The Deseasonalization of Animal Production

by

Jutta Roosen and David A. Hennessy*

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Authors are professor at the Department of Food Economics and Consumption Studies, University of Kiel and at the Department of Economics, Iowa State University, respectively.

Roosen is the corresponding author. She can be reached at Department of Food Economics and Consumption Studies, University of Kiel, Olshausenstr. 40, 24098 Kiel, Germany. Ph.: +49 431 880 4567, Fax: +49 431 880 7308, e-mail: jroosen@food-econ.uni-kiel.de.

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Abstract

We document the deseasonalization of animal production in the US and Europe. Hypotheses on causes and consequences of this trend are advanced. They pertain to feed costs, changes in animal productivity and cost fixity of the underlying technology, innovations in genetic control and epidemiology, and the capital intensity of production.

Keywords: Animal Production, Capital Intensity, Dairy, Industrialization, Seasonality

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Introduction

Since human settlement started about 10 to 12 millions years ago, humans relied on animals to provide for important nutrients. However, animal based food was expensive and husbandry competed in many regions for the use of land as plant growing area. Animal rearing consequently was either confined to land that could not be used otherwise or integrated in production systems coupling the joint production of animals and crops.

Integrated in such systems, animals were kept according to the annual cycle of plant growth and feed production. It was only during the 20th century, that humanity has experienced such enormous increases in plant productivity that could outpace the growing need for staple foods. These productivity gains were partly due to the development of mineral fertilizers and pesticides. Increasing nutrient availability and protecting plants from pests, soil productivity grew annually by 2% over the last century. Furthermore, mechanization of agriculture helped increasing the productivity of labor. Beyond sustaining a population growth from 1 to 6 billion people over the 20th century, advances in agricultural productivity made it possible that consumers in the industrialized world could increase their consumption of meat and other animal products to formerly unknown levels. As animal feed has become available plentiful and cheap on a year-round basis, animal production could prosper.

Advances in transportation did its due part enabling the shipping of feed and fertilizer over long distances, hence disentangling the traditional link between animal and crop agriculture. And the development of hybrid corn, a cheap fodder, nowadays even apt to northern short growing seasons, made it possible to break the link between cattle or dairy breeding and grassland, the former being dependent on a sufficient supply of roughage.

According to a hypothesis in Allen and Lueck, the seasonal character of agricultural production presents a major impediment to industrialization and specialization of labor. The control enhancing nature of the last century's more significant technological innovations suggest that animal production seasonality should have declined as a consequence. The argument is as follows. Increasing crop sector productivity and developments in transportation have led to a declining dependence between of animal production and feed production. At the same time advances in veterinary sciences have promoted animal production in confined areas that may be geographically separated from the production of fodder inputs and suitable locations for animal waste disposal. Confined animals are protected from the vagaries of inclement weather and receive a regular and controlled supply of feed all-year round. Animal production thus became less dependent on seasonal cycles, opening new opportunities for industrialization and productivity growths. It is to be expected that animal production has become less seasonal.

The purpose of this paper is to document the deseasonalization of animal production using time series and statistical trends available for the latter half of the 20th century. We exemplify our argument using data for selected productions in North America and Western Europe. Hypotheses on causes and consequences of this deseasonlizing trend are advanced. They are related to the availability of cheap feed, the change in animal productivity and technology of animal husbandry, the control of genetics and of animal epidemiology.

Our analysis is structured as follows. After this introduction, we review some of the most important trends in animal production in the industrialized world during the last 50 years. Based on time-series data of monthly animal production of dairy, beef and pork in various countries, we present and discuss seasonality indicators. We proceed, in a third section, developing some hypotheses on the causal relationships for deseasonaliazation. The paper concludes on suggestions for future research identifying the causes and consequences of deseasonalized animal production.

A Historic Perspective on Deseasonalization

The Changing Nature of Agricultural Production

Agricultural development in the industrialized world was characterized by a number of technological advances during the 20th century. Table 1 presents an overview of notable technical innovations during the first 40 years of that century. Changes pertain to the mechanization of agriculture, advances in pest and disease control, improved management of soil fertility and new animal breeding techniques.

