Profitability and Adoption of Organic Agriculture:
Essays on the Decision to Transition

A THESIS
SUBMITTED TO THE FACULTY OF THE GRADUATE SCHOOL
OF THE UNIVERSITY OF MINNESOTA
BY

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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

Dr. Robert P. King, Adviser

July 2014

Acknowledgments

There are several people whom I would like to thank for their support during my graduate studies. I am most grateful to my adviser and mentor Rob King for the guidance that he has given me during my time at the University of Minnesota. Rob has not only been a patient teacher and helped me navigate the degree program, but has also served as a model for the type of professor and colleague that I hope to become. Thank you.

I would also like to thank the other members of my committee, Jeff Apland, Jeff Coulter, and Terry Hurley, for their helpful advice and constructive comments on this dissertation, both in the preliminary stages and in its final defense. My studies have also greatly benefited from the instruction, advice, and collaboration of several other members of the Applied Economics faculty, notably Bill Lazarus, Liz Davis, and Jay Coggins.

I would like to thank the Applied Economics library and administrative staff who help everything run smoothly and get too little recognition. Elaine Reber, Sue Pohlod, and Linda Eells were particularly helpful and fun to work with.

Finally, I would like to acknowledge the patience and support of my wife, Annie. The pursuit of a Ph.D. affects every member of a family, and without her (apparently sincere) words of encouragement, I never would have completed the degree. Although I can't say that my toddler son Louis made it easier to complete this dissertation, he certainly made it more fun to go home at the end of the day.

Abstract

This dissertation focuses on the economics of organic agricultural production and the decision that conventional farmers face: whether to convert to an organic system or not. Previous research has compared the profitability of organic and conventional cropping systems and has consistently concluded that organic crop production is at least as profitable as conventional production. Despite the apparent profitability advantage of organic production, growth in certified organic cropland has slowed in recent years, and an increasing portion of organic food consumption in the United States is being satisfied by imports. The essays in this dissertation seek to explain this discrepancy by presenting a more complete analysis of organic system profitability and the dynamics of the transition decision than has previously been available.

The first essay uses data from a long-term cropping systems trial to estimate the maximum farm size that can be managed under conventional and organic rotations, subject to different machinery complement scenarios and appropriate yield penalties for management delays. Using these farm size results I estimate whole-farm net returns for each system and then compare the estimated distributions of net returns using stochastic dominance criteria. The second essay extends a much smaller line of research on organic transition and models the decision to transition to organic crop production as a dynamic programming problem in which investment (i.e. transition) is reversible but includes sunk costs. The optimal transition decision's sensitivity to farm size and expected organic returns is explored, as well as the impact of high relative returns to conventional production in the short-term. The third essay ties the results from the dynamic programming model to empirical data on aggregate dairy farm transition behavior over time. Using techniques developed for dynamic panel data, I estimate the threshold values that define the regimes of optimal disinvestment, inaction, and investment in organic milk production. A short fourth essay ties the results of the previous chapters to the broader literature on the motivation and characteristics of organic and transitioning farmers. The barriers to organic transition that have been identified by research in other fields are discussed in the context of the economics of organic transition.

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1 Introduction

The late 20th and early 21st centuries have seen remarkable development in the organic foods sector in the United States and around the world. Once a niche market, organic foods were for many years available almost exclusively in specialty stores and through direct marketing channels. Now, a wide range of organic products is available at nearly all supermarkets in the United States and Europe (Dimitri and Oberholtzer, 2009). Organic agriculture is a frequent topic in the popular press, and it elicits strong opinions from both supporters and detractors. Despite the strong sales growth and "buzz" surrounding organic foods, organic production of crops and livestock in the United States still accounts for only a small percentage of the country's total agricultural output. Rates of growth in the acreage devoted to organic crop production have been high, yet less than 1% of U.S. crop acreage has been certified as organic. Similarly, although organic dairy production had expanded to 40 states by 2011, less than 3% of all milk cows are certified as organic (USDA-ERS, 2013a; USDA-ERS, 2013b). It has also become evident that growth in organic production in the U.S. has not kept up with the growth in consumer demand for organic foods. Although for many years the U.S. was a net exporter of organic crops, imports now exceed exports by a wide margin, and even organic crops that are widely grown in the U.S. (e.g. soybeans, corn, wheat) are being imported in significant quantities (USDA-FAS, 2014). This raises concerns with many consumers of organic food products who are attracted to the organic label for the perceived environmental benefits of organic farming and believe that imported foods are less environmentally sustainable (e.g. Charles, 2014). Only with significant transition of conventional farmland to organic production will further growth in organic consumption be supported domestically.

This dissertation focuses on the economics of the adoption of organic agricultural production methods in the United States. In general, these essays are directed at furthering the understanding of organic transition rates, and why organic adoption has failed to meet early expectations and current consumer demand. The decision to transition a farm operation from a conventional system to an organic system is complex, with many interacting social, philosophical, and economic components. Though the focus of this dissertation is on the economics of the transition decision, ignoring the other related factors would result in an incomplete treatment of the problem. The rest of this introductory chapter will provide an overview of the organic transition decision and a brief discussion of the challenges that transitioning farms face. Within this context I will outline the primary research questions addressed in each dissertation chapter and their implications for the organic agricultural sector. My goal is to provide a document that contributes to the current understanding of organic transition and helps guide the direction of future research in the economics of organic agriculture in general.

1.1 Background on Organic Agriculture in the United States

If a conventional farmer wishes to market crops or livestock products as "organic" in the United States, he or she must first achieve organic certification[1.1] of his or her cropland or animals. Certification of organic compliance is based on a set of regulations administered by the USDA National Organic Program (NOP). The organic standards include provisions that prohibit the use of transgenic seed and most synthetic fertilizers and pesticides and that require animals to be provided a certain level of access to pasture. In order to achieve organic certification, cropland must be managed in accordance with the organic standards for 3 years prior to certification, and animals must be managed according to the organic standards for 1 year before certification. This period is referred to as the "organic transition period" (USDA-AMS, 2013). During the transition period, most farms achieve lower yields than they did under conventional management. Moreover, crops and livestock products cannot be marketed as organic during this period, often resulting in substantially lower

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[1.1] Farms whose annual gross revenue does not exceed $5,000 may market products as organic without certification, though the USDA Organic Standards must still be followed.

revenues for transitioning farms. There can also be additional transition costs associated with changes in machinery, navigating regulatory hurdles, and learning to manage an organic system.

Though obtaining organic certification is often costly, consumers have been willing to pay significant price premiums for organic food products, making organic production profitable for many farms. These price premiums (i.e. the difference between organic and conventional prices) vary by product and over time, but are often from 30% to 100% of the conventional price at the retail level (Greene et al., 2009). Farm-gate prices for some organic commodities often exceed double the conventional prices (e.g. USDA-AMS, 2014). Moreover, consumer demand for organic foods continues to grow at high rates as the availability of organic food products has expanded to mainstream supermarkets and club stores (Dimitri and Oberholtzer, 2009). Though growth in retail sales dropped during and immediately after the recession years of 2008-2009, by 2012 retail sales of organic food products in the U.S. were once again growing by more than 10% annually (Karst, 2013). Similar growth has been observed in Europe, with the total retail market for organic products in the European Union reaching $30 billion in 2011, which is roughly equal in size to the U.S. market (Cottingham, 2013).

Organic crop and livestock production has also shown strong, if uneven, growth in the last two decades. In the 1990's, fewer than one million of the nation's 300 million acres of total cropland were certified organic[1.2], though annual rates of growth were high (ranging between 15% and 35%). Although organic acreage continued to expand in the first decade of the 21st century, the rate of growth slowed to the single digits and approached zero in some years (USDA-ERS, 2013a). Similar patterns were observed in the number of organic milk cows in the U.S., with annual growth rates ranging from 0% to 50%. The development of the organic industry in Europe preceded that of the U.S., partly due to relatively strong

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[1.2] Though the USDA-NOP was not established until 2002, in prior years farms could be certified as organic by state or independent bodies, under varying sets of standards.

public support for organic production, and by 1999 there were already seven million acres of organic farmland in Europe (Sylvander and Le Floch-Wadel, 2000). However, like in the U.S., the growth in farm acres devoted to organic production in Europe has recently slowed, and some European countries have failed to meet publicly stated goals for expansion of organic production (Acs et al., 2007).

1.2 Dissertation Objectives

The goal of this dissertation is to provide an analysis of the organic transition decision and an explanation for the disparity in growth rates between organic production and organic consumption in the U.S. Little previous research has been focused on the economics of organic transition, partly because few data exist on the cost and returns that farmer's face during the transition period. There have been several studies, in the midwestern U.S. and elsewhere, that have compared the profitability of organic and conventional crop production systems without addressing the role of the transition process in the farm-level decision to adopt organic management. The essays in this dissertation will help to fill this gap by focusing on the transition decision explicitly, for both crop and dairy farms. Though production and financial data from transitioning farms is still sparse, this dissertation provides a framework for the analysis of organic transition that can be adapted as additional data become available.

Chapter two introduces a method to compare the whole-farm profitability of conventional and organic cropping systems. While previous studies have found that organic crop production can be more profitable than conventional production on a per-acre basis, this essay recognizes that farms often cannot simply switch from one system to another without significant changes to machinery fleet, farm acreage under management, or both. By estimating the maximum farm size that can be managed under each system, given the same machinery and labor resources, returns to a conventional system can be more appropriately compared to an organic system. The contribution of this essay is not only in the presentation of a more appropriate profitability comparison than has previously been available, but also in the demonstration that the management requirements of diverse organic crop rotations make it more difficult to scale up organic production than conventional production. Thus, organic transition is more attractive for small farms than large farms, a result consistent with observed adoption patterns.

Chapter three focuses on the dynamic nature of the transition decision itself, as it is faced by a representative crop farm. By modeling the organic transition as a decision that is reversible but entails substantial sunk costs, this analysis shows that the three-year transition period required for organic certification presents a significant barrier to organic adoption and that only during periods of relatively low returns to conventional crop production is organic transition optimal. Furthermore, the range of market conditions within which it is optimal to initiate organic transition is fairly narrow under most scenarios, and only during a few years in the past decade have these conditions been observed in the Midwest. Sensitivity to changes in farm size, organic price premiums, and organic grain yields is explored, and the analysis provides further insight into the effect that varying perceptions of the organic market may have on transition rates.

Chapter four presents an empirical application of the theory of investment under uncertainty to organic dairy transition. The theory, as well as the results from Chapter three, predicts that there is a range of market conditions for which it is optimal to neither transition to, nor abandon, organic production. In this analysis I estimate the boundaries of this range for U.S. organic dairy investment using data on the number of organic milk cows in each state over time, as well as data on organic and conventional dairy returns. If the predicted investment patterns hold, there will be distinct investment regimes within which organic dairy herd sizes are affected differently by the relative profitability of organic dairy management. In addition to providing insight into organic dairy transition patterns, this essay offers a novel application of econometric methods that combine threshold estimation procedures with analysis of dynamic panel data.

