the vector of productivities for the commodity in region *j* at time *t*. The $a_{..}^{j}$ and $b_{..}^{j}$ parameters pertain to the seasonality and productivity indicators, respectively. The true VAR model is thought to go up to lag *p*, and the remaining *d* lags are included to make estimates amenable to Wald tests (Dolado and Lütkepohl). According to Dolado and Lütkepohl the following causality tests are performed. For deseasonalization to cause productivity gains, $H_0 : a_{21} = a_{22} = \dots = a_{2p} = 0$ should be rejected. For productivity gains to precede deseasonalization, $H_0 : b_{11} = b_{12} = \dots = b_{1p} = 0$ should be rejected.

As to the formal test of (5), it is based on the assumption that the structural relationship and the parameters, such as mean, variance and trend, do not change over time. When dealing with long time series this assumption is likely unrealistic and structural breaks in at least one parameter are likely. A classical testing procedure for structural change is based on Chow's test, which applies for a known break date. The sample is split into two subsamples, estimates are made of the parameters for each subsample and an F-test is applied on the equality of parameters. The limit of this test is that the break-date must be known a priori (Hansen).

Alternatively the timing of the structural change can be estimated. As we have no *a priori* knowledge of any break in the relationship, we would like the data to tell us if and when a break occurred. Bai (1997) proposes a least squares estimation of a change point in multiple regressions. The analysis is extended in Bai and Perron and Bai, Lumsdaine and Stock in two ways. Bai and Perron develop the procedure to estimate multiple structural changes occurring at unknown dates. Bai, Lumsdaine and Stock construct confidence intervals for the date of a single break in multivariate time series, including I(0), I(1) and deterministically trending regressors. In this latter test, the width of the asymptotic confidence interval does not decrease with sample size, but is inversely related to the number of series that have a common break date. A similar approach is developed in Murray and Papell. The approach of estimating a single break point on multivariate time series proposed in Bai, Lumsdaine and Stock is extended to multiple break points in Bai (2000).

Following Bai (2000) we use a quasi-likelihood ratio procedure to estimate the change date. For the VAR($p+d$) model in (5), the method compares the quasi-likelihood ratio estimated over the entire sample based on a single parameter vector with the pair of quasi-likelihood ratios obtained by estimating over the period before and the period after the break. If the whole sample log quasi-likelihood exceeds the sum across the pair of time periods, then we assert that a break is not present and we choose the whole sample estimates. Otherwise, we assert a break at the identified point. Since in the case with a break the subsample estimates are completely independent, all parameters including the variance of the error term may differ. With this approach to estimating the VAR($p+d$) model we apply the procedure of Dolado and Lütkepohl to test for causality.

Results for sovereign countries and US states are presented in table 10. The first column indicates the country/state and commodity. For each pair, but with three exceptions, tests are performed on two periods. Two exceptions are TX-Milk and WA-Milk, for which no date break was detected. The third exception is US-Milk where we detect a second break. The break year is indicated in the third column, and is the year in which the earlier parameter regime ends. Note that the beginning year of the first regime and the end year of the final regime depend on data availability as indicated in table 2.[6] The 4th column reports on the optimal number of lags, p, to be included in the VAR analysis based on the Schwartz-Bayesian Information criterion.

The results of the causality tests are reported in columns 5-6 and 7-8. Columns 5 and 6 report the test statistic and respective p-value on the test that productivity growth causes, or precedes, a decline in seasonality. Columns 7 and 8 do the same for the reverse hypothesis that a

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[6] We would have liked to base this analysis on time series of equal length, and this would require us to restrict the dates covered to the lowest common denominator. But the longest time series available in our sample reveals interesting results that differ from those exhibited by shorter time series, and we decided to use the maximum information available in our analysis.

decline in seasonality precedes productivity growth. Note that the hypotheses are not mutually exclusive. It could happen that both hypotheses are accepted (two-way causality), or that neither hypothesis is accepted (no causality). To help the reader in interpreting the results, we include a final column indicating any detected causal relationship.

We turn first to the results on sovereign countries. For dairy, only milk production in the US gives a significant result in the causality test. There are two breaks, 1957 and 1979.[7] The test shows that for the period prior to 1957, deseasonalization (growth in E) preceded productivity growth. For each other country and commodity, there is one break and it occurs early in the last quarter of the Century. For instance with CAN-Milk, UK-Milk and US-Pork the break occurs in the early 1980s while it occurs at about 1975 for milk in Germany.

Looking at dairy in US states in the lower part of table 10, there are significant results in the causality test for CA, ID, and VA in the second time regime and these regimes start around about 1974. As for KY, the results indicate that productivity preceded E in the period up to 1979. The result for New York is quite distinct. Here we observe causality going from E to P during the first period, lasting up to 1976.

