**Supplementary Appendix**

**Change in Hay-to-Milk Price Responsiveness with Dairy Industry Expansion**

**Table of Contents**

**Table 1A.** Cow Inventory Growth Rates Top 10 (as of 2019) Dairy Producing U.S. States, 2002-2019………………………………………………………………………………………………..2

**Table 2A.** Stationarity Tests of Hay and Milk Price Series Level and First Differences…….……..3

**Table 3A.** Adjusted- Values for Level Models with Stocks-to-Use Ratios from State, Western Region, and U.S…………………………………………………………………………................4

General description of price transmission estimation in a cointegration framework in the context of the hay-to-milk price relationship………………………………………………..……….……..5

Appendix references…………………………………………………………………………….…7

**Table 1A.** Cow inventory growth rates for top 10 (as of 2019) dairy-producing U.S. states, 2002-2019

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Year** | **CA** | **ID** | **MI** | **MN** | **NM** | **NY** | **PA** | **TX** | **WA** | **WI** |
| 2002 | 3.85% | 6.50% | -0.33% | -3.85% | 11.11% | 0.75% | -3.61% | -8.70% | 0.41% | -3.40% |
| 2003 | 3.09% | 3.45% | 0.67% | -4.00% | 8.28% | 0.00% | 0.34% | 1.59% | 0.00% | -1.17% |
| 2004 | 1.80% | 5.64% | -0.33% | -3.13% | 3.50% | -2.52% | -4.41% | -0.94% | -2.83% | -1.58% |
| 2005 | 2.35% | 5.58% | 2.33% | -1.08% | -2.15% | -1.22% | 0.35% | 0.32% | -2.08% | -0.80% |
| 2006 | 1.72% | 8.74% | 2.28% | -2.17% | 6.92% | 0.00% | -1.41% | 10.06% | 0.85% | 0.40% |
| 2007 | 1.13% | 6.13% | 4.14% | 1.11% | 0.00% | -3.38% | -1.43% | 8.57% | -0.84% | 0.40% |
| 2008 | 2.51% | 5.58% | 5.20% | 1.76% | -2.94% | -0.32% | 0.36% | 5.26% | 3.40% | 0.40% |
| 2009 | 0.27% | 4.53% | 2.62% | 1.08% | 1.82% | -0.16% | -0.36% | 7.50% | 0.41% | 0.40% |
| 2010 | -4.35% | -0.72% | 0.28% | 0.43% | -5.36% | -2.40% | -1.82% | -4.65% | -0.41% | 0.40% |
| 2011 | -0.57% | 4.36% | 1.98% | 0.00% | 1.26% | 0.00% | 0.56% | 3.66% | 3.70% | 0.40% |
| 2012 | 1.71% | 1.22% | 2.77% | -1.06% | 4.04% | 0.00% | -0.55% | 2.35% | 4.37% | 0.00% |
| 2013 | 0.00% | -0.17% | 1.62% | 0.00% | -4.48% | 0.00% | -0.93% | 0.00% | 0.38% | 0.40% |
| 2014 | 0.00% | -2.59% | 1.06% | -1.08% | 0.94% | 0.82% | -0.93% | 1.15% | 0.76% | 0.00% |
| 2015 | 0.00% | 2.48% | 5.77% | 0.00% | 0.00% | 0.00% | 0.00% | 6.82% | 4.14% | 0.39% |
| 2016 | -0.56% | 1.38% | 2.23% | 0.00% | -2.48% | 0.81% | 0.00% | -2.13% | 0.00% | 0.39% |
| 2017 | -0.85% | 2.21% | 3.16% | 0.00% | 3.17% | 0.00% | -0.94% | 8.70% | -0.72% | 0.00% |
| 2018 | -0.85% | 0.00% | 0.71% | -1.09% | 2.15% | 0.81% | 0.00% | 6.00% | 0.00% | -0.39% |
| 2019 | -0.57% | 2.33% | -1.40% | -1.10% | -2.11% | 0.00% | -3.81% | 2.83% | 1.82% | -0.39% |

Source: Authors’ calculations from USDA-NASS data.

**Table 2A.** Stationarity tests of hay and milk price series levels and first differences

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Hay | | | | | | | | |
|  | Levels: without trend | | | Levels: with trend | | | First differences | | |
|  | CA | ID | NM | CA | ID | NM | CA | ID | NM |
| DF | -1.49 | -1.83 | -1.45 | -1.79 | -1.98 | -1.68 | -9.74\*\* | -14.34\*\* | -11.64\*\* |
| PP | -1.95 | -2.04 | -1.80 | -2.48 | -2.27 | -2.17 | -9.74\*\* | -14.44\*\* | -11.83\*\* |
|  | Milk | | | | | | | | |
|  | Levels: without trend | | | Levels: with trend | | | First differences | | |
|  | CA | ID | NM | CA | ID | NM | CA | ID | NM |
| DF | -1.89 | -2.02 | -2.04 | -2.33 | -2.54 | -2.31 | -8.65\*\* | -9.45\*\* | -8.70\*\* |
| PP | -2.60 | -2.47 | -2.74 | -3.15 | -3.09 | -3.08 | -8.40\*\* | -9.03\*\* | -8.41\*\* |

Note: Series stationarity test critical values are provided in Fuller (1996). \*\* and \* denote statistical significance at the 1% and 5% significance levels, respectively.

**Table 3A.** Adjusted- values for level models with stocks-to-use ratios from state, Western region, and U.S.

|  |  |
| --- | --- |
| California – state | 0.57 |
| California –West | 0.62 |
| California – U.S. | 0.61 |
| Idaho – state | 0.49 |
| Idaho – West | 0.50 |
| Idaho – U.S. | 0.47 |
| New Mexico – state | 0.33 |
| New Mexico – West | 0.36 |
| New Mexico – U.S. | 0.40 |

*General description of price transmission estimation in a cointegration framework*

Cointegration between two price variables implies that they tend to move together over the long run despite potential short-run deviations (Banerjee et al., 1993; Baffes and Gardner, 2003). Due to the linkage between dairy production and demand for hay as feed in dairy rations, it is expected that hay and milk prices are cointegrated.

Investigation of whether this hypothesis is consistent with the data can be conducted using a model that includes the hay price for each month, , as the dependent variable, and the monthly milk price, , as the explanatory variable. The resulting level regression model has the form:

(1A) ,

where is the intercept, is the long-run price responsiveness parameter, and is a random error. Stationarity of the estimated residuals from regression of equation (1A), , where the hat (^) signifies estimated, imply that the prices are cointegrated. This means the variables move together over the long run despite short-run deviations (Phillips and Ouliaris, 1990).

Price series such as those in equation (1A) may be non-stationary, meaning they do not have a constant mean (or detrended mean) and variance over the observation period. Given non-stationary series level and theory-based expectations that the prices move together over the long run, then the short-run relationship between the variables can be estimated within an associated error correction mechanism (ECM) model. The ECM model for this case has the form:

(2A) ,

such that signifies the first difference of the price variable, are the lagged estimated residuals from estimation of the associated level model in equation (1). is the ECM term. The estimated value of the ECM term, , represents the extent to which divergences between the prices are corrected in each month. is the short run (one month) price responsiveness parameter. is a random error. Statistical significance of the estimated ECM parameter, , implies that the series move back toward each other after short-run deviations. Thus, the statistical significance of the ECM parameter is an additional indicator of cointegration (Banerjee et al., 1993).

**References**

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