Chapter five provides a more in-depth discussion of the barriers to organic transition that are faced by crop and dairy farms in the U.S. The results from the previous chapters are tied to literature from other social sciences to frame the economic analyses presented in this dissertation in the context of the larger discussion of the organic foods industry, organic farming, and the social and political challenges facing both. This chapter addresses the beliefs and attitudes of both conventional and organic farmers and examines how these beliefs relate directly to the economic analyses of the organic transition decision discussed throughout this dissertation. Important technical and regulatory challenges are also addressed and effective policy targeting organic agricultural production is discussed. The dissertation closes with a short concluding chapter.

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2 A Whole-Farm Profitability Analysis of Organic and Conventional Cropping Systems [2.1]

2.1 Introduction

Research comparing the profitability of conventional and organic farm management systems in the midwestern United States has a long history. While some research has found that organic cropping systems are less profitable than conventional systems, e.g. (Dobbs and Smolik, 1996), most studies have shown that returns to organic farm management are equal to or exceed those to conventional management. An early study by Lockeretz et al. (1981) compared diversified organic farms to similarly sized conventional farms from the same geographic area. The authors concluded that at conventional prices organic farms earned roughly the same per-acre returns as conventional farms, with lower production costs nearly offsetting lower revenues on the organic farms. Other studies have used long-term trial data, rather than case studies, to examine the profitability of organic systems. Helmers et al. (1986) evaluated eight years of yield data from an experimental trial and concluded that organic rotations were neither less profitable nor more risky than the same rotations managed with synthetic pesticides and fertilizers. Similarly, based on three years of trial data in Iowa, Delate et al. (2003) found that a 4-year organic rotation earned greater net returns than a conventional corn-soybean rotation when organic price premiums were taken into account. More recently, an analysis of data from a long-term experiment in Wisconsin found that with organic premiums an organic grain rotation outperformed conventional and no-till cropping systems. Furthermore, when measures of risk exposure were taken into account, the results were largely unchanged (Chavas et al., 2009). In Minnesota, Delbridge et al. (2011) used 18 years of experimental trial data to find that net

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[2.1] A slightly different version of this essay is published as:

Delbridge, T.A., C. Fernholz, R.P. King, and W. Lazarus. 2013. "A whole-farm profitability analysis of organic and conventional cropping systems." *Agricultural Systems* 122:1-10.

returns to a 4-year organic grain and forage rotation exceeded the net returns to both an equivalent rotation and a 2-year corn-soybean rotation that were managed conventionally, but only when organic price premiums were considered. Studies comparing the profitability of organic and conventional crop production systems in Canada (Smith et al., 2004) and in Europe (Lien et al., 2006; Kerselaers et al., 2007) have shown similar results.

Results from previous research are supported by newly available empirical data on the financial performance of organic farms. The University of Minnesota Center for Farm Financial Management's FINBIN database (www.finbin.umn.edu), which collects data on both conventional and organic farm financial outcomes in Minnesota, shows that several major organic crop enterprises have outperformed their conventional counterparts in terms of returns over direct expenses per acre. In fact, FINBIN data show that from 2006 to 2010, growers of organic corn earned an average of $477 per acre over direct expenses compared to $236 per acre for conventional corn. Over this same period organic soybean returned an average of $185 per acre, while conventional soybean returned $174 per acre (Center for Farm Financial Management, 2011). Though these data cannot be used to directly compare specific cropping systems, as they are averages drawing on a diverse set of farm types and rotation designs, they are largely consistent with the findings of the previously mentioned studies. Additional empirical evidence is provided by McBride and Greene (2009) which shows, using data from the USDA ARMS survey, that organic soybean production was significantly more profitable than conventional production in 2006. Though soybean yields on organic farms were low relative to conventional yields, a substantial organic price premium resulted in higher net returns per acre.

Despite the reported profitability advantage of organic cropping systems, only a small percentage of total cropland has been transitioned to organic management. Recent studies that have sought to explain this discrepancy have concluded that organic production may be more risky than conventional systems (Acs et al., 2009) or that there is a significant option value of delaying transition, despite higher returns to organic management (Wossink and Kuminoff, 2010). However, there has not been a careful study of organic profitability that emphasizes potential differences in overhead costs and farm size between organic and conventional cropping systems and their impact on whole-farm profitability. Unfortunately, much of the research on the comparative profitability of organic and conventional cropping systems has either ignored the overhead expenses that are associated with owning and housing farm machinery or has assumed that both organic and conventional crop management systems face the same machinery ownership costs. This assumption, though convenient for making comparisons of the profitability of cropping systems based on experimental trial data, may lead to an understatement of the true costs of organic farm management. Organic cropping systems in the midwestern United States include rotations of three or more crops and require machinery that conventional farms in the region often do not own (e.g. forage harvest equipment). Though additional machinery requirements on organic farms do not necessarily increase operating expenses (e.g. labor, fuel) relative to conventional farms, they may increase overhead costs associated with the financing, maintenance, and depreciation of the additional equipment.

Furthermore, organic and conventional crop farms may differ in size as a result of differences in management requirements between the two systems. Empirical data show that, among contributors to the FINBIN farm financial database, the average Minnesota organic crop farm is smaller than the average conventional crop farm (665 ac and 1100 ac respectively) (Center for Farm Financial Management, 2011). If this size difference is the result of differences in management requirements between the two systems, it should be considered in an analysis of whole-farm profitability. Not only could differences in farm size significantly impact the per-acre machinery ownership costs on organic and conventional farms, but farm-level profits could actually be lower for organic crop farms, even when the per-acre returns are considerably higher than those generated under conventional management. The objective of this study is to analyze the profitability of organic and conventional cropping systems at the whole-farm level, taking into account the effects of farm size, machinery complement, and overhead expenses on total farm revenues and costs.

2.2 Methods

This study extends the analysis of per-acre net returns presented in Delbridge et al. (2011) to account for differences in farm size and overhead costs that result from differing management requirements of conventional and organic cropping systems. Much of the methodology used in Delbridge et al. (2011) with respect to the analysis of the experimental trial data, as well as the prices of inputs and commodities, is repeated here in order to present a whole-farm analysis that is easily compared to the previous per-acre results. Additionally, a similar stochastic dominance analysis is employed to compare the net return distributions from each of the crop rotation and farm size scenarios.

2.2.1 Data

As described in Porter et al. (2003) and Coulter et al. (2011), the Variable Input Crop Management Systems (VICMS) trial was initiated in 1989 in southwestern Minnesota ($44°15'$ N, $95°19'$ W). Two crop rotations and four management strategies were included in the trial in each crop year resulting in eight distinct rotation-strategy treatments. Each of the eight treatments was replicated in three plots each year. The crop rotations were a two-year corn-soybean rotation, and a four-year corn-soybean-oat/alfalfa-alfalfa rotation. The management strategies were zero-input, low-chemical-input, high-chemical-input (CI), and organic-input (OI). For the purposes of this study, only the OI 4-year rotation and the CI 2-year rotation are analyzed, as these rotations are considered to most closely represent the predominant organic and conventional crop rotations in the region.

In the CI strategy, weeds and insect pests were controlled with broadcast pesticides, synthetic fertilizers were applied at rates appropriate for aggressive yield goals, and insect and herbicide resistant seed was planted in later years of the trial. In the OI strategy, weeds were managed mechanically, beef manure was used for fertilization, and organically produced seed was used when available (Coulter et al., 2011). Records were kept of each field operation carried out in each treatment, as well as the formulations and rates of all input applications. Additionally, days suitable for fieldwork were recorded throughout the duration of the VICMS trial.

As explained in detail in Delbridge et al. (2011), costs of purchased inputs for all years of the trial are calculated using input prices from 2010. Nutrients applied through synthetic fertilizer and beef manure are priced using market rates for synthetic fertilizers. Costs of chemical pesticide applications are calculated using 2010 prices when possible. Although 2010 prices are attributed to all seed used in the trial, different prices are applied depending on whether the planted seed was conventional, organic, or contained insect or herbicide resistant traits.

In the current study, a constant land rent charge of $168 per acre is attributed to the production costs of both rotations (Center for Farm Financial Management, 2011). That amount is the average land rent paid by corn producers in southwest Minnesota in 2010. A total of $21 per acre, meant to represent the direct payments likely to be received by crop farms in southwest Minnesota, is added to the revenues derived from each cropping system. This payment level is based on the assumption that half of each system's total cropland would be registered as corn "base-acres" and half would be registered as soybean "base-acres". Though the organic rotation currently being considered also includes cropland planted in alfalfa or oat, which were not eligible for crop subsidy payments prior to the establishment of the direct payment system, all land is assumed to have been registered as corn or soybean "base-acres" prior to organic certification (USDA- Farm Service Agency, 2008).

Crop insurance plays an important role in reducing production and price risk for crop producers and should certainly be included in an analysis of whole-farm returns to management. Several yield and revenue protection products have recently been made available for growers of selected organic crops, including corn and soybean. Pricing and indemnity payments for these products depend on the recent relationship between organic and conventional commodity prices (USDA- Risk Management Agency, 2011). However, yield and revenue data required to determine appropriate premium rates for these products are limited, and many growers believe that currently available yield and revenue insurance products for organic crops are not priced as attractively as are comparable products for conventional crops. In order to treat each system equally, we construct a simple, actuarially fair yield protection product for each crop with a yield guarantee of 75% of the 18-year average trial yield. The price election is equal to the average commodity price from 2006-2010 and an actuarially fair premium, equal to the average indemnity for that price election, is charged to each crop in each system.

As in Delbridge et al. (2011), prices for both organic and conventional corn, soybean, and oat are the average prices received by growers contributing to the FINBIN database for each year from 2006 to 2010 (Table 3.4). Conventional alfalfa prices are taken from the Southwest Minnesota Farm Business Management Association Annual Reports from 1993 to 2010 (Table 3.5). No organic price premiums are considered for alfalfa because of the unavailability of organic alfalfa hay price data for southwestern Minnesota.

2.2.2 Yields

Detrended corn yields within the VICMS trial are not significantly different between the OI 4-year and the CI 2-year rotations, though soybean yield is significantly less in the OI 4-year rotation (Table 3.3). Oat and alfalfa are not included in the CI 2-year rotation and are therefore not directly compared with yields from the OI 4-year rotation, although Delbridge

Table 2.1: Prices of conventional and organic corn, soybean, oat, and oat straw, 2006-2010^{a}.

Year	Corn	Soybean	Oat	Oat straw
	———-$/bushel———-			—$/ton—
Conventional				
2006	2.87	6.04	1.93	39.78
2007	3.66	9.28	2.50	37.53
2008	3.86	9.55	2.63	41.24
2009	3.66	9.53	2.02	40.93
2010	4.60	10.67	2.53	42.00
Organic				
2006	5.39	14.54	3.09	39.78
2007	8.38	19.35	4.66	37.53
2008	9.07	21.83	4.79	41.24
2009	6.45	18.70	4.33	40.93
2010	7.22	19.03	4.30	42.00

a. Source: Delbridge et al. 2011

et al. (2011) show that yields of oat and alfalfa within the OI system are equal to or greater than those from the same rotation managed conventionally. Coulter et al. (2011) present a complete discussion of VICMS trial yields for all systems and rotations.