Although the picture could be clearer, a possible interpretation of the results goes as follows. Consistent with proposition 1, during the 1930s-1950s technical progress was only made possible after production seasonality became sufficiently low that return on capital exceeded the cost of capital. This interpretation is suggested by the US-Milk result. Capital intensive technology adoption then continued to the point where the high levels of installed capital requires further endogenous changes in equilibrium production seasonality to be biased toward aseasonality. For dairy in US states evidence suggests that, from about 1970 onward, productivity growth fostered less seasonal agriculture. This is observed in California, Idaho, and Virginia. For Kentucky, and arguably also for Canada, this trend is observed during the first

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[7] Using CUSUM and Chow test analysis, Erdogdu also found evidence of structural change in US livestock production seasonality.

period. But as break points are estimated independently, it happens that the break point is relatively late in those two areas (1979 and 1983). Perhaps in these cases much of this causality has been captured in the first period and not the second. At variance to the other states is New York, where we observe causality from E to P in the first period. But again, this first period ends in 1976, and it may pick up a belated trend from the first period that we detected at the US level in dairying.[8]

Corroborating evidence for conclusions in table 10 is provided by figure 1 and data on the capitalization of US farms during the period 1935-45. During that wartime period, capital availability was extremely limited in the UK and the US; capital on US farms actually declined (Gardner). And only in this period do we observe increases in seasonality in both the US and the UK. In the 1980s capital declined as well on US farms during the farm crisis of that time, but deseasonalization of dairy production continued unabated. This suggests that the possible link between seasonality and capital depth has changed over these periods.

Discussion

Evidence presented provides qualified support for the hypothesis that deseasonalization was first necessary to induce productivity growth and only then did productivity growth precede lower seasonality. Placing our analysis in context with macroeconomic writing on industrialization, we note that industrial agriculture has adapted widely from manufacturing innovations. These adaptations have tended to be capital intensive, supporting the idea that spillovers from industrialization in other sectors can lay the foundations for an industrialized format in animal agriculture. A cause for delay may have been limited knowledge on and control of animal

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[8] Remember that US dairy data is available since 1930, but state-level data series commence in 1950. With the US milk regime break in 1957, most of the data that identified $E \rightarrow P$ is not available at state-level. Indeed at the US level we find a second break in 1979, similar to the breaks identified across different US states.

biology, as reflected by the high level of production seasonality. Innovations surrounding bioengineering since the early 1950s may have removed this impediment.

An alternative hypothesis we cannot rule out without further data analysis is simultaneity, where both deseasonalization and productivity growth occur together.[9] One important limitation of our analysis is that the available time series are too short. To clearly identify the importance of deseasonalization early in the industrialization of animal growing, time series have to start before WW-II and this type of data was available to us only for US-Milk.

With the importance of aseasonality induced productivity growth commencing in the late seventies or early eighties for most US states, it would be interesting to find out if it arose directly through changes in production and processing technologies, or through less direct routes. Agency and firm governance effects may have played a role. Sumner and Wolf use the 1993 Farm Cost and Returns Survey to discuss the impact of vertical integration on dairy production structure.[10] They show that the degree of vertical integration is much larger in the Pacific states of the US, the states that have taken production share from the traditional dairy regions of the Upper Midwest and Northeast in the past 30 years.

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[9] A theoretical foundation for the idea of simultaneity can be developed from equilibrium in systems with generalized complementarities. See Milgrom, Qian, and Roberts (1991) for a model identifying conditions supporting sequential directed adjustments in industry behavior that, as time intervals decline to zero, would support simultaneous adjustments.

[10] The dairy states we analyzed do not coincide with those of the US Department of Agriculture Farm Cost and Returns Survey as analysed in Sumner and Wolf. There Georgia, Florida, Missouri, and Vermont are included, but Idaho, Illinois, Indiana, and Virginia are not.

References

Allen, D.W., and D. Lueck. *The Nature of the Farm: Contracts, Risk, and Organization in Agriculture*. Cambridge, MA: MIT Press, 2002.

Anderson, M.D. “An Agricultural Theory of Business Cycles.” *American Economic Review* 21(September 1931):427–449.

Bai, J. “Estimation of a Change Point in Multiple Regression Models.” *Review of Economics and Statistics* 79(November 1997):551–563.

Bai, J. “Vector Autoregressive Models with Structural Changes in Regression Coefficients and in Variance-Covariance Matrices.” *Annals of Economics and Finance* 1(November 2000):301-336.

Bai, J., R.L. Lumsdaine, and J.H. Stock. “Testing For and Dating Common Breaks in Multivariate Time Series.” *Review of Economic Studies* 65(July 1998):395–432.

Bai, J., and P. Perron. “Estimating and Testing Linear Models with Multiple Structural Changes.” *Econometrica* 66(January 1998):47–78.

Barkema, A. “Reaching Consumers in the Twenty-first Century: The Short Way Around the Barn.” *American Journal of Agricultural Economics* 75(December 1993):1126–1131.

Becker, G.S., and K.M. Murphy. “The Division of Labor, Coordination Costs, and Knowledge.” *Quarterly Journal of Economics* 107(November 1992):1137–1160.