For our purposes the evidence reported in this table is too limited in at least two respects: It only covers innovations until 1940, and important additional discoveries were made later on. Indeed, output indicators of US farm production show a significant increase in annual growth from 1940 onwards. Secondly it refers to the United States, and we also will consider evidence from Europe. However, we can trust that similar technologies became available on the old continent at about the same time, while adoption rates may have differed across countries and regions. A further limitation of this table arises out of its arrangement. That is, many plant innovations, such as the development of hybrid corn and other feed producing plants had significant repercussions on the development of animal production systems. When analyzing the developments in animal production, attention should not be confined to ‘animal’ technologies.

Innovations in milk production serve as an example: Between 1920 and 1960, major steps in innovation were taken by the innovation of vacuum-driven milking machines, fans for ventilation and hay drying, refrigerated bulk tanks for milk storage, barn cleaners for manure removal, pipeline milkers and milking parlors, silo unloaders, augers, grinders, and other feed-handling equipment, and electric fencing. In consequence, the number of hours needed to produce 100 lbs. of milk declined from 3.8 hours in 1910, to 3.4 in 1935-39 down to 0.2 hours in the1980 (Gardner, p.15). Similar increases in labor productivity are estimated for hogs and broilers.

Innovation did not only impact production but also marketing. Technological progress has lowered the costs of transportation for inputs going to the farm and for output going to the market. This has effectively lowered the cost of farm products. It has also changed the way in that product was marketed. While the cream separator was standard equipment on a dairy farm that sold only cream or butter in the early 19th century, it had essentially disappeared by the 1950s (Gardner, p. 28).

Subsequent to these technical changes, the economies of scope typical for agricultural production faded in the light of newly arising economies of scale. In the US, the census of 1900 reports that of the 5.7 million farms counted, 98% had chicken, 79% had at least one milk cow and 75% had pigs. In the 1992 census, the picture had changed and of the remaining 1.9 million farms only 4% reported chickens, 8% milk cows, and 10% pigs. Gardner (p.61) estimates the specialization index counting the number of commodities produced per farm that had declined from 5.6 in 1920 to 4.2, 2.7, and finally 1.8 and 1950, 1969, and 1992, respectively.

A consequence of the newly developed technologies was a decline in labor intensity and an increase in capital intensification. For the US, net investment on farms was positive for most years between 1940 and 1980. A decline in capital investment occurred only with the farm crises of the 1980 (for data see Gardner, p.263).

Similar developments occurred in Europe. We exemplify looking at the case of Germany. In the aftermath of worldwar II, agricultural production recovered. Intensifying with the use of synthetic fertilizers, yields rapidly increased beyond pre-war levels. Also, animal productivity increased and, e.g., annual production of milk per cow rose from 2,474 liters in 1950 to 3,444 liters in 1962 and 3,997 liters in 1975. As shown in table 2, mechanization progressed in line with, but took on later than in the US. As an example, while the number of tractors exceeded that of traction animals in the US already in the early 1940, the same event occurred in Germany only in the late 1950 (Henning, p. 268). The later adoption of technologies in Germany can be explained by a number of factors: lesser openness to new technologies, climatic conditions less favorable to the adoption of combines, lack of interest in new investments (Henning, p. 269).

The importance of these developments for the productivity growth of agricultural production has extensively been documented and discussed in the literature. What is of interest to us, is its relation to the seasonal structure of animal production. In the economies of plenty having access to well functioning storage technologies, seasonal production does not seem much of an issue. But preservation of quality during storage is costly and the seasonality of agriculture may limit the access to further automization and industrialization. What's more, seasonality remains an important issue in extreme climate zones, see for example the preponderance of transhumance in sub-saharan Africa. The literature suggests that mechanization may limit its extent with which it affects nutrient availability and public health of the rural population (Moris), but further impact of deseasonalization on productivity growth has not been analyzed yet.

