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Transitioning to Organic Crop Production: A Dynamic Programming Approach

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Despite evidence that organic cropping systems in the Midwest can be more profitable than conventional systems, only a small percentage of cropland has been certified as organic. This paper models the decision to transition to organic crop production as a dynamic programming problem in which investment is reversible but includes sunk costs. Results indicate that the risk and unrecoverable costs associated with organic transition lead to a significant option value, and this provides a partial explanation for low transition rates in the baseline scenario. Sensitivity to expected organic yield and price levels is explored, as are the costliness of reverse transition and the short-term effect of high conventional return levels.

Key words: dynamic programming, organic farming, organic transition, real options

Introduction

Both experimental trials and empirical farm-level data have indicated that organic cropping systems in the midwestern United States can earn more on a per acre basis than the conventional corn-soybean rotation often used in the region (Helmers, Langemeier, and Atwood, 1986; Delate et al., 2003; Pimentel et al., 2005; Chavas, Posner, and Hedtcke, 2009; Delbridge et al., 2011; Center for Farm Financial Management, 2015). Research using trial data to compare returns to these two systems at the whole-farm level shows that with identical environmental conditions, labor, and machinery endowments the organic system can maintain the profitability advantage even when practiced on fewer acres (Delbridge et al., 2013). Although not all studies and data sources show a significant profitability advantage to organic farming in every year (Uematsu and Mishra, 2012; Center for Farm Financial Management, 2015), it certainly seems likely that a substantial number of farms in the Upper Midwest could increase profitability by adopting an organic production system. Despite this potential, the steady growth in consumer demand for organic foods (Osteen et al., 2012), and the strengthening public support for organic production (U.S. Department of Agriculture, 2013), less than 1% of U.S. cropland has been transitioned to organic management.[1] In fact, while total U.S. organic crop acreage has continued to increase, the rate of transition has slowed in recent years, and twenty states saw a net decrease in organic crop acreage from 2008 to 2011 (U.S. Department of Agriculture, Economic Research Service, 2013).

A farm's pursuit of organic certification entails significant transition costs and risk. Achieving organic certification for cropland requires a transition period of three years, during which the land is managed according to National Organic Program (NOP) requirements but the farm's products cannot be marketed as "organic" (U.S. Department of Agriculture. National Organic Program,

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[1] The percentage of organic cropland tends to be higher for fruit and vegetable crops than for the grains and oilseeds typically grown in the Midwest.

2013). Since crop yields typically fall during the organic transition and adopting an organic crop rotation often involves some diversification away from the most valuable crops, farms usually experience substantial reductions in gross revenue during the transition (Delbridge et al., 2015). Upon completion of the transition period organic crops can be sold at a significant premium and expected net farm income may be higher than that earned by conventional growers. However, given fluctuations in prices and yields achieved by both systems, any expected income advantage is uncertain, and returns to organic production may in fact be lower than those to conventional production. Initiating organic transition can, therefore, be viewed as a costly investment in a risky asset—organic certification—and the decision to transition (or not) takes on an interesting dynamic dimension.

This paper frames the decision to transition to organic crop production as a problem of investment under uncertainty and solves a farm manager's transition decision problem using a dynamic programming model. We use the model to determine whether the cost of transition (i.e., investment) and the uncertainty inherent in the organic transition can help explain low transition rates of U.S. cropland that are seemingly inconsistent with research comparing the profitability of organic and conventional cropping systems. This paper provides insights into how the optimal transition decision for farms of different sizes is affected by changes in organic yield levels and price premiums and explores the implications of high profits for conventional crop farms on organic transition rates in the short term.

The theory of investment under uncertainty presented by Dixit and Pindyck (1994) provides a useful framework for analyzing the decision to undertake organic transition. This real options approach recognizes that the expected net present value (NPV) gain associated with the investment must be greater than the direct investment cost plus the value of the option to delay the investment in order for an investment to be optimal. In many investment problems the expected NPV gain of the investment is greater than the direct investment cost but not greater than both the cost and the option value of delay. Thus, the investment is not undertaken even though the NPV of the investment is higher than the NPV of the current use of capital.

Real options theory has been applied to many agricultural land use problems. Tegene, Wiebe, and Kuhn (1999) found that payments to landowners for conservation easements failed to fully compensate for the landowners' option value, thus explaining low participation rates. Schatzki (2003) econometrically estimated the option value to delay conversion of cropland into forests and found that landowners consider significant option values when making this land use decision. Song, Zhao, and Swinton (2011) developed a "two-way" transition model for the decision to install perennial energy crops in place of annual row crops and showed that far fewer acres would be converted to energy crops than would be predicted by an NPV model.

There have been a few recent attempts to apply real options theory to the decision of organic transition. Musshoff and Hirschauer (2008) applied a dynamic decision model to farm-level data from Germany and Austria to help explain the slow rate of organic transition of farmland in general and the differing rates between the two countries. The study concluded that the returns to the organic and conventional cropping systems followed different stochastic processes in Austria and Germany and that this helps explain the different rates of organic transition in the two countries. Kuminoff and Wossink (2010) used data on organic soybean production in the United States to estimate the size of the incentive that would be required to induce transition of a conventional farm. They concluded that the incentive needed to induce transition would be much higher under a real options model than it would be under an NPV framework, suggesting a significant option value.

This paper contributes to this literature by modeling the decision to transition to organic crop production as a dynamic programming problem in which investment is reversible but includes unrecoverable (or sunk) costs in the form of foregone income during organic transition. We use the model to explore how the uncertainty regarding future returns to organic management and the prospect of incurring transition-related sunk costs affect the probability of organic adoption and how this effect varies with the expected profitability of the organic system. By analyzing the decision to transition under several different farm-size scenarios and organic price premium levels, we provide insights into the ways in which the size distribution of organic farms is likely to shift with fluctuations in conventional farm returns. Both long-term (i.e., steady-state) and short-term transition outcomes are investigated, providing a more complete understanding of the farm-level decision to initiate organic transition than has previously been available.

Organic Transition Decision Model

We consider a model in which a risk-neutral farm manager faces two alternatives: management of a conventional corn-soybean crop rotation or management of an organic corn-soybean-oat/alfalfa-alfalfa crop rotation.[2] If organic management is chosen, two conditions are possible: certified organic and transitional. Because organic management is more labor intensive, the amount of land that can be farmed may also be affected. After the land is managed in the transitional state for two consecutive periods (i.e., years), the land is certified as organic in the third period and the crops produced receive organic price premiums.[3] If a decision is made to manage the land conventionally, the farm loses any organic certification and any progress toward completion of the thirty-six-month transition. During the transition period, crop yields and production costs are assumed to be the same as those faced by the organic system and crop prices are assumed to be the same as those received for conventional crops.

The model has a single control variable—the production method chosen for the farm, x_t, which takes a value of 0 when conventional production methods are used and a value of 1 when organic production methods are used. There are two state variables—the farm's transition status, s_t, and the current per acre revenue for the conventional rotation, cr_t. The transition status variable, s_t, is coded to indicate whether the farm is certified organic, in transition, or neither (i.e., conventional). This variable also provides information on the number of crop years since the farm has abandoned organic certification, which can impact the acreage available for conventional management in some model scenarios.