Blayney, D.P. *The Changing Landscape of U.S. Milk Production*. Economic Research Service, United States Department of Agriculture. Statistical Bulletin No. 978, Washington, DC, 2002.

Boehlje, M. “Industrialization of Agriculture: What are the Implications?” *Choices* 11(First Quarter 1996):30–34.

Chandler, A.D. *Scale and Scope: The Dynamics of Industrial Capitalism.* Cambridge, MA: Belknap/Harvard University Press, 1990.

Chen, B.-L., and K. Shimomura. “Self-Fulfilling Expectations and Economic Growth: A Model of Technology Adoption an Industrialization.” *International Economic Review* 39(February 1998):151–170.

Chow, G.C. “Tests of Equality between Sets of Coefficients in Two Linear Regressions.” *Econometrica* 28(July 1960):591–605.

Ciccone, A. “Input Chains and Industrialization.” *Review of Economic Studies* 69(July 2002):565–587.

Dolado, J.J., and H. Lütkepohl. “Making Wald Tests Work for Cointegrated VAR Systems.”

Econometric Reviews 15(November 1996):369–386.

Drabenstott, M. “Industrialization: Steady Current or Tidal Wave?” *Choices* 9(Fourth Quarter 1994):4–8.

Enders, W. *Applied Econometric Time Series*. New York: Wiley, 1995.

Erdogdu, O.S. *Industrialization of Animal Agriculture: Seasonality in the Pork, Beef, and Milk Markets*. Unpublished creative component for M.S. degree in economics, Iowa State University, Ames, IA, 2002.

Gans, J. “Fixed Cost Assumptions in Industrialization Theories.” *Economics Letters* 56(September 1997):111–119.

Gans, J. “Industrialization with a Menu of Technologies: Appropriate Technologies and the ‘Big Push’.” *Structural Change and Economic Dynamics* 9(September 1998):333–348.

Gardner, B.L. *American Agriculture in the Twentieth Century*: *How it Flourished and What it Cost*. Cambridge, MA: Harvard University Press, 2002.

Gilbert, J., and R. Akor. “Increasing Structural Divergence in U.S. Dairying: California and Wisconsin since 1950.” *Rural Sociology* 53(Spring 1988):56–72.

Goodwin, B.K., T.J. Grennes, and L.A. Craig. “Mechanical Refrigeration and the Integration of Perishable Commodity Markets.” *Explorations in Economic History* 39(April 2002):154–182.

Granger, C.W.J., and P. Newbold. “Spurious Regressions in Economics.” *Journal of Econometrics* 2(July 1974):111–120.

Hall, B., and C. Cummins. *Times Series Processor Version 4.5–Reference Manual*. Palo Alto USA: TSP-International, 1999.

Hansen, B. “The New Econometrics of Structural Change: Dating Breaks in U.S. Labor Productivity.” *Journal of Economic Perspectives* 15(Fall 2001):117–128.

Hayami, Y., and V. Ruttan. *Agricultural Development: An International Perspective*, revised ed. Baltimore: John Hopkins University Press, 1985.

Hennessy, D.A. “Information Asymmetry as a Reason for Food Industry Vertical Integration.” *American Journal of Agricultural Economics* 78(November 1996):1034–1043.

Hennessy, D.A., Miranowski, J.A., and B.A. Babcock. “Genetic Information in Agricultural Productivity and Product Development.” *American Journal of Agricultural Economics* 86(Forthcoming 2004):xxx–xxx.

Johansen, S. “Statistical Analysis of Cointegration Vectors.” *Journal of Economic Dynamics and*

Control 12(June/September 1988):231–254.

Johansen, S., and K. Juselius. “Maximum Likelihood Estimation and Inference on Cointegration –With Applications to the Demand for Money.” *Oxford Bulletin of Economics and Statistics* 52(May 1990):169–210.

Jorgenson, D.G. “The Development of a Dual Economy.” *Economic Journal* 71(June 1961):309–334.

Jovanovic, B., and P.L. Rousseau. “Specific Capital and the Division of Rents.” Working paper, Department of Economics, New York University, New York, 2003.

Kinsey, J. “Changes in Food Consumption from Mass Market to Niche Markets.” *Food and Agricultural Markets: The Quiet Revolution*. National Planning Association Report No. 270. L.P. Schertz and L.M. Daft, eds., pp. 19-43. Washington, DC, 1994.

Kuznets, S. *Toward a Theory of Economic Growth with Reflections on the Economic Growth of Nations*. New York: Norton, 1968.

Larson, D.F., Butzler, R., Mundlak, Y., and A. Crego. “A Cross-Country Database for Sector Investment and Capital.” *World Bank Economic Review* 14(May 2000):371–391.

Matsuyama, K. “Increasing Returns, Industrialization and Indeterminacy of Equilibrium.” *Quarterly Journal of Economics* 106(May 1991):617–650.