Seasonal Patterns in Agriculture

One does not have to look far into the past to notice the changing pattern of seasonality. However, the evidence is impressive, when one looks at long time series. Table 3 reports the data we have used. The data 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 number of days to yield average daily production and multiplied by thirty, so that we work with months normalized to the length of thirty days.

Seasonality of production has been measured by two concentration indices: The Hirshfeld-Herfindahl index (HI) and the maximum entropy index (EI). Denoting the monthly share of month *m* in annual production in year *t* as s_{mt}, HI is calculated as

$$HI_t = \sum_{m=1}^{12} \left(s_{mt} \times 100 \right)^2$$

EI is calculated as

$$EI_t = \sum_{m=1}^{12} s_{mt} \, \ln\left(s_{mt} \right)$$

Less seasonality in production triggers a lower HI and a rising EI. In fact, for monthly production shares, EI reaches a maximum of ln(12) = 2.4849 when an equal share of 1/12 is produced in each and every month of the year whereas HI has value 833.33 in this case..

Table 4 reports the calculated indices. It is obvious that seasonality has been declining in all production systems. The most impressive decline and that we observe, is in dairy production. In particular Canada changed from a completely seasonal to a completely aseasonal system in the period from 1945 to today. A similar trend to a lesser extent is observable for pork. For beef, no clear trend is discernable.

Documenting deseasonalization

To understand the dynamics behind the decline in seasonality, we test the hypothesis that EI is converging to an aseasonal system.[1] If deseasonalization follows a geometric convergence process, then it can be modeled as

$$\overline{EI} - EI_t = a_1\left(\overline{EI} - EI_{t-1}\right)$$

This process is equivalent to an AR1 process with a constraint on the constant

$$EI_t = a_0 + a_1 EI_{t-1}$$

where $a_0 = (1 - a_1)\overline{EI}$ and $\overline{EI} = \ln(1/12)$. In this process a_1 is the convergence rate, the higher its value, the faster EI converges to $\overline{EI}$.

The results are given in Table 5. The hypothesis H_0: $a_0 = (1 - a_1)\overline{EI}$ of constant convergence to the aseasonal system is rejected but for milk in Canada and the US. Convergence rate for milk vary between 0.842 in the UK and 0.975 in the US. They are considerably lower, but significant, for pork where they vary between 0.180 in Germany and 0.672 in the US. There are insignificantly different from zero for beef in Germany and in the US.

Productivity and Seasonality

Analyses in economic history have shown evidence that strong seasonal fluctuations in labor availability hinder productivity growth. Sokoloff and Dollar explain differences in the organization of manufacturing in early industrialized England and US in by difference in seasonal agriculture

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[1] All regressions have also been performed with HI. Because both indices are highly correlated, the results are virtually identical. To save space, we only report on the results for EI.

and labor availability. In England's more seasonal economy, cottage manufacturing could compete with technically more productive manufacturies because it took a better advantage of labor supply peaks in winter months.

As Allen and Lueck have argued, seasonality may not only influence the industrialization of an economy in its entirety and in particular of the manufacturing sector, but also slow down the industrialization of agriculture. Automatization of production processes is hindered by the fact that distinct tasks, such as calving, milking, preparation of silage and feed, have to be performed at different times.

Two hypotheses emerge: (1) deseasonalization of production technologies is a necessary given for raising productivity and/or (2) deseasonalization occurred only because of deseasonalizing (Hicks biased) technical progress in productivity. In the following we test for these two hypotheses using causality tests. We do so by concentrating on milk production. For dairy we have found strong deseasonalizing trends. Dairy is also a production system whose seasonality is a result of cost saving emerging from feed availability and breeding stock.

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 highle autocorrelated residuals and may bias conventional hypothesis tests (Granger and Newbold). To circumvent this problem it has become common practice to first test for the cointegration among the series. If series are known to be I(1) but not cointegrated, the practice is to estimate a VAR model in the differences, while if the series are known to be integrated, causality can be determined using a error-correction model. Although we will adopt a procedure proposed by Dolado and Lütkepohl that avoids possible problems with pretesting for cointegration, we will first test for unit roots and cointegration, before engaging in causality tests.