For the sake of simplicity, the gross revenue per acre achieved by the conventional cropping system, cr_t, is modeled as a single stochastic process rather than as a joint distribution of separate crop yield and price processes. A lack of long-term data on organic commodity prices and transitional yields precludes the estimation of similar stochastic processes for organic and transitional system revenues. Although evidence suggests that organic and conventional crop prices may be independent of one another (Singerman, Lence, and Kimble-Evans, 2010), crop yields from the two systems are certainly related through a similar yield response to weather. Therefore, organic and transitional revenues are modeled as functions of conventional revenues.

The farm manager's objective is to maximize the expected value of discounted annual net income over an infinite planning horizon subject to the equations of motion for the two state variables. Current net income, $f(x_t, s_t, cr_t)$, is a function of the control variable and the levels of both state variables.

This organic transition decision problem is modeled using yield and management data from a long-term cropping systems trial in southwest Minnesota. In this experimental trial, a four-year (corn-soybean-oat/alfalfa-alfalfa) rotation was managed organically and a two-year (corn-soybean) rotation was managed conventionally. These particular rotations were chosen by experiment station agronomists to reflect the region's most common organic and conventional crop production practices. For a full explanation of management practices and yield measurements, see Porter et al. (2003) and Coulter et al. (2011).

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[2] Throughout this article "organic" refers to management in accordance with NOP guidelines.

[3] Since transition officially starts at the time of last prohibited practice (e.g., herbicide spray) and ends at certification no sooner than thirty-six months later, cropland is commonly in "transition" for only two full crop years.

Transition Status

In a study of whole-farm profitability of organic and conventional cropping systems, Delbridge et al. (2013) found that a conventional corn-soybean rotation can be managed on a larger number of acres than an organic crop rotation given equal machinery and labor endowments. This is due primarily to the additional tillage passes needed for mechanical weed control in the organic system. In this paper we use the farm size results from Delbridge et al. (2013) to model the dynamics of the organic transition decision as a whole-farm problem. We consider three farm-size scenarios, with crop acreage for each system in each scenario taken from Delbridge et al. (2013). In the "small" scenario both the organic and conventional systems are managed on 320 acres. In the "medium" scenario the organic system is limited to 560 acres while the conventional system has access to 880 acres. And in the "large" scenario the organic system is managed on 800 acres and the conventional system is managed on 1,360 acres.

Differences in the number of acres farmed under conventional and organic management add some complexity—and cost—to the transition decision. Suppose a mid-sized conventional corn-soybean producer who farms 880 acres decides to adopt an organic system. Upon making the decision to transition the farm to organic production, the farmer reduces the acreage under cultivation to 560, following the results of Delbridge et al. (2013). In the tight land markets common in the Midwest, farm size is easily reduced by giving up rented land or renting out owned land. However, given the difficulty in acquiring leases on nearby land, a mid-sized organic farm with only 560 acres under cultivation may not be able to immediately expand to 880 acres in the event that the decision is made to surrender organic certification and adopt a conventional corn-soybean system. In the baseline model analysis, we assume that a farm switching from organic to conventional production gradually expands acreage to the conventional level for the relevant farm-size scenario in equal steps over a five-year period.

The interaction between s_t and the control variable, x_t, can result in three distinct situations for a farm producing organically: first year transition ($s_t \leq 4$ and $x = 1$), second year transition ($s_t = 5$ and $x = 1$), and certified organic ($s_t = 6$ and $x = 1$). In all these cases, acreage is set at the organic management level for the particular farm-size category. Five distinct situations are possible for conventional production when acreage adjusts gradually from the organic management level to the conventional management level: full conventional acreage ($s_t = 4$ and $x_t = 0$) and four acreage levels between the organic acreage and full conventional acreage ($s_t > 4$ and $x_t = 0$, and each of $s_t = [1,2,3]$ with $x_t = 0$). The dynamics of the transition status state variable are

$$(1) \qquad s_{t+1} = \begin{cases} 1 & \text{if } s_t > 4 \text{ and } x_t = 0 \\ \min(s_t + 1, 4) & \text{if } s_t < 5 \text{ and } x_t = 0 \\ 5 & \text{if } s_t < 5 \text{ and } x_t = 1 \\ \min(s_t + 1, 6) & \text{if } s_t > 4 \text{ and } x_t = 1. \end{cases}$$

We also consider an alternative organic surrender scenario in which reversion to full conventional crop acreage is immediate. In this case only three values of s_t are possible: $s_t = 4, 5$, or 6, representing conventional, transitional, or certified organic production, respectively.

Return Processes

Revenues achieved by the conventional system are assumed to follow a mean-reverting Ornstein-Uhlenbeck process of the form

$$(2) \qquad dcr = \eta(\overline{cr} - cr)dt + \sigma dz,$$

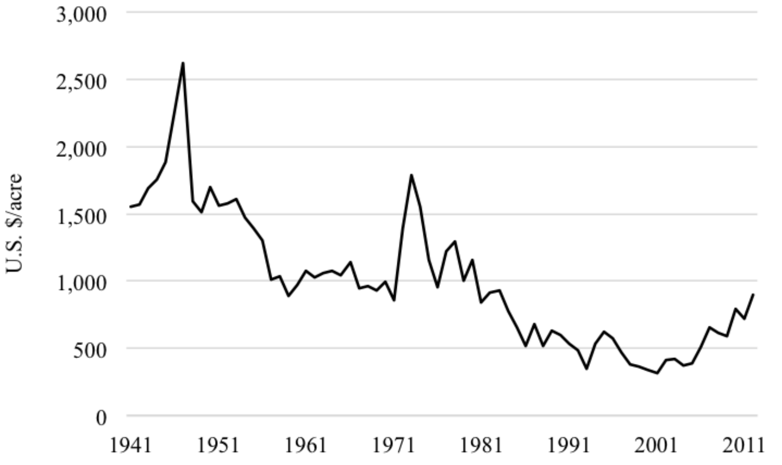

Figure 1. Detrended and Inflation-Adjusted Average Revenue Generated by a Conventional Corn-Soybean Rotation in Redwood County, MN, 1941–2012
Source: U.S. Department of Agriculture, National Agricultural Statistics Service (2013).

Table 1. Mean Reversion Parameters

Parameter		Estimate	Standard Error	P-value
	$\hat{\alpha}_0$	85.02	54.23	0.122
	$\hat{\alpha}_1$	−0.095	0.049	0.056
long-run mean	$\hat{\overline{cr}}$	899.33		
reversion rate	$\hat{\eta}$	0.095		
variance	$\hat{\sigma}$	201.99		

where η is the reversion parameter and $\overline{cr}$ and cr are the long-run mean revenue per acre and the current revenue per acre for a conventional corn-soybean crop rotation, respectively. The variance parameter is denoted by σ and dz is an increment of the Wiener process.

The discrete approximation of equation (2) can be written and estimated as

$$(3) \qquad \begin{aligned} cr_t - cr_{t-1} &= \eta\overline{cr} - \eta cr_{t-1} + \sigma\varepsilon \\ &= \alpha_0 + \alpha_1 cr_{t-1} + \sigma\varepsilon \end{aligned}$$

where $\hat{\overline{cr}} = -\frac{\hat{\alpha}_0}{\hat{\alpha}_1}$ and $\hat{\eta} = -\hat{\alpha}_1$. The estimate for the variance parameter, $\hat{\sigma}$, is the standard error of the regression and $\varepsilon \sim N(0,1)$.