Yields of organic corn and soybean observed in the VICMS trial are substantially higher than the yields often achieved by organic crop producers in Minnesota. From 2006 to 2010, the median organic corn yield in southwestern Minnesota was 130 bu/ac while the statewide median was only 107 bu/ac (Center for Farm Financial Management, 2011). This compares to 160 bu/ac that was achieved in the OI 4-year rotation of the VICMS trial over the same time period (Delbridge et al., 2011; Table 3.3). Similarly, from 2006 to 2010, the median yield of organic soybean was 27 bu/ac in southwestern Minnesota, and only 20 bu/ac for the state as a whole (Center for Farm Financial Management, 2011). Over this same period, the OI 4-year rotation in the VICMS trial recorded organic soybean production of 29 bu/ac (Table 3.3). This pattern of high trial yields relative to reported farm yields is not found in the conventional system. In fact, trial yields of corn and soybean within the

Table 2.2: Inflation-adjusted prices for alfalfa hay, 1993-2010[a].

Year	$/ton
1993	89.06
1994	109.98
1995	111.08
1996	108.90
1997	113.35
1998	140.89
1999	101.12
2000	107.45
2001	107.45
2002	132.24
2003	161.93
2004	134.74
2005	121.03
2006	125.28
2007	116.68
2008	117.15
2009	133.25
2010	99.18

a. Source: Delbridge et al. 2011

Table 2.3: Mean detrended crop yields for full and reduced yield scenarios from the Variable Input Crop Management Systems (VICMS) trial for the chemical input (CI) 2-year and organic input (OI) 4-year crop rotations, 1993-2010.

	CI 2-year		OI 4-year			
	Corn	Soybean	Corn	Soybean	Oat	Alfalfa
	——-bu/ac——		————bu/ac————			—ton/ac—
Full organic trial yield scenario						
Mean	173.4	47.9	167.1	35.8	74.3	5.1
SD	29.0	7.1	25.8	11.5	32.9	0.6
Reduced organic yield scenario						
Mean	173.4	47.9	125.3	26.9	74.3	5.1
SD	29.0	7.1	19.4	8.6	32.9	0.6

CI 2-year rotation closely mirror the yields achieved on crop farms throughout Minnesota. The Minnesota median conventional corn and soybean yields from 2006 to 2010 were 172 bu/ac and 46 bu/ac, respectively, while the CI 2-year rotation in the VICMS trial produced 167 bu/ac and 49 bu/ac over this period (Center for Farm Financial Management, 2011; Delbridge et al., 2011).

Multiple data sources indicate that high grain yields on organic crop farms are indeed achievable. Not only have results similar to those in the VICMS trial been replicated in other long-term trials (Delate et al., 2003; Pimentel et al., 2005), but data show that the top organic farmers in Minnesota report yields very similar to those reported by the VICMS trial (Center for Farm Financial Management, 2011). The disparity in yields between the top performing organic farms and the state and regional average organic yields is likely due to the complexity of managing organic systems, difficulties associated with achieving timely mechanical weed control, and a management "learning curve" inherent in transitioning from one farming system to another.

In order to reflect the divergence of trial results and state median yields, a "reduced yield" scenario is added to the net revenue analysis in which trial yields of organic corn and soybean are reduced by 25% (Table 3.3). Though the regional median is more relevant for comparison with the trial yields, the number of organic farms in southwest Minnesota is small, making regional median yields more sensitive to outliers than the state-wide median. Thus, a 25% reduction, which brings trial yields to a level in-between the southwestern Minnesota and state-wide median yields, is a conservative level of yield reduction for organic corn and soybean. No adjustment is made to either organic oat and alfalfa trial observations or to conventional corn and soybean observations. This reduced yield scenario, when compared to the baseline, full-yield scenario, is helpful in showing the sensitivity of whole-farm net returns to crop yield variations that are seen among organic crop farms.

2.2.3 Optimal Farm Size Determination

Researchers have previously used linear programming models to find optimal farm machinery complements for a given farm size and crop rotation (Pfeiffer and Peterson, 1980; Edwards and Boehlje, 1980). Others have considered the impact of weather variability, in the form of suitable field days, on the timeliness of field operations and subsequent farm size decisions (Apland, 1993). In this study, farm size is maximized by grid search using a spreadsheet tool developed for the scheduling of field operations on crop farms. Maximum crop area is determined for three different machinery size complements and each of the two relevant crop rotations, subject to timeliness penalties for delayed planting, harvest, and weed control. Days with suitable conditions for field operations are included in the model to account for historical weather variability. The final results of this procedure are estimates of the largest farms, in total crop acres, that could be managed within a corn-soybean-oat/alfalfa-alfalfa rotation managed organically and a corn-soybean rotation managed conventionally, without suffering unacceptable yield loss, given “small”, “medium”, or “large” machinery.

The three machinery complements were chosen based on discussions with local crop growers and university extension researchers (Table 2.4). The machinery complements are not meant to represent the optimal machinery decision for farms of specific sizes; rather they are sets of power units and implements that would likely be used together. For example, it is not likely that any grower would use both a 16-row corn planter (large) and a 4-row corn head for harvesting (small) on the same farm, so these pieces of equipment are not grouped together. Of course, changes to the machinery complements could result in different optimal farm sizes, but we are more interested in a comparison of the constraints to organic and conventional management than we are in selecting the optimal machinery complement for each rotation.

Yield penalties are assumed for delays in planting and weed control based on agronomic

Table 2.4: Implement sizes assumed for each of three machinery complements.

Implement	Size #1	Size #2	Size #3
		———-feet———-	
Chisel plow	15	23	57
Moldboard plow	9	12	12
Field cultivator	18	23	47
Row planter	15	40	60
Grain drill	16	20	30
Rotary hoe	21	40	40
Row cultivator	30	40	40
Corn head	15	20	30
Soybean head	18	30	35
Mower conditioner	9	12	12
Hay rake	20	25	32
Baler	12	20	20

research relevant to the region. Based on the guidelines provided by Nafziger (2009), penalties are attributed to delays in corn planting ranging from 0.5 bushels per day to 2 bushels per day as planting is delayed from the beginning to the end of May. Similarly, based on a study of soybean yield response to planting date in Wisconsin, a penalty of 0.4 bushels per day is assumed for each day that planting is delayed by weather or unavailability of labor beyond May 8th (Conley et al., 2008). A penalty of 0.5 bushels per day is applied for each day that the planting of oat is delayed between April 18 and May 14, and a penalty of 1.0 bushel per day for each day of planting delay after May 14 (Rankin, 2011). No late planting penalty is assumed for alfalfa, as alfalfa is planted with oat and no alfalfa harvest is carried out until the crop's second year. For both corn and soybean, penalties for delayed mechanical weed control are assumed to be 2.0% for each crop stage that weeds are not removed after the beginning of the critical time for weed removal (Knezevic, 2003). Total yield losses from all delays (planting and weed control) are deemed unacceptable if they reach 5.0% of the 18 year average detrended trial yield of corn, soybean, or oat. It is also considered unacceptable if poor weather or the lack of available labor precludes alfalfa harvest past the 15th of October. This date, which is earlier than the latest possible cutting date when over-wintering is not of concern (Undersander et al., 1994), reflects the importance of alfalfa biomass in meeting the following corn crop's nitrogen requirement.

Daily available labor is set at a maximum of 16 hours to reflect two full-time farm workers working 8 hours each day. Although 8 hours is surely shorter than the typical work day during critical planting, harvest and weed control periods, this accounts only for time spent actually operating machinery. No other farm management tasks are considered in the model. Machinery availability is considered separately from labor availability so that even when two workers are available on any given day, two field operations cannot be performed using the same machinery on different fields. No additional part-time or "peak-time" hired labor is allowed in this model, though this technique has been used in other studies. The initial farm size is set to 80 acres for each crop rotation and farm machinery complement, and the size is increased in 80 acre increments until unacceptable yield losses occur in more than one of the 18 years of trial data.

2.2.4 Machinery Costs

Once optimal farm sizes for both the CI 2-year and the OI 4-year rotations are established for each of three possible machinery complements, machinery costs are estimated for each scenario based on the field operation records from the VICMS trial. Machinery operating costs, which include operator labor, fuel, oil, and operation related repairs, are calculated using the University of Minnesota Extension Farm Machinery Economic Cost Estimation Spreadsheet (Lazarus and Smale, 2010a). The size of each implement is entered, along with farm size and the average number of annual machinery passes required each year (Table 3.7) to arrive at a per-acre operating cost for each pass with the implement (Table 2.6). The cost of operating both the implement and the associated power unit is included in this estimate. Whereas Delbridge et al. (2011) used the use-related costs averaged over several machinery sizes provided in Lazarus and Smale (2010b), the current study calculates operating costs separately for each implement's width, appropriate power unit, and annual hours of use in each farm size scenario. Though the cost of a single field operation with a given implement is assumed constant in all years, the number of operations carried out depends on agronomic conditions during the trial. Therefore, machinery operating costs vary from year to year and this variability tends to be greater for the OI system.

Ownership costs of farm machinery consist of interest, insurance, machinery housing, and depreciation. These costs, unlike operating costs, depend critically on the value, age, and annual hours of use of each piece of equipment. Although the annual hours of use for each piece of machinery are determined by the model depending on the machinery widths, farm size scenarios, and management requirements, making reasonable assumptions with respect to the equipment's value and age poses a challenge in calculating ownership expenses.

One possible approach is to assume that the hypothetical farms operating within both the CI 2-year and the OI 4-year rotation have purchased all equipment new in the current year. In this case current machinery list prices can be assumed and costs can be easily estimated using the previously mentioned machinery cost tools. Although this method can be consistently repeated for all rotations, farm sizes, and machinery complements, it yields cost estimates that are much higher than reported in farm financial data for crop farms in Minnesota.

Many farms, especially smaller crop farms, use implements and power units that are well beyond the 12-year useful life often assumed in machinery cost estimation tools. With this in mind, another possible method for calculating machinery ownership costs is to assume that all equipment used in each cropping system is 20-years old. Under this machinery age assumption the current value of all equipment would be much less than when new equipment is assumed, and yearly depreciation expense would decline accordingly. Though this method returns cost estimates similar to those reported in the empirical farm financial data for

Table 2.5: Average number of field passes per acre per year for the chemical input (CI) 2-year and organic input (OI) 4-year crop rotation, 1993-2010.

Implement	CI 2-year	OI 4-year
Chisel plow	0.5	0.25
Moldboard plow	0.5	0.25
Field cultivator	2.08	1.82
Row planter	1	0.5
Grain drill	0	0.25
Rotary hoe	0.08	0.67
Row cultivator	0.64	1.15
Combine: corn head	0.5	0.25
Combine: soybean head	0.5	0.5
Mower-conditioner	0	0.75
Hay Rake	0	0.75
Hay Baler	0	0.75
Total	5.86	7.74

organic farms, it yields cost estimates well below those reported for larger, conventional farms (Center for Farm Financial Management, 2011).

A third possible approach to estimating total machinery costs is to use the machinery cost estimation tools in conjunction with empirical data on average machinery age, type and size currently being used on conventional and organic farms. Unfortunately, little data of this nature exist. (Lazarus, 2010).

Instead of estimating ownership costs using arbitrary assumptions regarding machinery age and value, this study uses data on machinery ownership cost averages directly from the "Crop Enterprise Analysis" reports available in the FINBIN database for 2010 (Center for Farm Financial Management, 2011). An average overhead cost for the CI 2-year rotation is calculated using the enterprise reports for conventional corn and soybean and for the OI 4-year rotation using the reports for organic corn, soybean, oat, and alfalfa. This technique allows for differing machinery replacement strategies that are likely practiced on

Table 2.6: Average operating costs per acre by crop for the chemical input (CI) 2-year and organic input (OI) 4-year rotations and each machinery complement scenario, 1993-2010^{a}.