Stationarity Tests

Using the Dickey-Fuller procedure we test for the stationarity in of the EI index and productivity. 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. However the Phillips-Perron 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 productivity and EI are reported in table 7, both at the country and US state level. The table shows that we cannot reject a unit root for the series under scrutinity.

Cointegration

Having found evidence of a unit root, we can proceed with tests of cointegration. We use the Johansen maximum likelihood method (Johansen; Johansen and Julius) 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 tests for the unit root in the residual of these cointegrating regressions.

The results are reported in table 8. While the Engle-Granger method does not provide evidence against cointegration for all tested relationships, the results of the Johansen method are quite mixed. And so the cointegration of productivity and aseasonality is rejected for Germany, New York, Texas and Washington.

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 recur 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, 1992). An alternative is to employ an approach developed by Dolado and Lütkepol and been employed e.g. in Tsionas. Dolado and Lütkepol have shown that if variables are $I(d)$ and the true data-generativng process is a $Var(p)$, then by fitting a $VAR(p+d)$results in the usual asymptotics for Wald tests. This works because overparameterization of the VAR process avoids singularity in the test statistic. As Tsionas explains, in order to test for causality, one proceeds by fitting a $VAR(p+d)$ in levels and applies a standard F-test involving the coefficients of lags 1 to *p*.

Results in table 9 suggest that deseasonalization triggered productivity gains in NY, WI and WA, but that in CA, ID and KY productivity growth has caused a more aseasonal system. No causal relationship is evident for IL, IN, MI, MN, OH, PA and VA and a two-way causality is shown for TX.

Conclusion

We have developed a pathway to explain patterns in the deseasonalization phenomenon that has occurred in animal agriculture. It is based on the link between productivity progress made possible by more aseasonal systems, and that in itself has a bias towards less seasonality. We have also provided evidence to support the theory. We readily agree that other theories may also have merit in explaining part of the story.

Consider a feed cost motive. Many of the effects referred to above concern the price of concentrate feed relative to grass. While concentrated feed markets are quite integrated at the U.S. national level, this is not true of bulky hay and silage markets, while grass markets are very local. A reduction in the relative price of concentrate feed should promote confined production because concentrate feed is most readily fed indoors. For the five-year intervals 1953-1957 and 1996-2002, we considered the price of standard grade corn in Kansas City (#3 yellow in the earlier period and #2 yellow in the later period).[2] We considered also the USDA reported annual national prices of hay in those years. The hay to concentrate price ratio approximately doubled over that time interval, providing a further motive for non-seasonal dry-lot production where grass products are less significant inputs.

Or consider the demand-side motive for more information and safer raw materials that can yield more differentiated processed product, as discussed in Barkema or Kinsey. This can explain growing vertical coordination in the food system. It could also provide a motive for larger scale

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[2] Statistics are derived from data in various issues of *Agricultural Statistics*, United States Department of Agriculture.

production because industrial farms can be more readily monitored by means that also apply to more regular industries.

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Table 1. Notable technical innovations, 1900-1940

Machinery

All-purpose tractor
Pneumatic tires
Diesel tractor
Corn picker
Power mower
Silage and hay cropper
Pickup baler
Beet lifter and topper
Can harvester
Mulitrow planter
Fertilizer spreader
Power spreader
Automatic drainage pump
Spray irrigation equipment
Electric fence
Electric poultry equipment
Hay dryer
Crusher-mower
Duck-foot cultivator
Seed placement plates

Animal innovations

- Artificial insemination
- Controlled feeding
- Sanitation improvements in dairy
- Cross-breeding cattle, hogs, and poultry
- Improved balanced rations
- Improved control of insects and internal parasites
- Progeny testing
- Improved feed quality control
- Improved control of diseases:
  - Tuberculosis
  - Bang's Disease
  - Cattle Tick Feaver
  - Poultry diseases