Meeker, D.L. “What are the Livestock Industries Doing, and What do they Need from Us?” *Journal of Animal Science* 77(February 1999):361–366.

Milgrom, P.R., Y. Qian, and J. Roberts. “Complementarities, Momentum, and the Evolution of Modern Manufacturing.” *American Economic Review* 81(May 1991):84–88.

Mosconi, R., and C. Giannini. “Non-causality in Cointegrated Systems: Representation, Estimation and Testing.” *Oxford Bulletin of Economics and Statistics* 54(August 1992):399–417.

Murphy, K.M., A. Shleifer, and R.W. Vishny. “Industrialization and the Big Push.” *Journal of Political Economy* 97(October 1989):1003–1026.

Murray, C.J., and D.H. Papell. “Testing for Unit Roots in Panels in the Presence of Structural Change with an Application to OECD Unemployment.” *Nonstationary Panels, Panel Cointegration and Dynamic Panels*. B.H. Baltagi. ed., pp. 223–238. Amsterdam: JAI Press, 2000.

Phillips, P.C.B., and P. Perron. “Testing for a Unit Root in Time Series Regression.” *Biometrika* 75(June 1988):335–346.

Scitovsky, T. “Two Concepts of External Economies.” *Journal of Political Economy* 62(April

1954):142–151.

Sokoloff, K.L., and D. Dollar. “Agricultural Seasonality and the Origin of Manufacturing in Early Industrial Economies: The Contrast Between England and the United States.” *Journal of Economic History* 57(June 1997):288–321.

Sokoloff, K.L., and V. Tchakerian. “Manufacturing Where Agriculture Predominates: Evidence from the South and Midwest in 1860.” *Explorations in Economic History* 34(July 1997):243–264.

Sumner, D.A., and C.A. Wolf. “Diversification, Vertical Integration, and the Regional Pattern of Dairy Farm Size.” *Review of Agricultural Economics* 24(Fall/Winter 2002):442–457.

Tamime, A.Y., and B.A. Law, eds. *Mechanisation and Automation in Dairy Technology*. Sheffield, UK: Sheffield Academic Press, 2001.

Tsionas, E. “Inflation and Productivity: Empirical Evidence from Europe.” *Review of International Economics* 11(February 2003):114–129.

Yule, G. “Why Do We Sometimes Get Nonsense Correlations Between Time Series? *Journal of the Royal Statistical Society* 89(January 1926):1–63.

Table 1. Seasonal Bias in Noteworthy Dairy Production Innovations, 1900-2000

Pro-seasonal	*Seasonality neutral*	*Anti-seasonal*
P1. Electric fencing	N1. Genetic Innovation	A1. Artificial insemination
P2. Irrigation technologies	N2. Antibiotics	A2. Housing innovations
P3. Forage preservation innovations	N3. Sanitation technologies	A3. Electricity in milking parlor
	N4. Fertilization technologies	A4. Refrigerated bulk tanks
P4. Storage innovations for dairy output	N5. Tractor	A5. Transfer pipes to bulk tanks
		A6. Mechanized feed handling
		A7. Robotic milking machines
		A8. Downstream processing
		A9. Bulk milk handling/marketing
		A10. Manure handling methods
		A11. Specialization in other outputs
		A12. National transportation and storage innovations for feed

Table 2. Monthly Production Data Used

Product	Country	Series	Units	Time covered	Source
Milk	US	Milk Production	Mill lbs	1930 - 2000	USDA-NASS
	DE	Delivery to dairies	Mill liters	1951 - 2001	*Agrarwirtschaft*
	CAN	Milk Production	000 liters	1945 - 2000	Statistics Canada
	UK	Milk Production	Mill liters	1936 - 2002	Up to Nov-1994 UK Milk Marketing Board, starting Dec 1994 Rural Payments Agency
Pork	US[a]	Production	Mill lbs	1944 - 1981; 1983 - 2000	USDA-NASS
	DE[b]	Production	000 tons	1951 - 1989; 1991 - 2000	*Agrarwirtschaft*
	UK	Production	000 heads	1973 - 2000	DEFRA
Beef	US[a]	Production	Mill lbs	1944 - 1981; 1983 - 2000	USDA-NASS
	DE	Slaughter	000 heads	1951 - 2000	*Agrarwirtschaft*
	UK	Slaughter	000 heads	1973 - 2000	DEFRA

[a] US pork and beef monthly production data are missing in 1982, a year the NASS service suffered severe budget cuts. To fill in the gap in the time series data, the calculated E was filled in using a cubic trend function.

[b] No coherent monthly production data are available for DE pork in the unification year, 1990.