Crop rotation		Machinery Complement		
		Size #1	Size #2	Size #3
		———-	US $/ac	———-
CI 2-year	Corn	241.98	236.02	234.09
	Soybean	106.32	97.87	96.77
	Rotation average	174.15	166.94	165.43
OI 4-year	Corn	214.47	205.08	202.13
	Soybean	102.64	91.90	89.28
	Oat	145.35	139.88	138.58
	Alfalfa	150.60	124.71	124.76
	Rotation average	153.26	140.39	138.69

a. Crop insurance premiums included for full trial yield and observed organic premiums scenario.

conventional and organic crop farms while capturing differences in other overhead expense categories not accounted for in the machinery cost calculations. The cost categories within the FINBIN reports that are used to calculate machinery ownership costs include “machinery and building depreciation”, “interest” and “machinery leases”. Though the FINBIN database does not distinguish between interest on machinery purchases and other interest paid, interest expense related to machinery is estimated based on the proportion of machinery assets to total assets from the FINBIN “Balance Sheet- Market Values” for crop farms. Cost categories for “building leases”, “farm insurance”, “utilities”, and “miscellaneous” farm expense are also included in the overhead costs for each cropping system and farm size scenario. The machinery ownership cost average for the enterprises included in the OI 4-year rotation is $160 per acre. This is compared to an average of $152 per acre for the conventional enterprises included in the CI 2-year rotation[2.2] (Table 2.7).

[2.2] Although FINBIN enterprise reports can be queried for different farm sizes, there is not a sufficient number of contributing organic farms to allow this distinction for organic crops. One potential shortcoming of using FINBIN enterprise reports that include all organic farms is that it assumes away any size economies

Table 2.7: Per-acre overhead costs for the chemical input (CI) 2-year and organic input (OI) 4-year rotations and each machinery complement scenario.

Crop rotation	Cost category	US $/ac
CI 2-year	Machinery and building depreciation	36.24
	Interest on machinery purchases	2.71
	Farm insurance	5.90
	Utilities	4.14
	Machinery and building leases	3.65
	Miscellaneous	8.96
	Machinery ownership costs	61.59
	Land rent	168.00
	Total overhead costs	229.59
OI 4-year	Machinery and Building Depreciation	35.15
	Interest on machinery purchases	2.88
	Farm insurance	6.03
	Utilities	6.67
	Machinery and building leases	2.59
	Miscellaneous	11.63
	Machinery ownership costs	64.94
	Land rent	168.00
	Total overhead costs	232.94

2.2.5 Net Return Distributions and Stochastic Dominance Analysis

Replicating procedures described more fully in Delbridge et al. (2011), we define 90 states of nature for conventional and organic crop yields, prices, and operating costs by pairing crop prices for corn, soybean, and oat from each of five years (2006-2010) with detrended crop yields and inflation adjusted direct operating expenses for corn, soybean, and oat from each of 18 years (1993-2010). Alfalfa yields and direct expenses for each of the 18 trial years are matched with inflation adjusted local alfalfa prices for the corresponding years (Nordquist et al., 2011; USDA-National Agricultural Statistics Service, 2011). These

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in ownership costs. However, conventional corn enterprise reports show that there is very little variation in machinery ownership costs over different farm sizes. This suggests that attributing a single overhead cost to each machinery complement scenario for each cropping system is appropriate.

alfalfa yield-price pairs are replicated five times and matched with corresponding yield-price sets for the other crops. In effect, this procedure creates a 90 element nonparametric representation of the joint distribution of conventional and organic prices and yields. It preserves observed correlations among crop yields and the correlation between alfalfa yield and prices that results from a lack of integration into regional and national markets for alfalfa hay, while assuming that farm-level yields for more easily transported field crops are statistically independent of regional price levels. It also preserves observed correlations among crop prices.

Whole farm net revenue for cropping system $i \in \{CI, OI\}$, machinery complement $j \in \{1, 2, 3\}$, and state of nature $k \in \{1, 2, \ldots, 90\}$ is denoted as π_{ijk}, and is defined as:

$$\pi_{ijk} = (CR_{ik} + I_{ik} + DP - DC_{ijk} - FC_i)H_{ij} \tag{2.1}$$

CR_{ik} is crop revenue per acre for cropping system i in state of nature k and is the sum of the products of price and yield for each crop in the system weighted by the share of crop area for each crop. I_{ik} is crop insurance indemnities per acre for cropping system i in state of nature k and is the sum of indemnities for individual crops weighted by the share of area for each crop. The indemnity for a particular crop in a given state of nature is zero unless yield for that state of nature falls below the yield guarantee. DP is direct payments per acre, which are constant across cropping systems, machinery complements, and states of nature. DC_{ijk} is direct cost per acre for cropping system i and farm size j in state of nature k, the sum of purchased input and machinery operating costs and crop insurance premiums for each crop in the system weighted by the share of area for each crop. FC_i is fixed cost per acre, the sum of machinery ownership, farm insurance, utility, and land rental costs for cropping system i on a per acre basis. H_{ij} is the number of acres for copping system i and machinery complement j.

Cumulative distribution functions (CDFs) of net returns are compared by both first-degree (FSD) and second-degree (SSD) stochastic dominance (Hadar and Russell, 1969). CDF A dominates CDF B by FSD if A is less than or equal to B for all levels of X. CDF A dominates CDF B by SSD if the area under A is less than the area under B at all values of X. FSD is the least restrictive of the stochastic efficiency criteria so if a distribution dominates by FSD then it also dominates by SSD. FSD can easily be established by visual inspection of the CDFs, and SSD is confirmed for each comparison using numerical integration.

2.3 Results

To analyze the whole-farm profitability of organic and conventional cropping systems in the Midwest we first establish the maximum farm size that can be managed under each system and machinery complement scenario. We then use these farm sizes to estimate whole-farm production costs for each system. Finally we construct net revenue distributions and analyze them using stochastic dominance criteria.

2.3.1 Farm Size

There are substantial differences in the maximum farm size estimates returned by the farm size model for the organic and conventional cropping systems. Perhaps surprisingly, with machinery complement #1 (the smallest grouping) the maximum farm size is 320 total acres for both the OI 4-year rotation and the CI 2-year rotation. Machinery complement #2 allows for larger operations for both rotations, though the increase in farm size is much larger for the CI system. Under machinery complement #2 the OI 4-year rotation reaches a maximum of 560 acres while the maximum farm size for the CI 2-year rotation is 880 acres. For machinery complement #3 (the largest machinery complement), the OI 4-year cropping system can be managed on up to 800 total acres and the CI 2-year system can be managed on up to 1,360 total crop acres before the model returns unacceptable yield losses. An increase in farm machinery size from complement #1 to complement #3 allows an increase in farm size of 1,040 acres for the CI system but only 480 acres for the OI 4-year rotation.

In the case of the OI 4-year rotation, yield penalties related to corn planting delay and the restriction on alfalfa harvest delays are the most frequently binding constraints in the farm size model. Yield penalties due to delays in soybean planting and mechanical weed control are less frequently binding with these machinery size groupings. For the CI 2-year rotation, the yield penalty from delayed corn planting is the binding constraint with all three machinery complements. In the CI 2-year rotation, there are fewer field operations than in the OI 4-year rotation and therefore less competition for limited labor and machinery time. Furthermore, because both corn and soybean are planted early in the spring in the CI system relative to the OI system, and because the associated yield penalties are quadratic in nature, when there are planting delays, daily penalties are usually smaller in the CI system than in the OI system. Thus in most years planting can be delayed longer in the CI system without triggering the unacceptable 5% yield loss level. Late planting in organic management systems for the purpose of weed control may not only affect yield of late planted corn and soybean, but may also increase the probability of significant additional yield loss if weather precludes field work during this critical time.

2.3.2 Production Costs

In both the CI 2-year and the OI 4-year rotations, per-acre machinery operating costs decrease as machinery size increases. Larger implements, able to complete field operations in less time than smaller implements, have lower per-acre labor costs. Machinery operating costs and purchased inputs for the OI 4-year rotation averaged across all years and crops are \$153, \$140, and \$139 per acre for machinery complements #1, #2, and #3, respectively. Similarly, the average costs of machinery operations and purchased inputs for the CI 2-year rotation are \$174, \$167, and \$166 per acre for the same machinery complements (Table 2.6).

Though the organic system requires more machinery passes per year than the conventional system, when averaged over all crops in the rotations (Table 3.7) higher average weed control costs in the CI 2-year rotation contribute to higher average operating costs compared to the OI 4-year rotation (Delbridge et al., 2011).

2.3.3 Net Returns

When full organic price premiums and observed trial yields are considered, the average whole-farm net return to the OI 4-year rotation is greater than the average net return to the CI 2-year rotation for each of the three machinery complements, despite the fact that the CI system has more crop land under machinery complements #2 and #3 (Table 2.8). Returns to the CI system are also more variable than those to the OI system for these machinery groupings, as more crop land results in larger swings in profits between those years with strong yields and high prices and those without[2.3]. When the recorded organic price premiums from recent years are reduced by half, the mean net return to the OI 4-year rotation is still higher than to the CI 2-year rotation with machinery complement #1, though the CI 2-year rotation has a higher mean net return with each of the larger machinery complements (Table 2.8). It is also noteworthy that the distribution of net returns to the OI rotation under machinery complement #1 with less than full price premiums has a lower variance than that for the corresponding CI scenario. Because organic rotations are often more diverse than conventional grain rotations they are likely to have less variable returns when compared to farms of equal size with shorter rotations. Finally, when organic crops receive conventional prices, the mean net return for the OI 4-year rotation falls well below that for the CI 2-year rotation for each machinery complement.

Under the reduced yield scenario, in which organic corn and soybean yields in the OI

[2.3] The yield protection crop insurance product that is applied to both systems has only a minor impact on the variability of net returns. Indemnities are received in only 2 of 36 crop years in the CI rotation and 14 of 72 crop years in the OI rotation. The inclusion of the insurance product does not affect the stochastic dominance results that follow.

4-year rotation are reduced by 25%, the CI 2-year rotation results in a higher average net return than the OI 4-year rotation for all but the smallest machinery complement, even with full organic premiums (Table 2.9). The results for machinery complement #1 allow us to compare the net returns to equally sized small farms managed with the OI and CI cropping systems. We can achieve a similar comparison for larger farms by focusing on the CI rotation under machinery complement #2 (880 acres) and the OI rotation under machinery complement #3 (800 acres). Under the reduced yield scenario, the OI system with machinery complement #3 generates a greater average net return, with a smaller variance, than the CI system with machinery group #2, but only when full organic premiums are applied. A reduction in organic premiums in addition to the reduced organic yields eliminates the profitability advantage of the organic cropping system (Table 2.9).