Plant innovations

- Hybrid corn
- Rust-resistant wheat and oats
- Longer-staple cotton
- Early maturing sorghums
- Cold-tolerant sugar cane
- Improved lespedeza strains
- New sweet potato varieties
- Plant hormones
- Disease-resistance:
  - Sugar cane
  - Barley
- Wilt-resistant alfalfa
- Scale-resistant potatoes
- Improved insect control:
  - Quarantine methods
  - Poisons and traps
  - Tillage and rotations

Land-use improvements

- Terracing and contour plowing
- Strip cropping
- New crop rotations
- Green manure and cover crops
- Phosphate fertilization of pastures
- Range improvements
- Higher-analysis fertilizers
- Minor plant food elements
- Legumes for nitrogen fixation
- Increased lime applications

Source: U.S. Department of Agriculture (1940), cited according to Gardner, 2002, p. 9

Table 2. Number of Tractors, Combines, and Automatic Milking Machines in the Federal Republic of Germany (millions)

	Tractors	Combines	Automatic Milking Machines
1949	0.077	-	0.006
1953	0.288	0.004	0.040
1960	0.902	0.032	0.291
1970/75	1.250	0.140	0.481

Source: Henning, 1978, p. 267.

Table 3. Monthly Production Data Used

Product	Country	Series	Units	Time covered	Source
Milk	US[a]	Milk Production	Mill lbs	1930 - 2000	USDA-NASS
	DE	Delivery to dairies	Mill liters	1951 - 2001	*Agrarwirtschaft*
	CA	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	Production	Mill lbs	1944 - 1981; 1983 - 2000	USDA-NASS
	DE	Production	000 tons	1951 - 1989; 1991 - 2000	*Agrarwirtschaft*
	UK	Production	000 heads	1973 - 2000	DEFRA
Beef	US	Production	Mill lbs	1944 - 1981; 1983 - 2000	USDA-NASS
	DE	Slaughter	000 heads	1951 - 2000	*Agrarwirtschaft*
	UK	slaughter	000 heads	1973 - 2000	DEFRA

Table 4. Indices of Seasonal Production, Averages per Decade

	Hirshfeld-Herfindahl Index[a]				Maximum Entropy Index[b]			
	1930-39	1950-59	1970-79	1990-2000	1930-39	1950-59	1970-79	1990-2000
Milk								
US	851	849	837	835	2.4746	2.4759	2.4828	2.4842
CA	-	900	858	835	-	2.4447	2.4699	2.4842
UK	847	843	843	836	2.4765	2.4791	2.4794	2.4833
DE	-	857	846	837	-	2.4708	2.4772	2.4829
Pork								
US	-	854	841	837	-	2.4728	2.4804	2.4824
UK	-	-	844	843	-	-	2.4788	2.4789
DE	-	839	835	836	-	2.4817	2.4839	2.4833
Beef								
US	-	838	836	836	-	2.4823	2.4833	2.4832
UK	-	-	850	857	-	-	2.4750	2.4708
DE		844	841	844		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 5. Trends in Deseasonalization – Animal Production in Selected Countries[a]

	Const	**EI_{t-1}**	**R^2**	**DW**	**p-value** $a_0 = (1-a_1)\overline{EI}$	**Chow-test** (p-value)
Milk						
UK	0.391**	0.842***	0.703	2.304	0.021	0.868
	(0.170)	(0.068)				(0.425)
DE	0.207*	0.917***	0.879	2.841	0.089	3.145
	(0.122)	(0.049)				(0.052)
CAN	0.062	0.975***	0.939	2.631	0.151	0.680
	(0.043)	(0.030				(0.510)
US	0.076	0.969***	0.983	2.608	0.306	0.765
	(0.075)	(0.030)				(0.471)
Pork						
UK	1.234**	0.502**	0.212	2.044	0.010	0.470
	(0.479)	(0.193)				(0.631)
DE	2.046***	0.176**	0.098	1.708	0.000	2.868
	(0.193)	(0.078)				(0.067)
US	0.809***	0.673***	0.456	2.222	0.001	1.187
	(0.250)	(0.101)				(0.313)
Beef						
UK	1.599***	0.354*	0.128	1.996	0.000	1.291
	(0.457)	(0.185)				(0.294)
DE	2.469***	0.004	0.001	1.965	0.000	0.371
	(0.360)	(0.145)				(0.692)
US	2.198***	0.114	0.013	2.002	0.000	0.744
	(0.339)	(0.137)				(0.406)

[a] *, **, *** denotes significance at the 0.1, 0.05, and 0.01 significance level according to the p-value.