Table 3a. Indices of Seasonal Production, Averages per Decade

	Peak-Trough Ratio[a]				Entropy Index[b]			
	1930-39	1950-59	1970-79	1990-99	1930-39	1950-59	1970-79	1990-99
Milk								
US	1.5190	1.4940	1.2361	1.1444	2.4746	2.4759	2.4828	2.4842
CAN	-	2.3164	1.6990	1.1208	-	2.4447	2.4699	2.4842
UK	1.4762	1.3996	1.3913	1.2060	2.4765	2.4791	2.4794	2.4833
DE	-	1.6512	1.4519	1.2182	-	2.4708	2.4772	2.4829
Pork								
US	-	1.6294	1.3919	1.2668	-	2.4728	2.4804	2.4824
UK	-	-	1.3980	1.4198	-	-	2.4788	2.4789
DE	-	1.3007	1.1616	1.2194	-	2.4817	2.4839	2.4833
Beef								
US	-	1.2855	1.2207	1.2096	-	2.4823	2.4833	2.4832
UK	-	-	1.5736	1.8329	-	-	2.4750	2.4708
DE	-	1.4325	1.3455	1.4542	-	2.4784	2.4805	2.4785

[a] A decline in the index represents a decline in the seasonality of production.
[b] A rise in the index represents a decline in the seasonality of production.

Table 3b. Indices of Seasonal Production, Averages per Decade

	Peak-Trough Ratio			Entropy Index[b]		
State	1950-59	1970-79	1990-99	1950-59	1970-79	1990-99
California	1.262	1.159	1.087	2.4818	2.4838	2.4846
Idaho	1.498	1.259	1.158	2.4754	2.4822	2.4836
Illinois	1.468	1.205	1.146	2.4773	2.4831	2.4837
Indiana	1.518	1.174	1.110	2.4755	2.4837	2.4843
Kentucky	1.742	1.445	1.184	2.4647	2.4779	2.4834
Michigan	1.435	1.107	1.084	2.4786	2.4844	2.4846
Minnesota	1.927	1.465	1.153	2.4613	2.4750	2.4835
New York	1.505	1.227	1.105	2.4751	2.4825	2.4844
Ohio	1.413	1.191	1.122	2.4782	2.4835	2.4841
Pennsylvania	1.367	1.157	1.101	2.4802	2.4839	2.4844
Texas	1.320	1.145	1.302	2.4804	2.4839	2.4808
Virginia	1.386	1.150	1.149	2.4778	2.4838	2.4840
Washington	1.498	1.184	1.083	2.4761	2.4835	2.4846
Wisconsin	1.695	1.322	1.134	2.4697	2.4809	2.4841

[a] A decline in the index represents a decline in the seasonality of production.
[b] A rise in the index represents a decline in the seasonality of production.

Table 4. Dairy Production Shares by U.S. State and by Decade, 1950-2002

State	1950	1960	1970	1980	1990	2002
California	5.1	6.58[a]	8.18	10.68	14.28	20.58
Idaho	1.0	1.38	1.39	1.58	2.08	4.88
Illinois	4.5	3.49	2.49	2.09	1.79	1.29
Indiana	3.2	2.69	2.09	1.79	1.59	1.5
Kentucky	2.1	2.1	2.1	1.79	1.59	1.09
Michigan	4.6	4.29	3.99	3.9	3.59	3.5
Minnesota	6.9	8.48	8.29	7.49	6.89	5.09
New York	7.6	8.48	8.88	8.59	7.59	7.29
Ohio	4.5	4.39	3.89	3.49	3.29	2.69
Pennsylvania	4.8	5.68	6.18	6.68	6.88	6.39
Texas	3.0	2.49	2.68	2.88	3.78	3.19
Virginia	1.7	1.59	1.5	1.5	1.49	1.19
Washington	1.5	1.5	1.88	2.38	3.08	3.38
Wisconsin	12.7	14.38	15.88	17.48	16.49	13.09
H, US level	407	501	566	651	691	786

[a] The arrows indicate the direction of change in shares since the previous decade.

Table 5. Trends in Deseasonalization–Animal Production in Selected Countries

	a_0, (t-value)[a]	a_1, (t-value)	R^2	Durbin-Watson	p-value, $a_0 = (1 - a_1)\bar{E}$
Milk					
UK	0.391**	0.842***	0.703	2.304	0.021
	(0.170)	(0.068)			
DE	0.207*	0.917***	0.879	2.841	0.089
	(0.122)	(0.049)			
CAN	0.062	0.975***	0.939	2.631	0.151
	(0.043)	(0.030			
US	0.076	0.969***	0.983	2.608	0.306
	(0.075)	(0.030)			
Pork					
UK	1.234**	0.502**	0.212	2.044	0.010
	(0.479)	(0.193)			
DE	2.046***	0.176**	0.098	1.708	0.000
	(0.193)	(0.078)			
US	0.809***	0.673***	0.456	2.222	0.001
	(0.250)	(0.101)			
Beef					
UK	1.599***	0.354*	0.128	1.996	0.000
	(0.457)	(0.185)			
DE	2.469***	0.004	0.001	1.965	0.000
	(0.360)	(0.145)			
US	2.198***	0.114	0.013	2.002	0.000
	(0.339)	(0.137)			

[a] *, **, and *** identify significance at the 10%, 5%, and 1% levels, respectively.