A seventy-one-year series[4] of observed gross revenues for a corn-soybean rotation was constructed using detrended county yield and inflation-adjusted state crop price data from USDA-NASS (figure 1; U.S. Department of Agriculture, National Agricultural Statistics Service, 2013). This series was used to estimate $\hat{\alpha}_0$ and $\hat{\alpha}_1$ from the discretized version of the mean reversion process in equation (3) by OLS.

Although the parameter estimates are significant at low confidence levels (table 1), these OLS t-tests are invalid under the null hypothesis of a unit root. Both an Augmented Dickey-Fuller test and a Phillips-Perron test fail to reject the null hypothesis of a unit root ($P = 0.156$ and $P = 0.0786$, respectively), casting doubt on the choice of mean reversion as a suitable choice for modeling revenues to conventional corn-soybean production. However, given the fact that many years of data are often needed to confirm the stationarity of slowly reverting processes (Dixit and Pindyck,

[4] This is the full range of available yield and price data.

Table 2. Inflation-Adjusted Prices of Conventional and Organic Corn, Soybean, Oat, and Oat Straw, 2006–2012

Year	Corn	Soybean	Oat	Oat Straw
	\$/bushel	\$/bushel	\$/bushel	\$/ton
Conventional				
2006	3.28	6.87	–	–
2007	4.04	10.26	–	–
2008	4.13	10.17	–	–
2009	3.93	10.19	–	–
2010	4.85	11.22	–	–
2011	5.80	11.65	–	–
2012	6.50	13.8	–	–
Organic				
2006	6.14	16.55	3.52	45.3
2007	9.29	21.42	5.16	41.56
2008	9.66	23.28	5.11	43.98
2009	6.89	20.01	4.62	43.8
2010	7.60	20.04	4.52	44.22
2011	10.86	23.58	5.72	31.52
2012	13.95	30.27	5.91	50.16

1994) and that agricultural returns are commonly modeled as mean reverting (e.g., Jin et al., 2012; Bessembinder et al., 1995), it is reasonable to accept the estimated mean reversion parameters despite the lack of strong statistical significance.

Organic and transitional per acre revenues are modeled as simple linear functions of conventional revenues:

$$GR_i = \beta_{0i} + \beta_{1i} cr + \varepsilon_i \text{ for } i = o, r, \tag{4}$$

where GR_i is the per acre revenue for organic and transitional crop management, cr is the per acre revenue for conventional management, and ε_i is the error term for cropping system revenue distribution i. The organic system is denoted by $i = o$ and transitional production is denoted by $i = r$. To maintain notational consistency in the formulation of the decision problem that follows, we will also use GR_c to represent conventional revenues. That is, $GR_c \equiv cr$.

In order to estimate the parameters of equation (4), distributions of per acre revenues for each system were constructed using the detrended trial yield data from 1993–2012 and inflation-adjusted organic and conventional commodity prices from 2006–2012 (tables 2 and 3; Center for Farm Financial Management, 2015). Following the methodology outlined in Delbridge et al. (2011) and updated by Delbridge (2014),[5] independence was established between organic prices and grain yields. Then the twenty years of trial yield data were combined with the seven years of organic and conventional crop price data to achieve $20 \times 7 = 140$ possible revenue states for each system.[6] The distribution of organic revenues was constructed with organic yields and organic prices, while the distribution of transitional revenues was calculated by combining organic crop yields with conventional crop prices.[7]

[5] Delbridge et al. (2011) do not adjust commodity prices for inflation but Delbridge (2014) does adjust prices for inflation. Prices are adjusted in this paper to 2012 terms using the CPI.

[6] As noted in Delbridge et al. (2011), independence of alfalfa yields and prices cannot be established, and thus alfalfa yields are matched with the conventional alfalfa price from the year in which the hay was produced. No organic price premiums are applied to organic alfalfa production in any of the pricing scenarios.

[7] In some cases, transitional yields may be higher than organic yields because of lower weed pressure. Unfortunately, no suitable transitional crop yield data are available. Assuming transitional yields are equal to organic yields is a conservative approach that is sure not to overstate the attractiveness of an organic transition (Delbridge et al., 2015).

Table 3. Inflation-Adjusted Prices of Alfalfa Hay, 1993–2012

Year	Alfalfa Hay ($ /ton)
1993	$132
1994	$134
1995	$131
1996	$136
1997	$170
1998	$122
1999	$129
2000	$129
2001	$159
2002	$195
2003	$162
2004	$146
2005	$151
2006	$133
2007	$140
2008	$141
2009	$160
2010	$122
2011	$118
2012	$240

Table 4. Mean Detrended Trial Crop Yields for Full and Reduced-Yield Scenarios for the Conventional and Organic Crop Rotations, 1993–2012

	Conventional Two-Year		Organic Four-Year			
	Full Organic Trial Yield Ccenario					
	Corn (bu/ac)	Soybean (bu/ac)	Corn (bu/ac)	Soybean (bu/ac)	Oat (bu/ac)	Alfalfa (ton/ac)
Mean	174.0	47.2	166.9	36.3	74.9	4.9
SD	27.5	7.3	25.9	10.5	31.0	0.9
	Reduced Organic Yield Scenario					
	Corn (bu/ac)	Soybean (bu/ac)	Corn (bu/ac)	Soybean (bu/ac)	Oat (bu/ac)	Alfalfa (ton/ac)
Mean	174.0	47.2	133.5	36.3	74.9	4.9
SD	27.5	7.3	20.7	10.5	31.0	0.9

Additional scenarios in which organic price premiums and trial yields are reduced from observed levels are also considered and equation (4) was estimated separately for each. A reduced-yield scenario used organic corn yields that are 20% lower than those observed in the experimental trial. This scenario is included in recognition that the organic corn yields observed in the trial were substantially higher than the average corn yields reported by organic farmers in the state (Delbridge et al., 2013). Yield averages in the full-yield and reduced-yield scenarios are presented in table 4. Alternative organic price premium scenarios are also included to show the sensitivity of model results to potential decreases in organic prices beyond those levels represented by observed price data. Five price premium levels are considered, ranging from 0% of the organic price premium (i.e., conventional prices) to 100% of the premium (i.e., full organic prices) in increments of 25%.