Stochastic dominance analysis of the six whole-farm scenarios shows that when full yields and price premiums are taken into account, the OI 4-year rotation dominates the CI 2-year rotation with machinery complement #1 by FSD, but neither system dominates the other by FSD within machinery complements #2 or #3 (Figure 2.1). However, each of the OI 4-year rotations dominates the CI 2-year rotation within the same machinery group under SSD, despite having less crop land in complements #2 and #3. In Figure 2.2, we see that when only half of the observed organic price premiums are considered, the OI farm dominates the CI farm by SSD with machinery complement #1, but no ordering can be made of the systems within the larger machinery complements using either FSD or SSD criteria. It is also notable that the largest farm within the OI system (800 acres with machinery group #3) dominates the mid-size farm within the CI system (880 acres with machinery group #2) by FSD with full organic premiums and by SSD with half of the organic premiums (Figures 2.1, 2.2).

Focusing on the stochastic dominance analysis of the reduced organic yield scenarios shows that, unsurprisingly, the relative profitability of the organic system is sensitive to

Table 2.8: Average net return to the chemical input (CI) 2-year and organic input (OI) 4-year crop rotation for each machinery complement and pricing scenario with full trial yields, 1993-2010.

Crop rotation	Mach. Comp.	Farm size	Conventional Prices		Half Premiums		Full Premiums	
			Net return	SD	Net return	SD	Net return	SD
		–ac–	——-US $——-					
CI 2-year	#1	320	51,150	33,884				
	#2	880	147,007	93,172				
	#3	1,360	229,249	143,991				
OI 4-year	#1	320	24,942	20,259	68,296	27,358	111,650	36,988
	#2	560	50,858	35,471	126,727	47,897	202,597	64,750
	#3	800	74,021	50,689	182,405	68,438	290,790	92,510

Table 2.9: Average net return to the chemical input (CI) 2-year and organic input (OI) 4-year crop rotation for each machinery complement and pricing scenario with OI corn and soybean yields reduced by 25%, 1993-2010.

Crop rotation	Mach. Comp.	Farm size	Conventional Prices		Half Premiums		Full Premiums	
			Net return	SD	Net return	SD	Net return	SD
		–ac–	——-US $——-					
CI 2-year	#1	320	51,150	33,884				
	#2	880	147,007	93,172				
	#3	1,360	229,249	143,991				
OI 4-year	#1	320	6,014	17,281	39,949	22,599	73,884	29,832
	#2	560	17,734	30,256	77,120	39,567	136,507	52,226
	#3	800	26,701	43,243	111,539	56,541	196,376	74,622

corn and soybean yields. With organic corn and soybean yields reduced by 25%, the OI system does not dominate (and is not dominated by) the CI system by FSD or by SSD within machinery complement for the largest two machinery and farm size scenarios (Figure 2.3). In the smallest machinery and farm size scenario, in which the farm size is 320 acres for both systems, the OI rotation dominates by FSD despite the reduced organic yields. A comparison of the largest OI farm and the mid-sized CI farm leads to results similar to those from the full yield scenario. Even with reduced organic yields, the OI system with machinery complement #3 and 800 acres dominates the CI system with machinery complement #2 and 880 acres by SSD and very nearly satisfies the FSD criterion (Figure 2.3). Dominance is not maintained when both organic premiums and organic yields are reduced from their baseline levels (Figure 2.4).

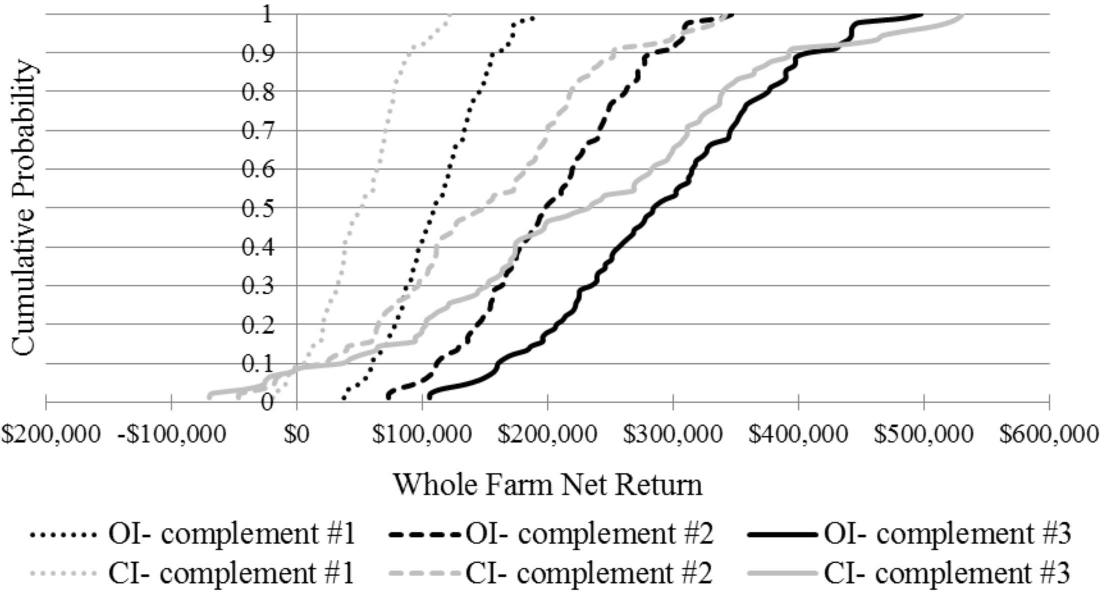

Figure 2.1: Cumulative distribution functions for the chemical input (CI) 2-year and organic input (OI) 4-year crop rotations, considering 100% of organic price premiums and each machinery complement scenario.

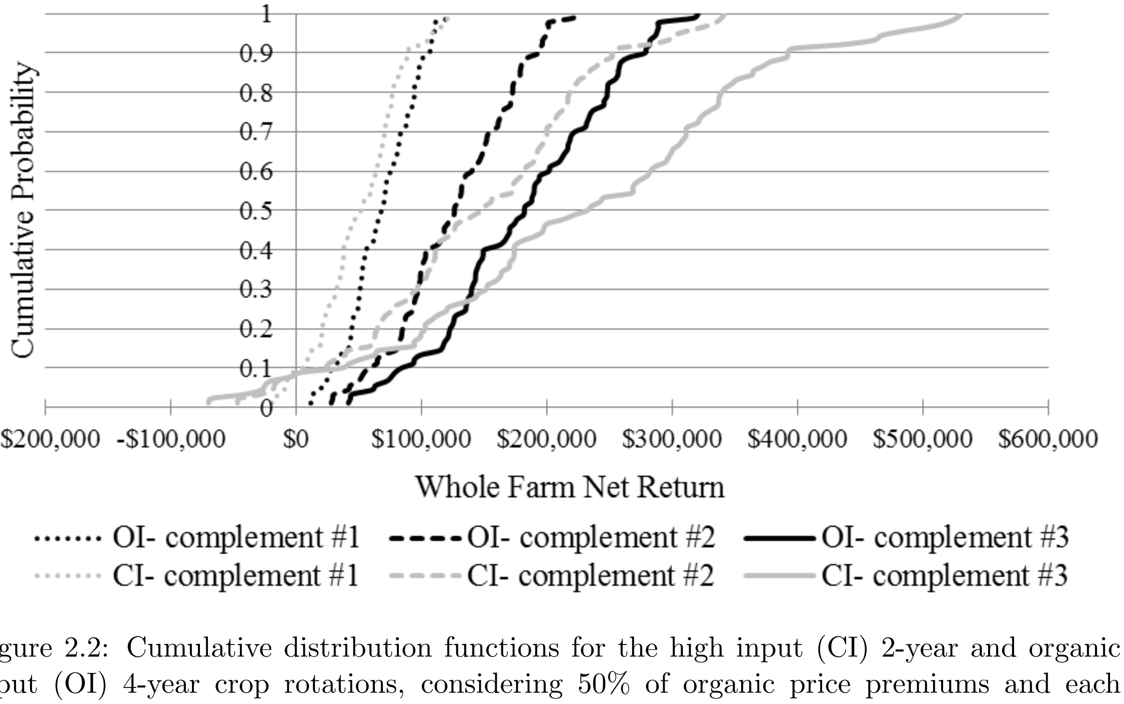

Figure 2.2: Cumulative distribution functions for the high input (CI) 2-year and organic input (OI) 4-year crop rotations, considering 50% of organic price premiums and each machinery complement scenario.

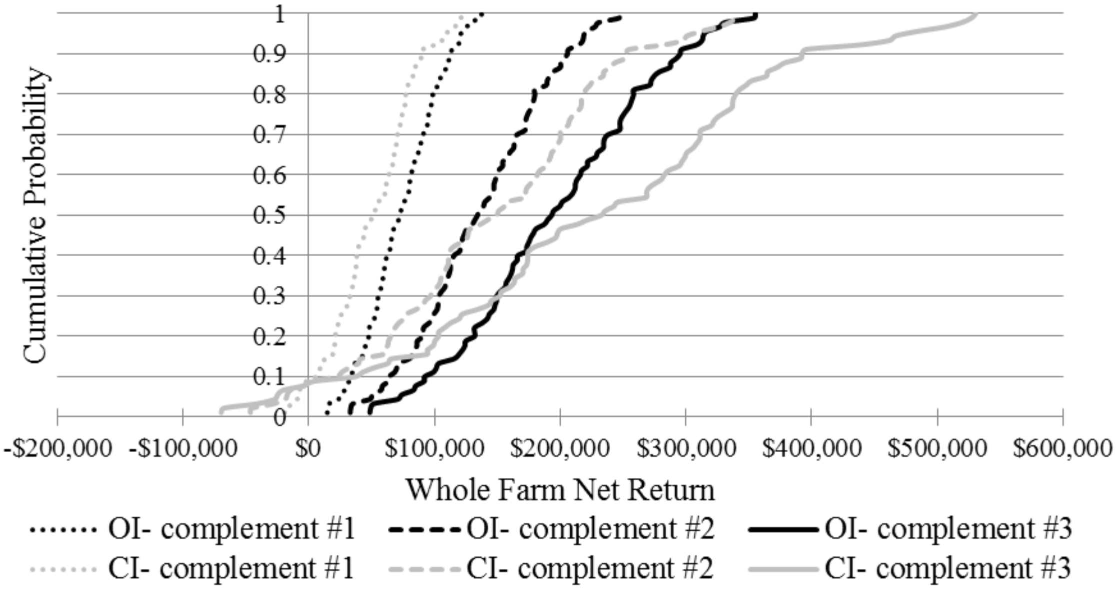

Figure 2.3: Cumulative distribution functions for the chemical input (CI) 2-year and organic input (OI) 4-year crop rotations, considering 100% of organic price premiums and each machinery complement scenario, with OI corn and soybean yields reduced by 25%.