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

	Const	**EI$_{t-1}$**	**R^2**	**DW**	**p-value**	**Chow-test**
	(t-value)	(t-value)			$H_0\colon a_0 = (1 - a_1)\overline{EI}$	(p-value)
CA	0.470***	0.811***	0.848	3.039	0.000	2.148
	(0.119)	(0.048)				(0.128)
ID	0.362***	0.854***	0.886	2.361	0.001	2.020
	(0.108)	(0.043)				(0.144)
IL	0.351**	0.859***	0.820	2.423	0.013	2.911
	(0.141)	(0.057)				(0.064)
IN	0.229***	0.908***	0.934	2.379	0.007	1.548
	(0.084)	(0.034)				(0.223)
KY	0.322	0.870***	0.874	2.749	0.005	4.242
	(0.116)	(0.047)				(0.020)
MI	0.228***	0.908***	0.962	2.087	0.000	1.182
	(0.063)	(0.026)				(0.315)
MN	0.176	0.929***	0.894	2.799	0.116	1.412
	(0.112)	(0.045)				(0.253)
NY	0.247*	0.900***	0.928	2.741	0.005	2.692
	(0.088)	(0.035)				(0.078)
OH	0.458***	0.815***	0.818	2.700	0.001	1.230
	(0.135)	(0.054)				(0.301)
PA	0.272**	0.890***	0.851	2.843	0.037	5.434
	(0.131)	(0.053)				(0.007)
TX	0.558***	0.775***	0.714	2.086	0.001	1.421
	(0.172)	(0.069)				(0.251)
VA	0.302***	0.878***	0.908	2.819	0.002	0.903
	(0.098)	(0.039)				(0.412)
WA	0.266***	0.893***	0.964	2.659	0.000	0.272
	(0.060)	(0.024)				(0.763)
WI	0.267***	0.892***	0.911	2.378	0.006	0.557
	(0.098)	(0.039)				(0.576)

[a] *, **, *** denotes significance at the 0.1, 0.05, and 0.01 significance level according to the p-value.

Table 7. Unit-Root Tests for EI and Productivity in Milk Production

	EI		**Productivity**	
	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 (01.06) [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 (9.992) [10]	0.049 (0.995) [2]	- 1.909 (0.972) [2]
US States-milk				
CA	- 3.989 (0.009) [2]	- 13.013 (0.266) [2]	- 2.897 (0.163) [2]	- 28.111 (0.013) [2]
ID	- 2.681 (0.244) [10]	- 19.550 (0.077) [10]	- 0.664 (0.975) [4]	- 2.067 (0.968) [4]
IL	- 0.876 (0.959) [4]	- 9.474 (0.473) [4]	- 1.041 (0.938) [2]	- 3.328 (0.922) [4]
IN	- 4.830 (0.0004) [6]	- 3.061 (0.934) [6]	- 1.862 (0.674) [3]	- 7.301 (0.640) [3]
KY	- 0.756 (0.969) [3]	- 16.303 (0.145) [3]	- 3.688 (0.023) [3]	- 24.012 (0.031) [3]
MI	- 3.534 (0.036) [2]	- 3.661 (0.906) [2]	- 1.554 (0.810) [2]	- 7.625 (0.614) [2]
MN	- 1.002 (0.944) [4]	- 24.935 (0.026) [4]	- 1.298 (0.888) [2]	- 5.144 (0.811) [2]
NY	- 4.190 (0.005) [9]	- 6.943 (0.669) [9]	- 1.435 (0.850) [2]	- 5.915 (0.752) [2]
OH	- 5.153 (0.0001) [2]	- 8.773 (0.524) [2]	- 1.668 (0765) [9]	- 16.116 (0.151) [9]
PA	- 0.767 (0.968) [4]	- 12.154 (0.308) [4]	- 1.602 (0.791) [2]	- 5.574 (0.779) [2]
TX	- 0.894 (0.957) [10]	- 8.917 (0.513) [10]	- 1.994 (0.605) [3]	- 20.738 (0.061) [3]
VA	- 1.429 (0.852) [10]	- 5.396 (0.792) [10]	- 1.634 (0.524) [2]	- 8.774 (0.524) [2]
WA	- 4.731 (0.001) [10]	- 5.918 (0.752) [10]	- 3.252 (0.075) [10]	- 9.585 (0.465) [2]
WI	- 2.418 (0.370) [6]	- 8.054 (0.579) [6]	- 2.307 (0.430) [2]	- 10.942 (0.376) [2]