Table 6. Trends in Deseasonalization–Dairy Production in Selected US States

	a_0, (t-value)[a]	a_1, (t-value)	R^2	Durbin-Watson	p-value, $a_0 = (1 - a_1)\bar{E}$
CA	0.470***	0.811***	0.848	3.039	0.000
	(0.119)	(0.048)			
ID	0.362***	0.854***	0.886	2.361	0.001
	(0.108)	(0.043)			
IL	0.351**	0.859***	0.820	2.423	0.013
	(0.141)	(0.057)			
IN	0.229***	0.908***	0.934	2.379	0.007
	(0.084)	(0.034)			
KY	0.322	0.870***	0.874	2.749	0.005
	(0.116)	(0.047)			
MI	0.228***	0.908***	0.962	2.087	0.000
	(0.063)	(0.026)			
MN	0.176	0.929***	0.894	2.799	0.116
	(0.112)	(0.045)			
NY	0.247*	0.900***	0.928	2.741	0.005
	(0.088)	(0.035)			
OH	0.458***	0.815***	0.818	2.700	0.001
	(0.135)	(0.054)			
PA	0.272**	0.890***	0.851	2.843	0.037
	(0.131)	(0.053)			
TX	0.558***	0.775***	0.714	2.086	0.001
	(0.172)	(0.069)			
VA	0.302***	0.878***	0.908	2.819	0.002
	(0.098)	(0.039)			
WA	0.266***	0.893***	0.964	2.659	0.000
	(0.060)	(0.024)			
WI	0.267***	0.892***	0.911	2.378	0.006
	(0.098)	(0.039)			

[a] *, **, and *** identify significance at the 10%, 5%, and 1% levels, respectively.

Table 7. Correlation between Production Shares, Seasonality and Productivity in 14 Dairy States in 1950 and 2000

	E		P	
	1950	2000	1950	2000
Shares	-0.231	0.256	0.459	0.402
E			0.194	0.358

Table 8. Unit-Root Tests for Entropy and Productivity in Milk Production

	E		P	
	Augmented Dickey-Fuller	*Phillips-Perron*	*Augmented Dickey-Fuller*	*Phillips-Perron*
US-Milk	- 2.847 (0.180) [10]	- 9.722 (0.455) [10]	- 1.484 (0.835) [2]	- 2.281 (0962) [2]
CAN-Milk	0.138 (0.995) [3]	- 4.584 (0.850) [3]	- 0.332 (0.989) [2]	- 0.926 (0.989) [2]
UK-Milk	- 2.141 (0.523) [2]	- 17.964 (0.106) [2]	- 1.605 (0.790) [2]	- 14.281 (0.212] [2]
DE-Milk	- 3.669 (0.024) [2]	- 31.356 (0.007) [2]	- 1.300 (0.888) [5]	- 6.298 (0.722) [5]
US-Pork	-4.745 (0.001) [10]	- 37.025 (0.002) [10]	0.049 (0.995) [2]	- 1.909 (0.972) [2]
US States-milk				
California	- 3.989 (0.009) [2]	- 13.013 (0.266) [2]	- 2.897 (0.163) [2]	- 28.111 (0.013) [2]
Idaho	- 2.681 (0.244) [10]	- 19.550 (0.077) [10]	- 0.664 (0.975) [4]	- 2.067 (0.968) [4]
Illinois	- 0.876 (0.959) [4]	- 9.474 (0.473) [4]	- 1.041 (0.938) [2]	- 3.328 (0.922) [4]
Indiana	- 4.830 (0.0004) [6]	- 3.061 (0.934) [6]	- 1.862 (0.674) [3]	- 7.301 (0.640) [3]
Kentucky	- 0.756 (0.969) [3]	- 16.303 (0.145) [3]	- 3.688 (0.023) [3]	- 24.012 (0.031) [3]
Michigan	- 3.534 (0.036) [2]	- 3.661 (0.906) [2]	- 1.554 (0.810) [2]	- 7.625 (0.614) [2]
Minnesota	- 1.002 (0.944) [4]	- 24.935 (0.026) [4]	- 1.298 (0.888) [2]	- 5.144 (0.811) [2]
New York	- 4.190 (0.005) [9]	- 6.943 (0.669) [9]	- 1.435 (0.850) [2]	- 5.915 (0.752) [2]
Ohio	- 5.153 (0.0001) [2]	- 8.773 (0.524) [2]	- 1.668 (0765) [9]	- 16.116 (0.151) [9]
Pennsylvania	- 0.767 (0.968) [4]	- 12.154 (0.308) [4]	- 1.602 (0.791) [2]	- 5.574 (0.779) [2]
Texas	- 0.894 (0.957) [10]	- 8.917 (0.513) [10]	- 1.994 (0.605) [3]	- 20.738 (0.061) [3]
Virginia	- 1.429 (0.852) [10]	- 5.396 (0.792) [10]	- 1.634 (0.524) [2]	- 8.774 (0.524) [2]
Washington	- 4.731 (0.001) [10]	- 5.918 (0.752) [10]	- 3.252 (0.075) [10]	- 9.585 (0.465) [2]
Wisconsin	- 2.418 (0.370) [6]	- 8.054 (0.579) [6]	- 2.307 (0.430) [2]	- 10.942 (0.376) [2]