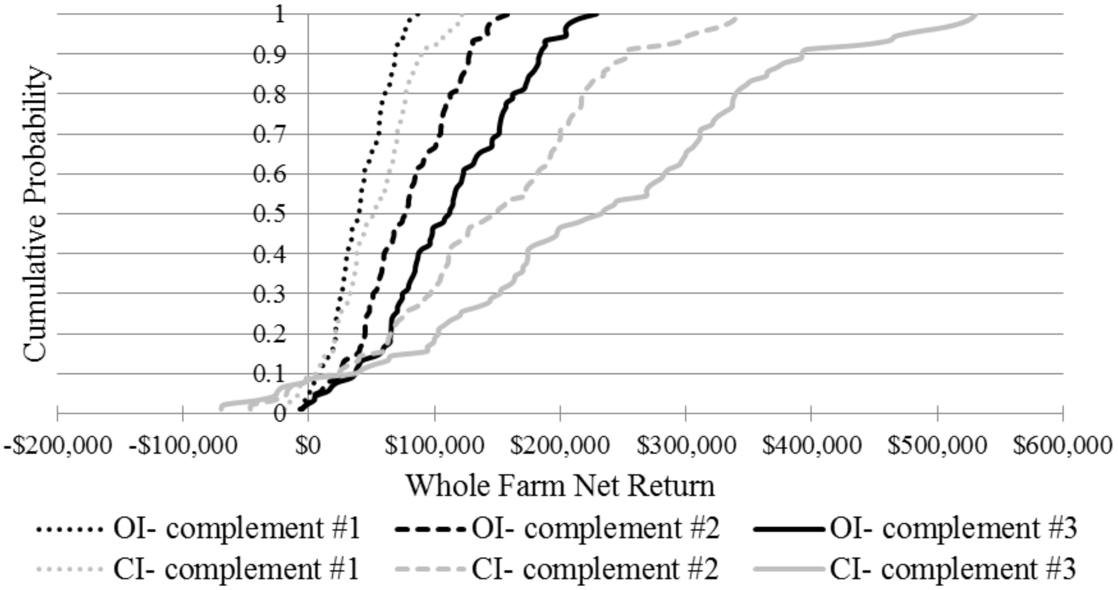

Figure 2.4: Cumulative distribution functions for the high input (CI) 2-year and organic input (OI) 4-year crop rotations, considering 50% of organic price premiums and each machinery complement scenario, with OI corn and soybean yields reduced by 25%.

2.4 Conclusions

While previous studies have found that organic cropping systems in the Midwest often outperform conventional systems on the basis of per-acre profitability, only a small percentage of total cropland in the region has been transitioned to organic management. This study aims to improve understanding of this discrepancy by extending this line of research with a whole-farm analysis, taking into account likely differences in farm size between the two systems. Maximum farm sizes have been estimated for different machinery complements using historical data on suitable days for field work and data on field operations for an organically managed 4-year crop rotation and a conventionally managed 2-year rotation. These farm sizes have been used in the calculation of more accurate machinery operating costs than are possible without assumptions regarding farm and machinery sizes. Machinery operating costs, empirical machinery ownership cost averages, trial production data, and observed market prices have been incorporated into a model that simulates whole-farm net return distributions for each cropping system.

Results of stochastic dominance analysis indicate that an organically managed crop farm in the Upper Midwest would be preferred by risk neutral and risk averse individuals to a conventionally managed crop farm (i.e. SSD), even when less total crop land is available, assuming yields are at levels reported by the VICMS trial. When comparing returns to these cropping systems on farms of similar sizes, results indicate that the organic rotation, at least on smaller farms, dominates the conventional rotation by FSD, which holds for all individuals that prefer more to less. This result does not necessarily hold when only half of the recent organic price premiums are applied to crops produced in the organic system, or when trial yields of organic corn and soybean are adjusted downward by 25%.

An interesting implication of these results is that small conventionally managed farms may be able to earn greater net returns if transitioned to organic production. Higher prices for organic crops and lower variable costs in an organic system allow for higher net returns per acre on organic crop farms than on conventional corn-soybean operations. However, more time-consuming organic management requirements, such as mechanical rather than chemical weed control, often allow conventional rotations to be managed on larger areas with the same labor and machinery resources. This provides some explanation for why empirical data show that organic crop farms are smaller, on average, than conventional crop farms. Thus, in cases where available crop land is limited, organic crop management may be the more attractive system. Moreover, in some cases it may be desirable for conventional farms to reduce their size as they transition to organic management, potentially increasing the proportion of crop land that is owned rather than leased.

There are several issues that must be kept in mind when considering these results. Empirical farm-level data show that average yields of organic crops in Minnesota are often lower than those achieved by university trials and the top performing organic crop farms. This study has shown that the profitability advantage enjoyed by the organic rotation analyzed here is not always maintained under lesser yields. In short, management matters, and not all organic farms will be able to outperform conventional farms of similar size. Perhaps as more agronomic research on organic management methods is undertaken and findings from that research are extended to producers, organic farm performance will more consistently approach that achieved under experimental conditions, but at this point there are certainly unique challenges and risks associated with organic crop management. Additionally, the machinery required for corn-soybean-oat/alfalfa-alfalfa rotation is significantly different from that required to manage a corn-soybean rotation, in both size and machinery type. It would be inaccurate to suggest that growers using one system could simply “switch” to the other system without significant changes to their machinery complement in addition to the changes to management practices. Both of these aspects of transition impose a cost on the transitioning grower that is not considered in this study.

Despite these caveats, it is surprising that the organic system is so competitive, even when yields and organic premiums are reduced from observed levels. This again raises the question of why more farms have not converted to organic production. While this study has shown that differences in farm size and overhead costs alone do not seem to account for the slow rate of organic transition, future analyses of the barriers to organic transition should take these factors into consideration.

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3 Transition to Organic Crop Production: a Dynamic Programming Approach

3.1 Introduction

Both experimental trials and empirical farm-level data have indicated that organic cropping systems in the midwestern U.S. can earn more on a per-acre basis than the conventional corn-soybean rotation that is 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, 2013). Research comparing the whole-farm net returns to these two systems indicates that with identical environmental conditions, labor, and machinery endowments, the organic system can also be more profitable[3.1] at the whole-farm level. Despite the growing public support for organic production (USDA, 2013), steady consumer demand for organic foods (Osteen et al., 2012), and the profitability advantages that would seemingly be available to some managers, less than 1% of U.S. cropland has been transitioned to organic management. In fact, while total U.S. organic crop acreage has continued to increase, the rate of transition has slowed in recent years, and 20 states saw a net decrease in organic crop acreage from 2008 to 2011 (USDA-ERS, 2013).

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" (USDA-AMS, 2013). Although transitioning farmers in some areas may be able to sell crops as "GMO Free" and receive small price premiums (Charles, 2014), most producers must sell transitional crops for conventional prices. Additional costs are often incurred before or during the transition

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[3.1] Farm-level financial data suggest that, on average, organic crop farms often have a lower rate of return on assets than conventional crop farms (Center for Farm Financial Management, 2012). However, these averages do not account for differences in the farms themselves (e.g. size, soil quality, management) that may affect profitability.

of cropland, such as those associated with machinery purchases and sales, learning about organic management techniques, and the time required to establish relationships with mentors, input suppliers, and buyers of organic products. As a result, the transition period is often one in which farms must accept significantly lower revenues and potentially higher costs than before they initiated transition. The transition decision is reversible because conventional practices (i.e. techniques prohibited by the NOP) can be used at any time. However, if prohibited techniques are used, the transition period must be restarted in order to eventually regain organic certification. Upon completion of the transition period, organic crop returns are subject to significant yield and price risk that is distinct, though related to, the risk faced by a conventional farm operation. Initiating organic transition can, then, be viewed as a costly investment in a risky asset, and the decision to transition (or not) takes on an interesting dynamic dimension.

This essay 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 if 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. We provide insights into how the optimal transition decision is affected by changes in organic yield and price levels, and we explore 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. In this real options approach, it is recognized that in order for an investment to be optimal, the expected net present value (NPV) of the investment must be greater than the direct investment cost plus the value of the option to delay the investment. In many investment problems the expected NPV 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 et al. (1999) found that payments to land owners for conservation easements failed to fully compensate for the land-owners' option value, thus explaining low participation rates. Schatzki (2003) econometrically estimated the option value to delay conversion of cropland into forests and found that land owners consider significant option values when making this land use decision. Song et al. (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 explains the different rates of organic transition in the two countries. Kuminoff and Wossink (2010) used data on organic soybean production in the U.S. to econometrically estimate the amount of an 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 than it would be under a NPV framework, suggesting a significant option value.

This essay contributes to this stream of the literature by modeling the decision to transition to organic crop production as a dynamic programming problem in which investment is reversible but includes sunk costs. Two key features of this model are the allowance of farm sizes that depend on which management system is chosen, and the ability to reverse transition once organic certification is achieved. This essay also takes advantage of unique data sets including a 20 year series of side-by-side organic and conventional cropping systems trial, and farm-level crop production data from Minnesota crop farms that have grown both organic and conventional crops in the same crop year. We analyze the decision to transition under several different assumptions of farm size, organic premium levels, and yield gaps between organic and conventional crop production. 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.

The essay continues with an explanation of the farm manager's organic transition decision problem and the structure of the model. The next section provides a discussion of the data and the estimation of the model's parameters. This is followed by a formulation of the model as a dynamic programming problem and an explanation of the numerical techniques used to solve the model. Finally, results are presented and the essay concludes with a discussion of the essay's implications.

3.2 Organic Transition Decision Problem

We consider a model in which a risk neutral farm manager faces two crop management alternatives: conventional management of a two-year corn-soybean rotation and organic[3.2] management of a four-year corn-soybean-oat/alfalfa-alfalfa rotation. If organic management is chosen, two conditions are possible; certified organic and transitional. 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[3.3]. If a decision is made to manage the land conventionally, the farm loses any organic certification

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

[3.3] Since transition officially starts at the time of last prohibited practice (e.g. herbicide spray) and ends at certification no sooner than 36 months later, cropland is commonly in "transition" for only two full crop years.

and any progress towards completion of the 36 month transition. During the transition period, crop yields and production costs are assumed to be the same as for the organic system and crop prices are assumed to be the same as those received by the conventional system.

The model has a single control variable - the production method chosen for the farm. This is denoted x_t and 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, and the current per-acre return for the conventional rotation. These are denoted s_t and cr_t respectively.

As reported in Delbridge et al. (2013), the maximum acreage that can be farmed organically with a specific machinery complement is less than the maximum acreage that can be farmed conventionally with the same equipment. This is due to additional tillage passes needed for mechanical weed control in the organic system. When a farm transitions its land to organic production, acreage can easily be reduced by giving up rented land or by renting out owned land. However, when a farm ceases organic production and begins to use conventional practices, it may be more difficult to expand acreage immediately. In this analysis, we assume that a farm switching from organic to conventional production expands acreage to the conventional level in equal steps over a five year period. Therefore, the transition status variable has five distinct values for conventional production ($s_t = 1{-}5$). As noted earlier, there are three distinct situations for organic production: first year transition ($s_t = 6$), second year transition ($s_t = 7$), and certified organic ($s_t = 8$). The dynamics of the transition status state variable are:

$$s_{t+1} = \begin{cases} 1 & \text{if } s_t > 5 \text{ and } x_t = 0 \\ \min(s_t + 1, 5) & \text{if } s_t < 6 \text{ and } x_t = 0 \\ 6 & \text{if } s_t < 6 \text{ and } x_t = 1 \\ \min(s_t + 1, 8) & \text{if } s_t > 5 \text{ and } x_t = 1. \end{cases} \tag{3.1}$$

For the sake of simplicity, the gross return per acre to the conventional cropping system is modeled as a single stochastic process rather than as a joint distribution of separate crop yield and price processes. Gross returns to the conventional system are assumed to follow a mean-reverting Ornstein-Uhlenbeck process of the form:

$$dcr = \eta(\overline{cr} - cr)dt + \sigma dz \tag{3.2}$$

where η is the reversion parameter, $\overline{cr}$ and cr are the long-run mean gross return and the annual per-acre gross return to a conventional corn-soybean crop rotation, respectively. The variance parameter is denoted by σ and dz is an increment of the Weiner process. The discrete version of equation (3.2) can be written as:

$$cr_t - cr_{t-1} = \alpha_0 + \alpha_1 cr_{t-1} + \epsilon_t \tag{3.3}$$

where $\overline{cr} = -\frac{\hat{\alpha}_0}{\hat{\alpha}_1}$, $\hat{\eta} = -\log(1+\hat{\alpha}_1)$, and $\hat{\sigma} = \hat{\sigma}_\epsilon \sqrt{\frac{\log(1+\hat{\alpha}_1)}{(1+\hat{\alpha}_1)^2-1}}$, and $\hat{\sigma}_\epsilon$ is the standard error of the regression (Dixit and Pindyck, 1994).