Table 5. OLS Estimates of Relationship between Organic and Conventional Revenues (i.e., equation 4) for Each Organic Yield and Price Premium Scenario

	Parameter Estimates			
Scenario	$\hat{\beta}_0$	**Standard Error**	$\hat{\beta}_1$	**Standard Error**
Full Yields, 100% Premiums	267.79	39.34	0.876	0.058
Full Yields, 75% Premiums	255.69	33.27	0.765	0.049
Full Yields, 50% Premiums	243.59	27.57	0.654	0.041
Full Yields, 25% Premiums	231.49	22.51	0.543	0.033
Full Yields, 0% Premiums	219.38	18.62	0.432	0.027
Reduced Yields, 100% Premiums	276.24	36.28	0.747	0.054
Reduced Yields, 75% Premiums	262.73	31.03	0.652	0.046
Reduced Yields, 50% Premiums	249.22	26.09	0.558	0.039
Reduced Yields, 25% Premiums	235.71	21.68	0.463	0.032
Reduced Yields, 0% Premiums	222.20	18.18	0.369	0.027

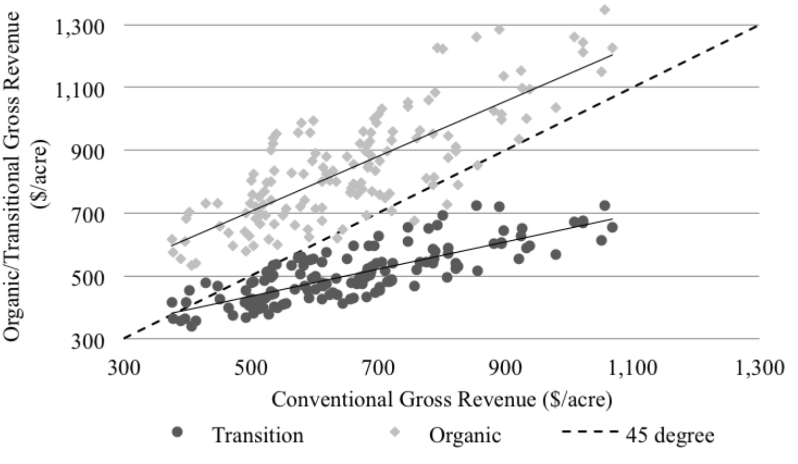

Figure 2. Revenue Generated by Transitional and Organic Management Relative to Conventional Management, Considering Full Yields and 100% Organic Price Premiums

Regression results for the baseline and alternative scenarios of equation (4) are presented in table 5. In all cases $\hat{\beta}_0$ is significantly greater than zero and $\hat{\beta}_1$ is significantly less than one. This implies that the relative attractiveness of the organic and transitional systems increases (decreases) as conventional revenues fall (rise). Figure 2 shows this relationship visually with a scatter plot of organic and transitional revenue distributions from full-yield and organic price premiums scenarios.

Current Net Return

The farm manager's single period return can be written as

$$f(x_t, s_t, cr_t) = (GR(x_t, s_t, cr_t) - c(x_t))a(x_t, s_t), \quad (5)$$

where $GR(x_t, s_t, cr_t)$ is the farm's revenue, which depends on the management decision (x_t), the organic transition status (s_t), and the current level of revenue generated by conventional production (cr_t). Production costs are denoted by $c(x_t)$ and the acreage available to the manager is denoted by $a(x_t, s_t)$.

Table 6. Production Costs for Each Cropping System and Farm-Size Scenario

	Conventional			Organic		
	Small	**Medium**	**Large**	**Small**	**Medium**	**Large**
Crop acreage	320	880	1,360	320	560	800
Operating cost	\$206	\$197	\$196	\$156	\$142	\$141
Overhead cost	\$303	\$303	\$303	\$314	\$314	\$314
Sum, $c(x)$	\$509	\$500	\$499	\$470	\$456	\$455

Table 7. Interaction between State and Control Variables and Associated Parameters

s	x	Acreage	Revenue	Production Costs
1	0	$a_O + 0.4(a_C - a_O)$	GR_c	*conventional*
2	0	$a_O + 0.6(a_C - a_O)$	GR_c	*conventional*
3	0	$a_O + 0.8(a_C - a_O)$	GR_c	*conventional*
4	0	a_C	GR_c	*conventional*
5	0	$a_O + 0.2(a_C - a_O)$	GR_c	*conventional*
6	0	$a_O + 0.2(a_C - a_O)$	GR_c	*conventional*
1	1	a_O	GR_r	*organic*
2	1	a_O	GR_r	*organic*
3	1	a_O	GR_r	*organic*
4	1	a_O	GR_r	*organic*
5	1	a_O	GR_r	*organic*
6	1	a_O	GR_o	*organic*

Production costs include both operating costs and fixed overhead costs. The operating cost, which is the sum of the cost of purchased inputs, machinery operations, and crop insurance premiums, was calculated for each system in each year based on the amount and type of inputs used and the number of machinery operations carried out in the experimental trial from 1993 to 2012 (Delbridge et al., 2011). An average operating cost over the twenty years of trial data was calculated for each system and farm size. Since the larger machinery assumed in the larger farm-size scenarios requires less labor and fuel per acre than does smaller machinery, operating costs fall as farm size increases. Average per acre overhead costs were taken from farm financial records for organic and conventional crop farms in Minnesota and do not vary across farm-size scenario (Center for Farm Financial Management, 2015; Delbridge et al., 2013).[8] Both operating and overhead costs were assumed constant from year to year, and the production costs incurred during organic transition years were assumed to be equal to those incurred under certified organic management. Operating and ownership costs for each system and size scenario are presented in table 6.

Acreage, revenue, and production costs all depend on the management decision and organic transition status. Table 7 presents the relationship between transition state variables, revenue levels, available acreage for crop production, and production costs.

[8] Limited data on organic farm overhead expenses preclude the inclusion of separate ownership costs for each farm-size scenario. However, FBM data from conventional crop farms show that overhead expenses do not tend to fluctuate greatly as farm size increases.

Dynamic Programming Formulation

The organic transition decision model can be expressed in the form of the Bellman equation as

$$V(s,cr) = \max_{x_t \in \{0,1\}} f(x_t, s_t, cr_t) + \delta \mathrm{E}V(g_1(x_t, s_t), g_2(cr_t)) \tag{6}$$

subject to

$$s_{t+1} = g_1(x_t, s_t) = \begin{cases} 1 & \text{if } s_t > 4 \text{ and } x_t = 0 \\ \min(s_t + 1, 4) & \text{if } s_t < 5 \text{ and } x_t = 0 \\ 5 & \text{if } s_t < 5 \text{ and } x_t = 1 \\ \min(s_t + 1, 6) & \text{if } s_t > 4 \text{ and } x_t = 1 \end{cases}$$

$$cr_{t+1} = g_2(cr_t) = \alpha_0 + (1 + \alpha_1)cr_t + \varepsilon_t$$

$$GR_{it} = h_i(cr_t) = \beta_{0i} + \beta_{1i}cr_t + \varepsilon_{it} \text{ for } i = r, o$$

where $V(s,cr)$ is the present value of the farm given the values of state variables s and cr and δ is a constant annual discount factor set equal to 0.04 throughout this analysis. We solve this problem numerically using the DPSOLVE routine provided in the COMPECON Toolbox package written for MATLAB by Miranda and Fackler (2004).[9] The DPSOLVE routine solves discrete time, continuous state decision models by approximating the value function $V(s,cr)$ using collocation methods. Once the value function is obtained and the optimal control path is established, Monte Carlo simulations are carried out to determine the likelihood of organic adoption given the fluctuations and shocks applied by the model. For this analysis, the probability of being certified organic at the end of a thirty-period simulation is output along with the critical threshold levels, which separate the ranges of optimal organic transition, inaction, and abandonment.