Table 9. Johansen and Engle-Granger test

	Johansen[a]		**Engel–Granger**[b]	
			(H_0: no cointegration)	
	Trace Statistic	Dep. Var.	t-test	p-value
US-E-Milk	12.839 (0.244) [2]	US-Milk-E	-2.795	0.361 [10]
		US-Milk-P	-0.493	0.994 [7]
CAN-E	12.705 (0.250) [1]	CAN-Milk-E	-2.043	0.753 [2]
		CAN-Milk-P	-2.111	0.723 [2]
UK-E	21.879 (0.015) [1]	UK-Milk-E	-3.079	0.231 [4]
		UK-Milk-P	-2.827	0.345 [10]
DE-E	15.619 (0.114) [2]	DE-Milk-E	- 3.042	0.246 [4]
		DE-Milk-P	- 0.738	0.989 [2]
US-E-Pork	13.258 (0.218) [11]	US-Pork-E	-1.560	0.909 [10]
		US-Pork-P	-1.674	0.882 [7]
US-States (milk only)				
CA-E	35.148 (0.0004) [1]	CA-E	- 2.935	0.293 [2]
		CA-P	- 3.060	0.238 [2]
ID-E	12.269 (0.284) [2]	ID-E	- 2.946	0.288 [2]
		ID-P	- 2.084	0.735 [2]
IL-E	15.079 (0.133) [1]	IL-E	- 3.227	0.176 [2]
		IL-P	- 1.879	0.818 [2]
IN-E	11.151 (0.372) [2]	IN-E	- 2.257	0.652 [3]
		IN-P	- 2.072	0.741 [3]
KY-E	14.030 (0.177) [6]	KY-E	- 1.110	0.970 [3]
		KY-P	- 3.450	0.111 [3]
MI-E	15.494 (0.118) [2]	MI-E	- 2.347	0.604 [2]
		MI-P	- 2.193	0.683 [2]
MN-E	8.450 (0.608) [3]	MN-E	- 2.493	0.524 [4]
		MN-P	- 2.270	0.645 [2]
NY-E	14.433 (0.159) [1]	NY-E	- 1.798	0.846 [2]
		NY-P	- 1.863	0.824 [2]
OH-E	22.494 (0.013) [9]	OH-E	- 1.743	0.863 [3]
		OH-P	- 1.745	0.862 [9]
PA-E	21.920 (0.015) [3]	PA-E	- 3.536	0.091 [2]
		PA-P	- 3.628	0.074 [2]
TX-E	9.684 (0.500) [11]	TX-E	- 1.139	0.968 [10]
		TX-P	- 2.559	0.487 [2]
VA-E	13.066 (0.230) [2]	VA-E	- 1.423	0.960 [10]
		VA-P	- 1.986	0.777 [2]
WA-E	24.755 (0.007) [3]	WA-E	- 2.325	0.616 [2]
		WA-P	- 3.496	0.100 [2]
WI-E	23.208 (0.011) [1]	WI-E	- 2.866	0.325 [2]
		WI-P	- 3.094	0.225 [2]

[a] Trace statistic stands for the Johansen trace statistic using a finite-sample correction (Hall and Cummins). The null hypothesis of p=0 indicates tests for no cointegration against the alternative of one or more cointgrating vectors (p>0). The p-value is reported in parentheses. The optimal lag length has been chosen using the Akaike-Information Criterion and is indicated in brackets.

[b] In the Engle-Granger method a large p-value shows evidence against cointegration. The optimal lag length has been chosen using the Akaike-Information Criterion and is indicated in brackets.

Table 10. Dolado and Lütkepohl Causality Test for Aseasonality and Productivity[a]