Table 8. Johanson and Engle-Granger test

	Johanson[a]		**Engel – Granger**[b]		
	$p = 0$: no cointegration vs. $p>0$ $p \leq 1$: cointegration of 1 or 0 vs. $p>1$		(H_0: no cointegration)		
	H_0: rank = p	Trace Statistic	Dep. Var.	t - test	p - value
US-EI	$p = 0$	12.839 (0.244) [1]	US-M-EI	-2.795	0.361 [10]
	$p \leq 1$	1.146 (0.303)	US-MProd	-0.493	0.994 [7]
CAN-EI	$p = 0$	12.705 (0.250) [0]	CAN-M-EI	-2.043	0.753 [2]
	$p \leq 1$	0.078 (0.609)	CAN-MProd	-2.111	0.723 [2]
UK-EI	$p = 0$	21.879 (0.015) [0]	UK-M-EI	-3.079	0.231 [4]
	$p \leq 1$	6.566 (0.009)	UK-MProd	-2.827	0.345 [10]
DE-EI	$p = 0$	15.619 (0.114) [1]	DE-M-EI	- 3.042	0.246 [4]
	$p \leq 1$	0.026 (0.624)	DE-MProd	- 0.738	0.989 [2]
US-EI	$p = 0$	13.258 (0.218) [10]	US-P-EI	-1.560	0.909 [10]
	$p \leq 1$	0.176 (0.581)	US-PProd	-1.674	0.882 [7]
US-States					
CA-EI	$p = 0$	35.148 (0.0004) [0]	CA-E	- 2.935	0.293 [2]
	$p \leq 1$	12.051 (0.0003)	CA-Prod	- 3.060	0.238 [2]
ID-EI	$p = 0$	12.269 (0.284) [1]	ID-E	- 2.946	0.288 [2]
	$p \leq 1$	0.650 (0.440)	ID-Prod	- 2.084	0.735 [2]
IL-EI	$p = 0$	15.079 (0.133) [0]	IL-E	- 3.227	0.176 [2]
	$p \leq 1$	1.204 (0.289)	IL-Prod	- 1.879	0.818 [2]
IN-EI	$p = 0$	11.151 (0.372) [1]	IN-E	- 2.257	0.652 [3]
	$p \leq 1$	4.358 (0.034)	IN-Prod	- 2.072	0.741 [3]
KY-EI	$p = 0$	14.030 (0.177) [5]	KY-E	- 1.110	0.970 [3]
	$p \leq 1$	0.415 (0.511)	KY-Prod	- 3.450	0.111 [3]
MI-EI	$p = 0$	9.034 (0.557) [0]	MI-E	- 2.347	0.604 [2]
	$p \leq 1$	2.640 (0.096)	MI-Prod	- 2.193	0.683 [2]
MN-EI	$p = 0$	8.450 (0.608) [2]	MN-E	- 2.493	0.524 [4]
	$p \leq 1$	0.206 (0 572)	MN-Prod	- 2.270	0.645 [2]
NY-EI	$p = 0$	14.433 (0.159) [0]	NY-E	- 1.798	0.846 [2]
	$p \leq 1$	3.278 (0.066)	NY-Prod	- 1.863	0.824 [2]
OH-EI	$p = 0$	22.494 (0.013) [8]	OH-E	- 1.743	0.863 [3]
	$p \leq 1$	1.301 (0.266)	OH-Prod	- 1.745	0.862 [9]
PA-EI	$p = 0$	21.920 (0.015) [2]	PN-E	- 3.536	0.091 [2]
	$p \leq 1$	1.180 (0.295)	PN-Prod	- 3.628	0.074 [2]
TX-EI	$p = 0$	9.684 (0.500) [10]	TX-E	- 1.139	0.968 [10]
	$p \leq 1$	0.108 (0.601)	TX-Prod	- 2.559	0.487 [2]
VA-EI	$p = 0$	13.066 (0.230) [1]	VA-E	- 1.423	0.960 [10]
	$p \leq 1$	0.306 (0.543)	VA-Prod	- 1.986	0.777 [2]
WA-EI	$p = 0$	24.755 (0.007) [2]	WA-E	- 2.325	0.616 [2]
	$p \leq 1$	10.360 (0.001)	WA-Prod	- 3.496	0.100 [2]
WI-EI	$p = 0$	23.208 (0.011) [0]	WI-E	- 2.866	0.325 [2]
	$p \leq 1$	5.965 (0.013)	WI-Prod.	- 3.094	0.225 [2]