It is well known that an investment decision under uncertainty leads to an option value, or a positive value associated with the ability to delay the investment decision until a later period (Dixit and Pindyck, 1994). Under an NPV decision rule, the farm manager will initiate organic transition when the NPV of the organic system exceeds the NPV of the conventional system plus the cost of transition. Under this decision framework, the organic producer will surrender organic certification and return to conventional management when the NPV of the conventional system exceeds the NPV of the organic system plus the cost of returning to conventional production. The existence of unrecoverable transition costs results in a range of conditions (i.e., a range of inaction) under which it is neither optimal to transition to organic management nor optimal to abandon certification if already achieved. Under the real options framework, in which delaying organic adoption and future organic re-certification are permitted, this range of inaction is larger than under the NPV framework. The degree to which these ranges of inaction differ is a result of the size of the option value and increases with greater uncertainty and higher transition costs. Whether or not adoption is more or less likely under the real options framework than under the NPV framework depends on the particular parameters, processes, and expected profitability of each production system.

In addition to the baseline analysis described above, we explore the sensitivity of the optimal transition strategy and expected outcomes to several model parameters and modeling choices. We include two different organic yield scenarios and several organic price premium scenarios. We investigate the effect that the level of "initial" per acre revenue generated by conventional management (denoted cr_0) has on organic transition probabilities in the short term. We also conduct sensitivity analysis with respect to the cost of organic abandonment by including a scenario in which a return to full conventional acreage is immediate upon surrender of organic certification.

[9] The MATLAB code and data input files are available from the authors on request.

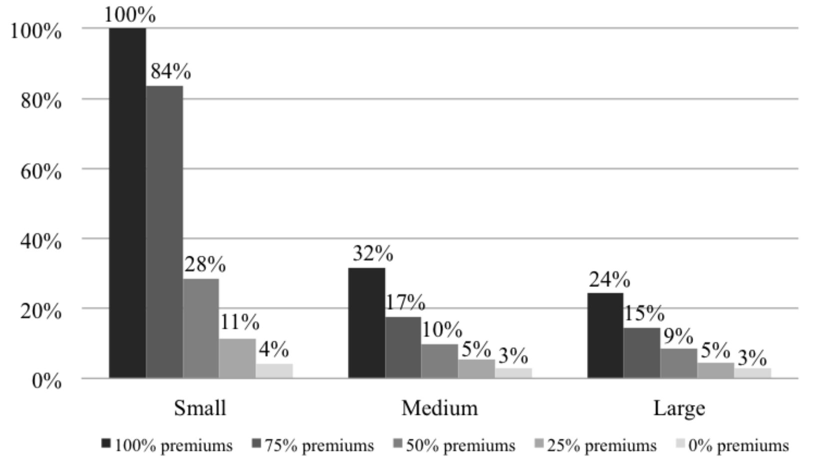

Figure 3. Steady-State Transition Probabilities for Each Farm-Size Scenario with Full Yields and Varying Levels of Organic Price Premiums (0%–100% of Observed Organic Premiums)

Results

In general, organic transition is more attractive when the revenue generated by conventional management is low. In the simplest model scenario, in which the revenue distributions are constructed using the yield data observed in the experimental trial and the observed organic price premiums, the steady state probability that organic management is optimal is 100% for the small farm, 32% for the medium farm, and 24% for the large farm (figure 3). That is, for the small farm scenario, organic transition is optimal under the entire range of market conditions permitted in the model. For the larger farm-size scenarios organic certification is much less likely to be optimal in the steady state, though the probability remains substantial. Note that for the largest two farm-size scenarios this result occurs despite the reduction in crop acreage that must be accepted when the farm is transitioned from conventional to organic management.

It is surprising that the organic system is so likely to be the profit maximizing alternative, especially for smaller farms, given that such a small portion of cropland in the United States is currently managed organically. However, it is possible that the seven-year series of commodity prices used in this analysis does not reflect the full range of price premiums that farms may reasonably expect when considering an organic transition. Given the small size of the organic market relative to the total agricultural market, farm managers may expect more widespread adoption of organic management to erode the price premiums that are necessary for organic farm profitability. Therefore, a careful analysis of the impact of a reduction in organic price premiums available to organic crop producers on the transition decision is informative. Figure 3 shows the response of the steady-state transition probabilities for each farm-size scenario as the organic price premiums available to corn, soybean, and oats are reduced from observed levels. Notably, organic management remains optimal in a significant percentage of possible outcomes, even with only 75% of the observed organic price premiums. However, when price premiums are very low there is only a very small probability that organic management is optimal in the steady state, even for the smallest farm.

Figure 4 shows the threshold values of conventional revenue that separate the regimes of optimal organic management, optimal inaction, and optimal conventional management. For example, with full organic premiums and the trial yield distribution, the large-sized farm will adopt organic management regardless of the current management system as long as the revenue earned by conventional management is below $483. When conventional revenue is between $483 and $945, the large conventional farm will optimally continue with conventional management and the large organic

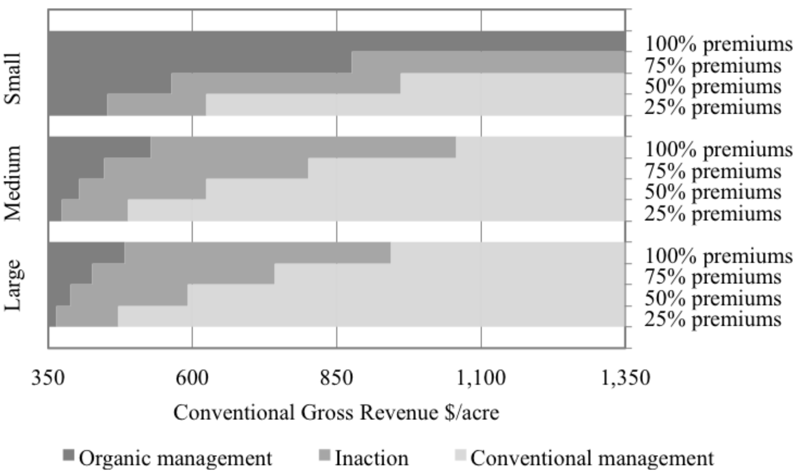

Figure 4. Critical Revenue Levels for Different Farm-Size Scenarios with Full Trial Yields and Varying Organic Price Premiums

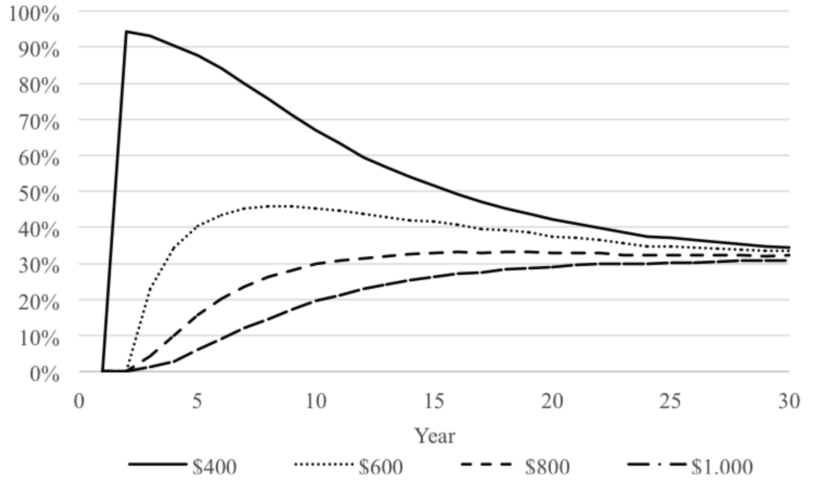

Figure 5. Transition Probabilities over Time for Different Starting Values of Conventional Revenue, Considering Medium Farm-Size Scenario with Full Yields and 100% Organic Price Premiums

farm will continue organic management. When conventional revenue is very high, above $945, the optimal strategy for the large farm is to farm conventionally, even if that requires an abandonment of organic certification. When organic premiums decrease, these threshold values also decrease because the organic system becomes less attractive. However, the range of inaction narrows as the organic price premiums are reduced, suggesting that the option value decreases when organic management is less profitable. The intuition behind this result is that a decrease in organic prices lessens the impact that organic yield fluctuations have on revenue. That is, variability (i.e., uncertainty) is reduced, reducing the option value associated with the transition decision.