Lack of long-term organic commodity price data precludes the estimation of a similar stochastic process for organic system gross returns. Similarly, the lack of a long-term series of transitional yield data precludes the estimation of a stochastic process for transitional gross returns. Although evidence suggests that organic and conventional crop prices may be independent of one another (Singerman, et. al, 2012), crop yields from the two systems are certainly related through a similar yield response to weather. Therefore, organic and transitional gross returns per acre are modeled as simple linear functions of conventional gross returns according to the equation:

$$GR_i = \beta_{0i} + \beta_{1i} cr + \epsilon_i \text{ for } i = o, r \tag{3.4}$$

where GR_i is the per-acre gross return to organic and transitional crop management, cr is the per-acre gross return to conventional management, and ϵ_i is the error term for cropping system gross return 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 gross returns. That is, $GR_c \equiv cr$. Table 3.1 presents the relationship between transition state variables, gross return levels, available acreage for crop production, and production costs.

Table 3.1: Description of transition state variable and associated parameters.

s	Description	Acreage	Gross returns	Production costs
1	conventional, 1	$a_O + 0.2(a_C - a_O)$	GR_c	*conventional*
2	conventional, 2	$a_O + 0.4(a_C - a_O)$	GR_c	*conventional*
3	conventional, 3	$a_O + 0.6(a_C - a_O)$	GR_c	*conventional*
4	conventional, 4	$a_O + 0.8(a_C - a_O)$	GR_c	*conventional*
5	conventional, 5	a_C	GR_c	*conventional*
6	transitional, 1	a_O	GR_r	*organic*
7	transitional, 2	a_O	GR_r	*organic*
8	certified organic	a_O	GR_o	*organic*

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

$$f(x_t, s_t, cr_t) = (GR(x_t, s_t, cr_t) - c(x_t))a(x_t, s_t) \tag{3.5}$$

where $GR(x_t, s_t, cr_t)$ is the farm's gross return which depends on the management decision (x_t), the organic transition status (s_t), and the current level of returns to conventional crop management (cr_t). Production costs are denoted by $c(x_t)$ and the acreage available to the manager is denoted by $a(x_t, s_t)$. The manager's objective is to maximize the discounted sum of returns, net of production costs, over an infinite time horizon. The objective function can be stated formally as:

$$\begin{aligned} &\underset{\{x_t\}_{t=0}^{\infty}}{\text{maximize}} && \mathrm{E}\left[\sum_{t=0}^{\infty} \delta^t f(x_t, s_t, cr_t)\right] \\ &\text{subject to} && \text{equations } (3.1), (3.3), \text{ and } (3.4). \end{aligned} \tag{3.6}$$

3.3 Data and Parameter Estimation

This organic transition decision 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 and a two-year (corn-soybean) rotation were managed under an “organic input” system, and a “high input” system that is typically used by conventional crop producers in the region. The long-term nature of the trial not only provides data that captures much of the yield variability in organic and conventional crop rotations but also allows time for the “agronomic transition” of the cropland and the accumulation of soil nutrients in a system with no synthetic amendments. Thus, the yield data used here are likely to be more representative of the true relationship between organic and conventional yields than data from short-term trials or recently transitioned farms. For a full explanation of management practices and yield measurements, see Porter et al. (2003) and Coulter et al. (2011).

The gross return to conventional corn and soybean production is modeled as the mean-reverting stochastic process in equation (3.2). A 71 year series[3.4] of gross returns to a corn-soybean rotation was constructed using detrended county yield and inflation-adjusted state crop price data from USDA-NASS (Figure 3.1; USDA-NASS, 2013). This series is used to obtain estimates of the mean reversion parameters η and σ. To do so, the values of α_0 and α_1 in equation (3.3) are estimated by OLS using the aforementioned series of county-level gross returns. The parameter estimates, which are presented in Table 3.2, are

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

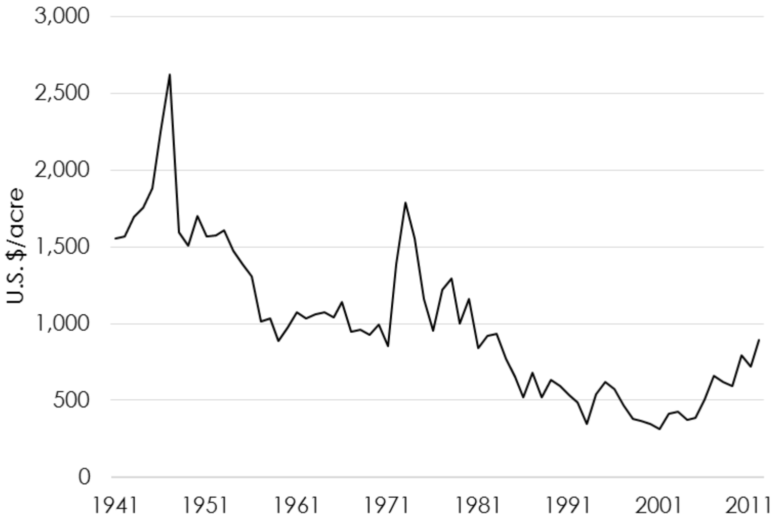

Figure 3.1: Detrended and inflation adjusted average gross returns to a conventional corn-soybean rotation in Redwood County, MN, 1941-2012 (USDA-NASS, 2013).

statistically significant only at relatively weak confidence levels (0.118 and 0.054 for $\hat{\alpha}_0$ and $\hat{\alpha}_1$ respectively). However, Dixit and Pindyck (1994) explain that the standard errors in this estimation can be unreliable and that even estimation with series as long as that available here can fail to confirm significant mean reversion with a high level of confidence. Because mean reversion is often accepted as an appropriate way to model agricultural returns (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.

As noted in Delbridge et al. (2013), the organic corn and soybean yields observed in the experimental trial were substantially higher than the average organic corn and soybean yields reported by organic farmers in the state. Average trial yields of organic corn and soybean (with no trend adjustment) from 2006 - 2012 were 155 bu/ac and 32 bu/ac respectively. This compares to average yields over this time period[3.5] of 107 bu/ac and 20 bu/ac achieved by organic farms that contribute to the University of Minnesota's FINBIN

[3.5] These are the only years for which both trial yields and FINBIN organic crop yields are available.

Table 3.2: Transition model parameters.

Mean Reversion	Parameter	Estimate	S.E.	P-value			
	$\hat{\alpha}_0$	86.07	54.43	0.118			
	$\hat{\alpha}_1$	-0.095	0.049	0.054			
long-run mean	$\overline{cr}$	904.17					
reversion rate	η	0.10					
variance	σ	150.59					
Discount Factor							
	δ	0.04					
	Conventional				Organic		
Crop Acres	Small	Medium	Large		Small	Medium	Large
	320	880	1,360		320	560	800
Production Costs							
Operating cost	\$206	\$197	\$196		\$156	\$142	\$141
Overhead cost	\$335	\$335	\$335		\$350	\$350	\$350
sum, $c(x)$	\$541	\$532	\$531		\$506	\$492	\$491

database. At first glance it might seem that the high yields achieved in the university trial are not achievable by most farms in the state and that a prudent correction would be to adjust trial yields downward to the level commonly achieved by area farms. However, Delbridge and King (2014) show that low state average organic yields are due, in part, to a selection effect among those that chose to transition to organic management. Delbridge and King argue that the farms that choose to adopt organic management tend to achieve lower conventional yields than neighboring farms and that their organic yield experience may not be representative of the true yield potential of the average conventional crop farm.

A more accurate picture of the conventional - organic yield gap can be achieved by focusing on the “partially transitioned” farms that have grown the same crop both organically and conventionally in the same year, and contribute to the FINBIN database. Delbridge and King (2014) report that among these farms, both organic corn and soybean yields are an average of 75% of the conventional yields achieved on the same farms. In the case of

Table 3.3: Mean detrended trial crop yields for full and reduced yield scenarios for the conventional and organic crop rotations, 1993-2012.

	CI two-year		OI four-year			
Full organic trial yield scenario						
	Corn	Soybean	Corn	Soybean	Oat	Alfalfa
	—bu/ac—		———bu/ac———			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	Soybean	Corn	Soybean	Oat	Alfalfa
	—bu/ac—		———bu/ac———			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

soybean this corresponds well to the yield gap observed in the experimental trial. For corn however, organic trial yields were an average of 95% of the conventional trial yields. Thus, we consider a reduced yield scenario in which organic corn yields are reduced from those observed in the trial data. We reduce organic trial corn yields by 20%, which is the level needed to bring the average yield to roughly 75% of the conventional trial corn yield. No adjustment is made to soybean, oat or alfalfa yields[3.6]. Yield averages in the full yield and reduced yield scenarios are presented in Table 3.3.

In order to estimate the parameters of equation (3.4), which relates organic and transitional gross returns to conventional gross returns, distributions of per-acre gross returns to each system are constructed using the detrended trial yield data from 1993 - 2012, and the inflation adjusted organic and conventional commodity prices from 2006-2012 (Tables 3.4-3.5; Center for Farm Financial Management, 2013). Following the methodology outlined in Delbridge et al. (2011) and updated by Delbridge (2014)[3.7], independence is established

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[3.6] Coutler et al. (2010) reports that organic oat and alfalfa trial yields are no lower than those observed in the conventional four-year rotation. This relationship is also observed in all available farm-level data.

[3.7] Delbridge et al. (2011) do not adjust commodity prices for inflation but Delbridge (2014) does adjust between organic prices and grain yields. Then the 20 years of trial yield data are combined with the 7 years of organic and conventional crop price data to achieve $20 \times 7 = 140$ possible gross return states for each system[3.8].

Table 3.4: Inflation-adjusted prices of conventional and organic corn, soybean, oat, and oat straw, 2006-2012.

Year	Corn	Soybean	Oat	Oat straw
	———-$/bushel———-			—$/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

A distribution of transitional gross returns is calculated by combining organic crop yields with conventional crop prices[3.9]. Additional scenarios, in which organic price premiums and organic trial yields are reduced from observed levels, are also considered and equation (3.4) is estimated separately for each. The regression residuals ϵ_i are retained as observations of an empirical distribution to be applied as random shocks in the dynamic programming model.