[a] Trace statistic stands for the Johanson trace statistic. The first null hypothesis of $p=0$ indicates tests for no integration against the alternative of one or more cointgrating vectors ($p>0$). In addition the test of maximal one cointegrating vector is tested the hypothesis of two or more integrating vectors ($p>1$). The optimal lag length has been chosen using the Akaike Information Criterion and is indicated in brackets.

Table 9. Dolado and Lütkepohl Causality Test for Milk Aseasonality and Productivity[a]

State	Causality	Number of lags p^b	F-test[c]	P-value	Conclusion
CA	Prod → EI	1	7.438***	0.009	EI → Prod
	EI → Prod		0.020	0.889	
ID	Prod → EI	2	0.3768**	0.031	EI → Prod
	EI → Prod		0.652	0.526	
IL	Prod → EI	2	0.521	0.598	No causality
	EI → Prod		0.359	0.700	
IN	Prod → EI	2	0.532	0.592	No causality
	EI → Prod		0.537	0.588	
KY	Prod → EI	1	3.053*	0.088	EI → Prod
	EI → Prod		0.155	0.696	
MI	Prod → EI	2	0.006	0.994	No causality
	EI → Prod		0.893	0.417	
MN	Prod → EI	3	1.784	0.166	No causality
	EI → Prod		0.778	0.513	
NY	Prod → EI	1	1.739	0.194	Prod → EI
	EI → Prod		2.875*	0.097	
OH	Prod → EI	1	0.429	0.516	No causality
	EI → Prod		0.009	0.925	
PA	Prod → EI	2	0.416	0.662	No causality
	EI → Prod		1.352	0.270	
TX	Prod → EI	1	11.182***	0.002	Two-way causality
	EI → Prod		5.568**	0.023	
VA	Prod → EI	2	1.127	0.334	No causality
	EI → Prod		0.244	0.785	
WA	Prod → EI	1	0.070	0.792	Prod → EI
	EI → Prod		3.110*	0.085	
WI	Prod → EI	1	2.720	0.106	Prod → EI
	EI → Prod		4.246**	0.045	

[a] In this test, one one proceeds by fitting a $VAR(p+d)$ in levels and applies a standard F-test involving the coefficients of lags 1 to p. The H_0 states that the causal variable of lag 1 to p are zero.
[b] The optimal number of lags was chosen according to the Schwartz Bayesian Information Criterion.
[c] *, **, *** denotes significance at the 0.1, 0.05, and 0.01 significance level according to the p-value.