A closer look at the time series of detrended and inflation-adjusted conventional revenues in figure 1 helps to put these critical values into perspective. As explained above, organic transition on a large farm becomes optimal only if conventional revenue falls below $483 per acre. In Redwood County, Minnesota, average revenue generated by a corn-soybean rotation have not been this low

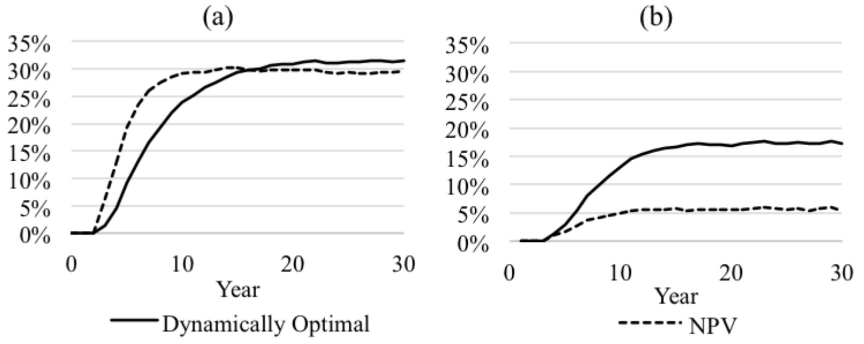

Figure 6. Transition Probabilities over Time for NPV and Dynamically Optimal Decision Rules Considering Medium Farm-Size Scenario with Full Yields

Notes: (a) 100% organic price premiums. (b) 75% of organic price premiums. Initial value of conventional revenue is set equal to long-run mean (i.e., $cr_0 = \overline{cr}$).

since 2005. Abandoning organic management becomes optimal for the large farm when conventional revenue surpasses \$945 per acre. It is noteworthy that in 2012 the average revenue for a corn-soybean rotation in Redwood County approached \$900 in Redwood County for the first time in thirty years. The range of inaction, at least for the medium and large farm-size scenarios, covers a large portion of the revenue levels observed in southwestern Minnesota in recent decades.

Effect of Conventional Revenue Levels on Transition in the Short Run

While steady-state transition probabilities provide useful insights on the impact of farm size and expected price premiums on organic adoption outcomes, transition rates in the short run are more relevant for many stakeholders interested in the supply of organic commodities. The primary determinate of the optimality of organic certification in the short run is the initial value of per acre conventional revenue, cr_0. Figure 5 shows the probability of organic certification for the medium-sized farm with full yields and price premiums over time for values of cr_0 ranging from \$400 to \$1,000 in increments of \$200. As cr_0 varies, the revenue levels that define the ranges of organic transition, inaction, and reverse transition remain unchanged. Therefore, the probability that a farm finds organic certification to be optimal in the long run is also unchanged. However, when cr_0 is increased the probability that the conventional revenue falls low enough to induce organic transition within ten years decreases substantially. For example, the probability that the farm finds organic certification to be the optimal strategy in year ten of the simulation is 67% when the initial conventional revenue value is \$400 but only 20% when the initial conventional revenue value is \$1,000. Given the high conventional commodity prices observed from 2010 to 2012, the impact of high conventional revenues on organic adoption in the short term is particularly noteworthy.

Transition Thresholds and Probabilities under NPV Decision Rule

Comparing the dynamically optimal organic adoption and abandonment thresholds presented above to the thresholds calculated under an NPV framework leads to additional insights regarding the role of the option value in the decision to undertake organic transition. Under the NPV framework the decision to adopt the alternative cropping system is made if the expected NPV gain of doing so more than offsets the cost of transition. The calculation of the expected NPV gain does not consider the option to delay and transition until a later period or the option to return to the original system if a transition is initiated. As a result, if the organic system is expected to be more profitable than the conventional system in the long run, there will be some conditions under which the NPV decision rule will dictate organic transition but the real options decision framework will call for a

Table 8. Critical Revenue Levels with Gradual and Immediate Return to Full Conventional Acreage upon Organic Surrender, Considering Full Trial Yield Scenario

Farm Size	Organic Premium	Gradual Adoption	Gradual Surrender	Immediate Adoption	Immediate Surrender
Small	100%	1,570	2,619	1,570	2,619
	75%	875	1,731	875	1,731
	50%	564	961	564	961
	25%	453	624	453	624
Medium	100%	527	1,058	608	1,018
	75%	447	802	534	816
	50%	403	624	488	666
	25%	373	488	458	543
Large	100%	483	945	576	931
	75%	426	742	520	767
	50%	389	592	483	640
	25%	364	472	458	534

continuation of conventional production until conditions become more favorable. Panel (a) of figure 6 shows the probability of optimal organic certification over time under both decision rules for a farmer in the medium farm-size scenario facing full yields and organic price premiums when the initial conventional revenue is set equal to its long-run mean. In this case organic adoption is initially made less likely by the positive option value and the effect persists for roughly fifteen years of the thirty-year simulation.

Panel (b) of figure 6 shows the probability of optimal organic adoption under both decision criteria for the same farm-size and yield scenario but with only 75% of the organic price premiums. In this scenario the expected revenue generated by the conventional system is higher than that generated by the organic system in the long run, leading to a lower probability of organic adoption than in the 100% price premium scenario. However, in this case the option value has a positive effect on the probability of organic adoption. Since the real options approach allows for organic certification and later abandonment, there are levels of conventional cropping system profitability under which it is optimal to undertake organic transition only if the farm can be returned to conventional production when market conditions shift. This illustrates that the effect of the option value on organic transition rates depends on the relative attractiveness of the specific systems being considered.

Alternative Organic Surrender Scenario

When the requirement that a return from organic acreage to full conventional acreage take place over five years is relaxed, the optimal organic adoption and surrender thresholds for medium and large farms shift (table 8). Since allowing an immediate return to full conventional acreage makes the abandonment of organic production costless, it also reduces the risk of initiating an organic transition in the first place. A reduction in the riskiness of an investment reduces the option value, which is reflected in a narrowing of the range of inaction (i.e., difference between surrender and adoption thresholds). In all scenarios, the organic adoption threshold shifts upward, indicating that transition is optimal under a wider range of conventional cropping system profitability levels than under the model's baseline scenario, in which a return to conventional management is costly. The shift of these optimal decision thresholds leads to an increase in probability that the farm will maximize net returns by achieving organic certification.