State/ Commodity	Causality	Break Year	Number of lags p^b	P → E		E → P		Conclusion
				χ^2-test	p-value	χ^2-test	p-value	
Countries								
US-Milk	1st period	1957, 1979	1	0.228	0.633	2.789	0.095	E → P
	2nd period			0.401	0.527	0.064	0.801	-
	3rd period			0.181	0.670	0.149	0.699	-
CAN-Milk	1st period	1983	1	1.918	0.166	0.001	0.975	-
	2nd period			0.008	0.927	0.002	0.966	-
UK-Milk	1st period	1984	1	0.008	0.806	0.187	0.666	-
	2nd period			0.073	0.787	0.139	0.710	-
DE-Milk	1st period	1975	2	0.018	0.893	0.159	0.690	-
	2nd period			0.010	0.920	1.014	0.314	-
US-Pork	1st period	1981	2	0.009	0.308	0.042	0.837	-
	2nd period			0.215	0.643	0.005	0.823	-
US-States Milk								
CA	1st period	1972	2	0.023	0.881	0.643	0.423	-
	2nd period			4.871	0.027	0.192	0.661	P → E
ID	1st period	1976	1	0.002	0.734	0.906	0.341	-
	2nd period			14.494	0.000	0.020	0.887	P → E
IL	1st period	1977	1	2.086	0.149	0.791	0.374	-
	2nd period			0.041	0.840	0.082	0.775	-
IN	1st period	1984	1	0.340	0.560	1.410	0.235	-
	2nd period			0.379	0.538	0.055	0.814	-
KY	1st period	1979	1	3.994	0.046	1.713	0.191	P → E
	2nd period			0.030	0.862	0.002	0.969	-
MI	1st period	1967	1	0.030	0.863	0.345	0.557	-
	2nd period			1.003	0.316	0.137	0.712	-
MN	1st period	1982	2	0.209	0.648	0.069	0.793	-
	2nd period			0.114	0.735	1.301	0.254	-
NY	1st period	1976	1	0.059	0.808	3.219	0.073	E → P
	2nd period			0.000	0.881	2.378	0.985	-
OH	1st period	1971	2	0.111	0.739	0.319	0.572	-
	2nd period			0.639	0.424	1.314	0.252	-
PA	1st period	1967	1	0.378	0.539	1.074	0.300	-
	2nd period			0.403	0.526	0.865	0.352	-
TX		None	2	0.054	0.817	1.373	0.241	-
VA	1st period	1972	1	0.001	0.817	0.002	0.961	-
	2nd period			14.409	0.000	0.271	0.603	P → E
WA		None	3	0.068	0.794	0.028	0.867	-
WI	1st period	1974	1	0.129	0.719	1.315	0.252	-
	2nd period			0.159	0.207	1.237	0.266	-

[a] In this test, proceed by fitting a $VAR(p+d)$ in levels and apply a standard F-test involving the coefficients of lags 1 to p. The H_0 states that the parameters of lag 1 to p to the causal variable are zero.
[b] The optimal number of lags was chosen according to the Schwartz-Bayesian Information Criterion.

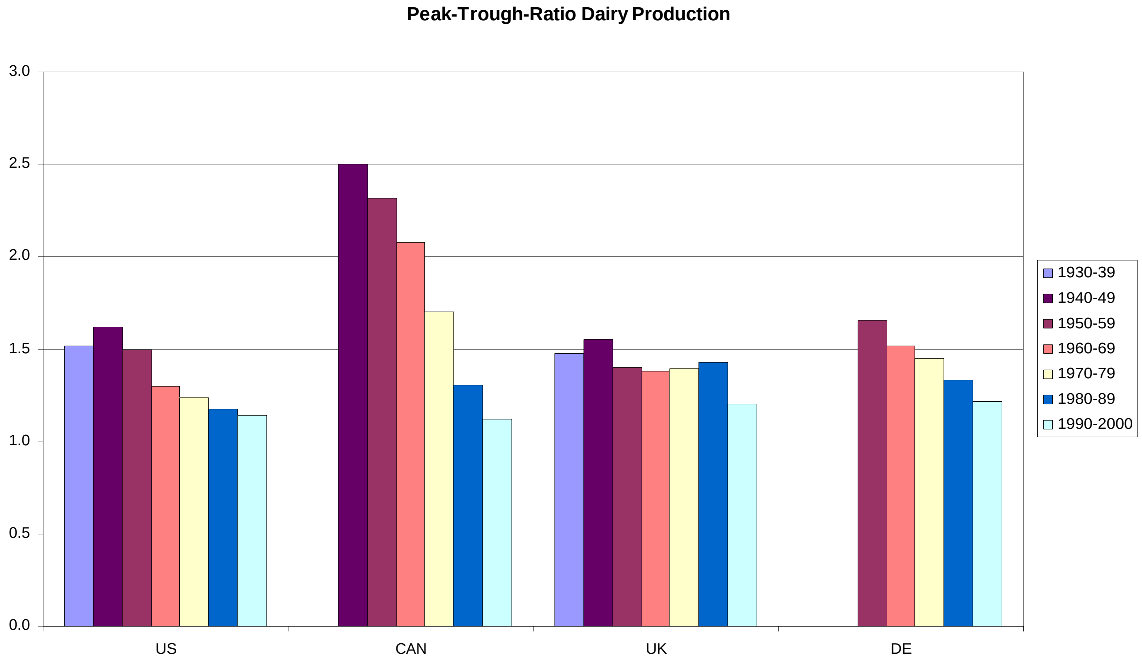

Figure 1. Changing Peak-Trough Ratios of Dairy Production in Selected Countries.