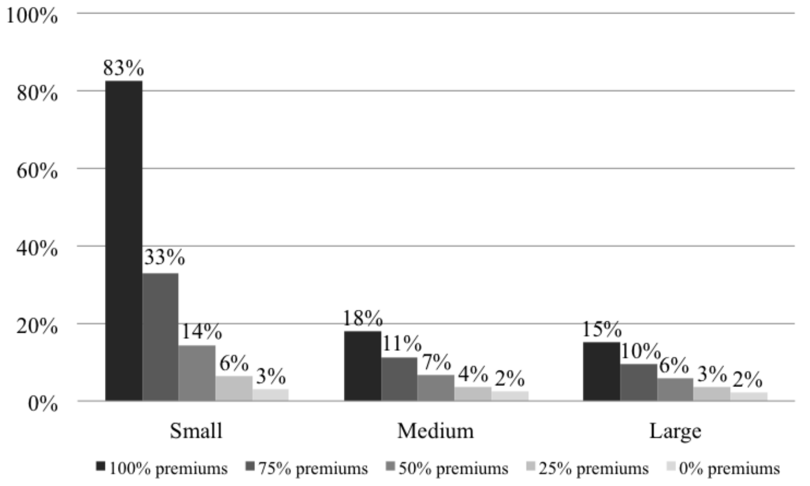

Figure 7. Steady-State Transition Probabilities for Each Farm-Size Scenario with Reduced Organic Yields Scenario and Varying Levels of Organic Price Premiums (0%–100% of Observed Organic Premiums)

Reduced Yields

Another major source of uncertainty in the decision to transition to organic crop management is the level of yields that can be expected once chemical fertilizers and pesticides are no longer used. Although the side-by-side experimental trial results show no significant decline in corn yields, farm-level data from organic corn producers show that most organic farms experience substantial declines in crop productivity under organic management. Figure 7 presents the steady-state transition probabilities for each farm size in the reduced-yield scenario, in which trial organic corn yields are reduced by 20%. Organic soybean, oat, and alfalfa yields are not adjusted in the reduced-yield scenario. A range of organic price premium reductions is applied as was done for the full-yield scenarios.

A comparison of figures 3 and 7 shows that the probability of organic transition with reduced corn yields decreases relative to the full-yield scenario, though the steady-state transition probabilities are still quite high. In fact, in the small farm scenario, in which both the organic and conventional systems are limited to 320 total acres, the probability that organic certification is achieved in the steady state is 83% when the observed organic price premiums are applied. In the larger farm-size scenarios with 100% premiums, the decreases in steady-state organic transition probabilities from the full-yield scenario to the reduced-yield scenario are from 32% to 18% for the medium farm and from 24% to 15% for the large farm. This suggests that the attractiveness of the organic system is fairly sensitive to the organic corn yields that are expected following the transition period.

Discussion

Although previous research shows that organic crop production can be more profitable than conventional production in the Midwest, relatively few crop acres have been transitioned, with the rate of growth in certified organic acreage slowing in recent years (U.S. Department of Agriculture, Economic Research Service, 2013). The obvious question is: if organic crop production is more profitable than conventional production, why are more farmers not undertaking transition? This paper uses dynamic programming methods to model the transition decision itself and investigate whether the costly transition period and uncertainty inherent in such a decision can explain low transition rates.

The results are mixed. Under the baseline scenario the model shows that organic production is an attractive alternative, especially for small farms. The larger farm-size scenarios, which allow conventional management on a greater number of acres than are allowed to the organic alternative, result in lower probabilities of optimal organic transition. The difference in transition probabilities across farm sizes is important given the increasing percentage of cropland controlled by large farms (MacDonald, Korb, and Hoppe, 2013). If organic management is less attractive to large farms, it may be particularly difficult for U.S. crop producers to satisfy high rates of growth in organic food product demand.

By reducing the level of price premiums received for organic crops from 100% (i.e., observed organic prices) to 0% (i.e., conventional prices) we are able to show how sensitive the optimal organic transition strategy is likely to be to shifts in market prices for organic commodities. While organic adoption is still likely optimal for small farms even with a premium level of 75%, a premium reduction of this size cuts the probability of optimal adoption by nearly half for the larger farm-size scenarios. Further reductions lower the likelihood of transition dramatically. Given this sensitivity to organic price premiums, farmer expectations that premiums will significantly erode as more land is converted to organic management may have a significant impact on current adoption rates.

Results from the reduced-yield scenario, in which organic corn yields are reduced from trial levels to reflect the yield patterns observed in farm-level data, show that the likelihood that organic management is the optimal production strategy is quite sensitive to assumptions regarding yield potential under organic management. In the larger farm-size scenarios, reducing the expected organic corn yield has the effect of reducing the probability of organic transition by roughly half. However, for the small farm-size scenario, organic transition is optimal in nearly all possible simulated outcomes, even with reduced organic corn yields, as long as full organic price premiums are received.

When the starting value of the conventional revenue process is varied, simulation results show that the probability of organic transition within ten years is highly sensitive and decreases dramatically as the initial conventional revenue value increases. This result is particularly relevant given the climate of high commodity prices and robust profits to Midwest crop farms observed from 2010 to 2012 and helps explain why organic transition rates did not recover quickly after the recession years of 2008 and 2009. As conventional corn and soybean prices have fallen significantly in the years since 2012, we may soon see a return to higher rates of organic certification of Midwestern cropland.

The comparison of adoption probabilities under the NPV framework and real options framework highlights the complexity of this cropping systems adoption problem. Under the most generous scenarios for the organic system (i.e., those based on experiment station yields and observed prices) the option value inhibits organic adoption in the short run. However, when the expected returns to organic production are lower than those in this baseline scenario, the dynamically optimal decision rule results in a higher probability of organic transition than would be expected under the NPV decision rule. That is, whether the real option encourages or discourages transition to an alternative cropping system depends on the particular return expectations and the system's dynamics.

Though this model in particular, and the theory of investment under uncertainty in general, help to better explain the dynamics of the organic adoption decision, additional research is needed. Possible areas of focus include: (i) developing more robust models of organic crop yields that would improve the accuracy of profitability forecasts, (ii) analyzing the role of land tenure status on the willingness to invest in organic transition, (iii) determining the degree to which management skill and technical learning curves act as barriers to organic adoption, and (iv) estimating the effect that further expansion of organic crop production will have on price premium levels.

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References

Bessembinder, H., J. F. Coughenour, P. J. Seguin, and M. M. Smoller. "Mean Reversion in Equilibrium Asset Prices: Evidence from the Futures Term Structure." *Journal of Finance* 50(1995):361–375. doi: 10.1111/j.1540-6261.1995.tb05178.x.

Center for Farm Financial Management. "FINBIN Farm Financial Database." 2015. St. Paul, MN: University of Minnesota. Available online at www.finbin.umn.edu.

Chavas, J.-P., J. L. Posner, and J. L. Hedtcke. "Organic and Conventional Production Systems in the Wisconsin Integrated Cropping Systems Trial: II. Economic and Risk Analysis 1993–2006." *Agronomy Journal* 101(2009):288–295. doi: 10.2134/agronj2008.0055x.

Coulter, J. A., C. C. Sheaffer, D. L. Wyse, M. J. Haar, P. M. Porter, S. R. Quiring, and L. D. Klossner. "Agronomic Performance of Cropping Systems with Contrasting Crop Rotations and External Inputs." *Agronomy Journal* 103(2011):182–192. doi: 10.2134/agronj2010.0211.

Delate, K., M. Duffy, C. Chase, A. Holste, H. Friedrich, and N. Wantate. "An Economic Comparison of Organic and Conventional Grain Crops in a Long-Term Agroecological Research (LTAR) Site in Iowa." *American Journal of Alternative Agriculture* 18(2003):59–69. doi: 10.1079/AJAA200235.

Delbridge, T. A. "Comparative Profitability of Organic and Conventional Cropping Systems: An Update to Per-Hectare and Whole-Farm Analysis." Staff Paper P14-5, University of Minnesota, Department of Applied Economics, St. Paul, MN, 2014. Available online at http://ageconsearch.umn.edu/handle/164685.

Delbridge, T. A., J. A. Coulter, R. P. King, C. C. Sheaffer, and D. L. Wyse. "Economic Performance of Long-Term Organic and Conventional Cropping Systems in Minnesota." *Agronomy Journal* 103(2011):1372–1382. doi: 10.2134/agronj2011.0371.

Delbridge, T. A., C. Fernholz, R. P. King, and W. Lazarus. "A Whole-Farm Profitability Analysis of Organic and Conventional Cropping Systems." *Agricultural Systems* 122(2013):1–10. doi: 10.1016/j.agsy.2013.07.007.

Delbridge, T. A., R. P. King, D. W. Nordquist, G. DiGiacomo, and M. Moynihan. "Farm Performance during the Transition to Organic Production: Analysis and Planning Tools Based on Minnesota Farm Record Data." Staff Paper P15-6, University of Minnesota, Department of Applied Economics, St. Paul, MN, 2015. Available online at http://purl.umn.edu/212429.

Dixit, A. K., and R. S. Pindyck. *Investment under Uncertainty*. Princeton, NJ: Princeton University Press, 1994.

Helmers, G. A., M. R. Langemeier, and J. Atwood. "An Economic Analysis of Alternative Cropping Systems for East-Central Nebraska." *American Journal of Alternative Agriculture* 1(1986):153–158. doi: 10.1017/S0889189300001223.

Jin, N., S. Lence, C. Hart, and D. Hayes. "The Long-Term Structure of Commodity Futures." *American Journal of Agricultural Economics* 94(2012):718–735. doi: 10.1093/ajae/aar137.

Kuminoff, N. V., and A. Wossink. "Why Isn't More US Farmland Organic?" *Journal of Agricultural Economics* 61(2010):240–258. doi: 10.1111/j.1477-9552.2009.00235.x.

MacDonald, J. M., P. Korb, and R. A. Hoppe. "Farm Size and the Organization of U.S. Crop Farming." Economic Research Report ERR-152, U. S. Department of Agriculture, Economic Research Service, Washington, DC, 2013. Available online at http://www.ers.usda.gov/media/1156726/err152.pdf.

Miranda, M. J., and P. L. Fackler. *Applied Computational Economics and Finance*. Cambridge, MA: MIT, 2004.

Musshoff, O., and N. Hirschauer. "Adoption of Organic Farming in Germany and Austria: An Integrative Dynamic Investment Perspective." *Agricultural Economics* 39(2008):135–145. doi: 10.1111/j.1574-0862.2008.00321.x.

Osteen, C., J. Gottlieb, U. Vasavada, M. Aillery, E. Ball, J. Beckman, A. Borchers, R. Claassen, K. Day-Rubenstein, R. Ebel, J. Fernandez-Cornejo, C. Greene, P. Heisey, D. Hellerstein, R. A. Hoppe, W.-Y. Huang, T. Kuethe, M. Livingston, C. Nickerson, M. O. Ribaudo, G. Schaible, and S. L. Wang. "Agricultural Resources and Environmental Indicators." Economic Information Bulletin EIB-98, U.S. Department of Agriculture, Economic Research Service, Washington, DC, 2012. Available online at http://www.ers.usda.gov/publications/eib-economic-information-bulletin/eib98.aspx.

Pimentel, D., P. Hepperly, J. Hanson, D. Douds, and R. Seidel. "Environmental, Energetic, and Economic Comparisons of Organic and Conventional Farming Systems." *BioScience* 55(2005):573–582. doi: 10.1641/0006-3568(2005)055[0573:EEAECO]2.0.CO;2.

Porter, P. M., D. R. Huggins, C. A. Perillo, S. R. Quiring, and R. K. Crookston. "Organic and Other Management Strategies with Two- and Four-Year Crop Rotations in Minnesota." *Agronomy Journal* 95(2003):233–244. doi: 10.2134/agronj2003.0233.

Schatzki, T. "Options, Uncertainty and Sunk Costs: An Empirical Analysis of Land Use Change." *Journal of Environmental Economics and Management* 46(2003):86–105. doi: 10.1016/S0095-0696(02)00030-X.

Singerman, A., S. H. Lence, and A. Kimble-Evans. "Organic Crop Prices, or 2x Conventional Ones?" Working Paper 113, Iowa State University, Department of Economics, Ames, IA, 2010. Available online at http://lib.dr.iastate.edu/econ_las_workingpapers/113/.

Song, F., J. Zhao, and S. M. Swinton. "Switching to Perennial Energy Crops under Uncertainty and Costly Reversibility." *American Journal of Agricultural Economics* 93(2011):768–783. doi: 10.1093/ajae/aar018.

Tegene, A., K. Wiebe, and B. Kuhn. "Irreversible Investment Under Uncertainty: Conservation Easements and the Option to Develop Agricultural Land." *Journal of Agricultural Economics* 50(1999):203–219. doi: 10.1111/j.1477-9552.1999.tb00808.x.

Uematsu, H., and A. K. Mishra. "Organic Farmers or Conventional Farmers: Where's the Money?" *Ecological Economics* 78(2012):55–62. doi: 10.1016/j.ecolecon.2012.03.013.

U.S. Department of Agriculture. "Agriculture Secretary Vilsack Unveils Vision for U.S. Organic Agriculture." News Release 0096.13, U. S. Department of Agriculture, Office of Communications, Washington, DC, 2013. Available online at http://www.usda.gov/wps/portal/usda/usdamediafb?contentid=2013/05/0096.xml.

U.S. Department of Agriculture, Economic Research Service. "Table 4. Certified Organic Producers, Pasture, and Cropland. Number of Certified Operations, by State, 2000–11. Total Acreage of Certified Organic Pasture and Cropland by State, 1997 and 2000–11." 2013. Available online at http://www.ers.usda.gov/data-products/organic-production.aspx.

U.S. Department of Agriculture, National Agricultural Statistics Service. "Quick Stats Tools." 2013. Available online at https://www.nass.usda.gov/QuickStats/.

U.S. Department of Agriculture. National Organic Program. *NOP Regulations*. Washington, DC: U.S. Department of Agriculture, Agricultural Marketing Service, 2013. Available online at https://www.ams.usda.gov/rules-regulations/ organic.