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prices for inflation. Prices are adjusted in this essay to 2012 terms using the CPI.

[3.8] 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.

[3.9] In some cases, transitional yields may be higher than organic yields because of lower weed pressure. Unfortunately, no suitable transitional crop yield data is 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.

Table 3.5: 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

Regression results for the baseline and select alternative scenarios are presented in Table 3.6. In all cases $\hat{\beta}_0$ is significantly greater than zero and $\hat{\beta}_1$ is significantly less than one. This implies that transitional and organic returns will be higher(lower) than conventional returns when conventional returns are low(high). Figure 3.2 shows this relationship visually with a scatter plot of organic and transitional return distributions from full yield and organic price premiums scenarios.

We consider three different farm size scenarios in the organic transition decision model. These farm sizes are those estimated by Delbridge et al. (2013) to be the largest that can be managed with each of three different machinery complements, without suffering unacceptable yield losses. The "small" machinery complement results in organic and conventional

Table 3.6: OLS estimates of equation (3.4) for select organic yield and price premium scenarios.

	Parameter Estimates			
Scenario	$\hat{\beta}_0$	S.E.	$\hat{\beta}_1$	S.E.
Full Yields, Full Premiums	267.79	39.34	0.876	0.058
Full Yields, Half Premiums	243.59	27.57	0.654	0.041
Full Yields, No Premiums	219.38	18.62	0.432	0.027
Reduced Yields, Full Premiums	256.15	35.23	0.773	0.052
Reduced Yields, Half Premiums	235.24	25.08	0.577	0.037
Reduced Yields, No Premiums	214.33	17.45	0.380	0.026

farm sizes of 320 acres for each system. The "medium" machinery complement results in organic and conventional farm sizes of 560 and 880 acres respectively. The "large" machinery complement results in an 800 acre organic farm and a 1,360 acre conventional farm (Table 3.2). Within the model, adoption of organic methods implies a switch in farm size from the conventional farm size under a given machinery complement to the organic farm size under that same complement. This requires the transitioning farm to give up cropland under the larger two machinery complement scenarios and requires no change in the smallest machinery complement scenario. As explained in the preceding section, a switch from conventional to organic management results in an immediate shift to the relevant organic acreage level but it is assumed to take five years to return to full conventional acreage when organic production is abandoned.

Production costs, denoted by $c(x_t)$ in equation (3.5), 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[3.10], is 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 1993-2012 (Delbridge et al., 2011). An average

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[3.10] As explained by Delbridge et al. (2013), an actuarially fair yield protection product is constructed for all crops in both rotations.

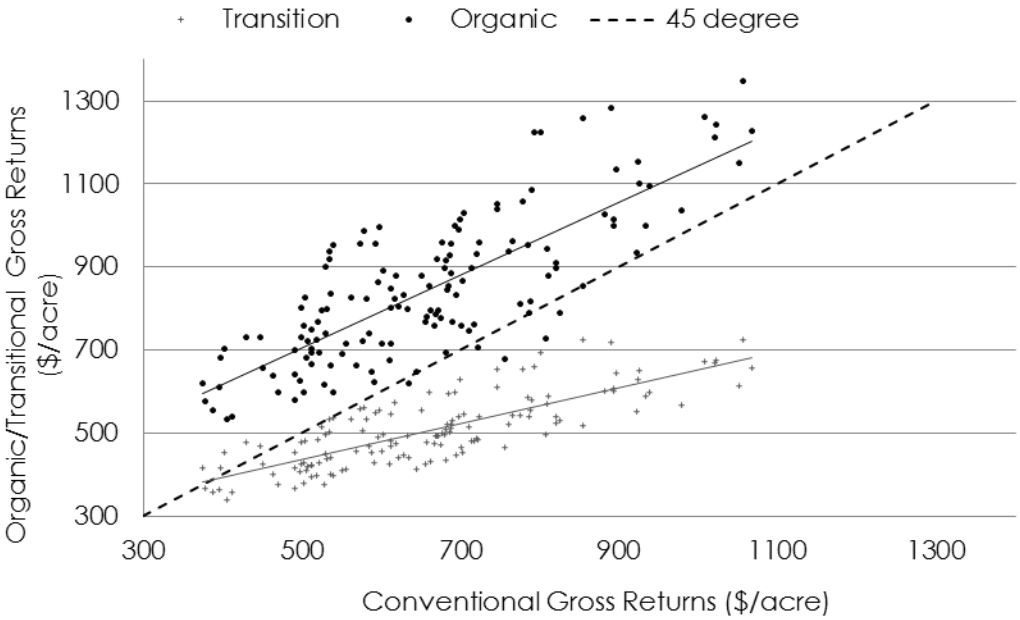

Figure 3.2: Gross returns to transitional and organic management relative to conventional management, with full organic prices and trial yields considered.

operating cost over the 20 years of trial data is calculated for each system and machinery complement scenario. Average per-acre overhead costs are taken from farm financial records for organic and conventional crop farms in Minnesota and do not vary across machinery complement scenario (Center for Farm Financial Management, 2013; Delbridge et al., 2013). Both operating and overhead costs are assumed constant across time periods, and the production costs incurred during the organic transition period are assumed to be the same for those incurred under certified organic management.

3.4 Dynamic Programming Formulation

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

$$V(s, cr) = \max_{x_t \in \{0,1\}} f(x_t, s_t, cr_t) + \delta \mathrm{E} V(g_1(x_t, s_t), g_2(cr_t)) \tag{3.7}$$

subject to

$$s_{t+1} = g_1(x_t, s_t) = \begin{cases} 1 & \text{if } s_t > 5 \text{ and } x_t = 0 \\ \min(s_t + 1, 5) & \text{if } s_t < 6 \text{ and } x_t = 0 \\ 6 & \text{if } s_t < 6 \text{ and } x_t = 1 \\ \min(s_t + 1, 8) & \text{if } s_t > 5 \text{ and } x_t = 1 \end{cases} \tag{3.8}$$

$$cr_{t+1} = g_2(cr_t) = \alpha_0 + (1 + \alpha_1) cr_t + \epsilon_t \tag{3.9}$$

$$GR_{it} = h_i(cr_t) = \beta_{0i} + \beta_{1i} cr_t + \epsilon_{it} \text{ for } i = r, o \tag{3.10}$$

where $V(s, cr)$ is the present value of the farm given the values of state variables s and cr. We solve this problem numerically using the DPSOLVE routine provided in the COMPECON Toolbox package written for MATLAB by Miranda and Fackler (2002). 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 possible organic transition outcomes given the fluctuations and shocks applied by the model. The probability of transition by the end of the 100 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). Because the farm manager described above faces substantial unrecoverable transition costs (in the form of reduced crop yields during the organic transition period and possible reduction in farm acreage), there will be a positive option value in this transition decision problem. A direct implication of the positive option value is that there will be some market conditions (i.e. levels of conventional gross returns) for which the NPV of the organic system is greater than the NPV of the conventional system, yet the optimal decision will be to continue with conventional crop management. Similarly, when the farm is being managed organically, there will be some conditions under which the NPV of the conventional cropping system is higher than the NPV of the organic system, yet abandonment of the organic system will be delayed because recertification will be costly. This results in hysteresis in the expansion of organic crop acres and the resulting supply of organic commodities. The range of conventional crop returns for which the optimal decision is neither to transition to, nor reverse transition from, organic management (i.e. the range of inaction) increases in size with greater uncertainty and higher transition costs.

Much of the uncertainty in a farmer's decision to transition to organic production is related to yield and long-term organic price premiums levels that can be expected following transition. To measure the sensitivity of the optimal transition strategy to organic yield and price changes, we include two different organic yield scenarios and several organic price premium scenarios. We are also interested in the effect that the level of "initial" per-acre returns to conventional management (denoted cr_0) has on organic transition probabilities in the short-term. Though the steady-state transition probabilities are not affected by the level of cr_0, the transition probabilities in the short-term are. To investigate this effect, we use the optimal policy returned by the function approximation method introduced above to simulate the transition outcomes after a period of 10 years for a range of possible values of cr_0.

3.5 Results

In general organic transition is more attractive when returns to conventional management are low. In the simplest model scenario, in which the gross return distributions are constructed using the yield data observed in the experimental trial and the observed organic price premiums, the probability that organic management is optimal in the steady state is 100% for the small farm, 30% for the medium farm, and 22% for the large farm (Figure 3.3). 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 is 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. Economic theory would suggest that in the long-run, price premiums will revert to the level at which the profitability of organic and conventional farm management is equal. 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 3.3 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 100% (i.e. observed organic prices) to 0% (i.e. conventional prices) in increments of 25%. 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

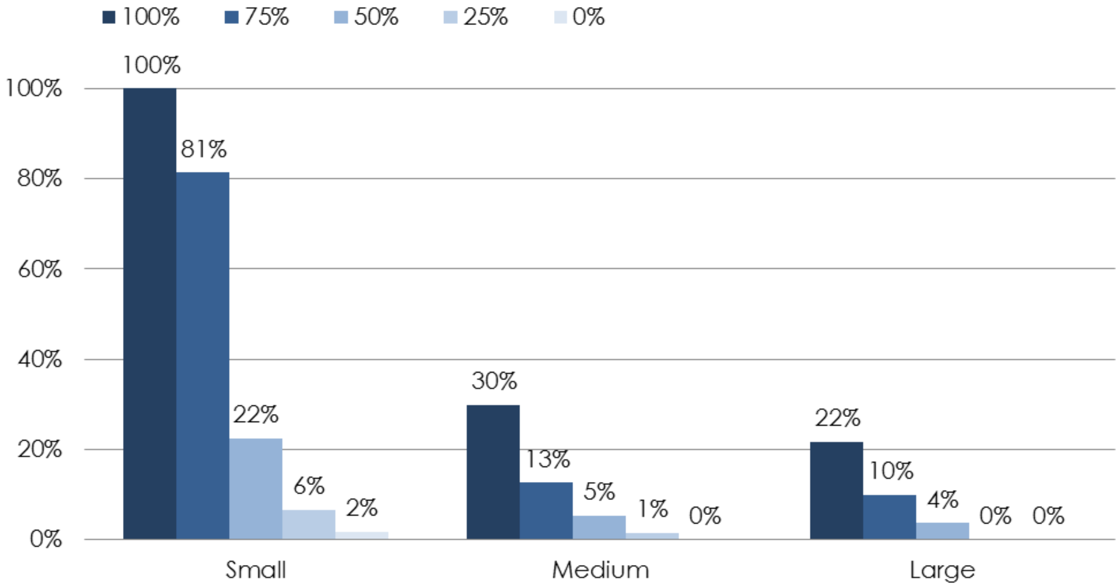

Figure 3.3: Steady state transition probabilities for each farm size scenario with full observed trial yields and varying levels of organic price premiums (0%-100% of observed organic premiums).

small probability that organic management is optimal in the steady state, even for the smallest farm.

The results from the dynamic programming model also tell us a great deal about the option value related to the decision to initiate organic transition, and how this option value is affected by changes in yields, prices, and farm size. Figure 3.4 shows the threshold values of conventional gross returns 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 returns to conventional management are below \$443. When conventional gross returns are between \$443 and \$850, the large conventional farm will optimally continue with conventional management and the large organic farm will continue organic management. When conventional returns are very

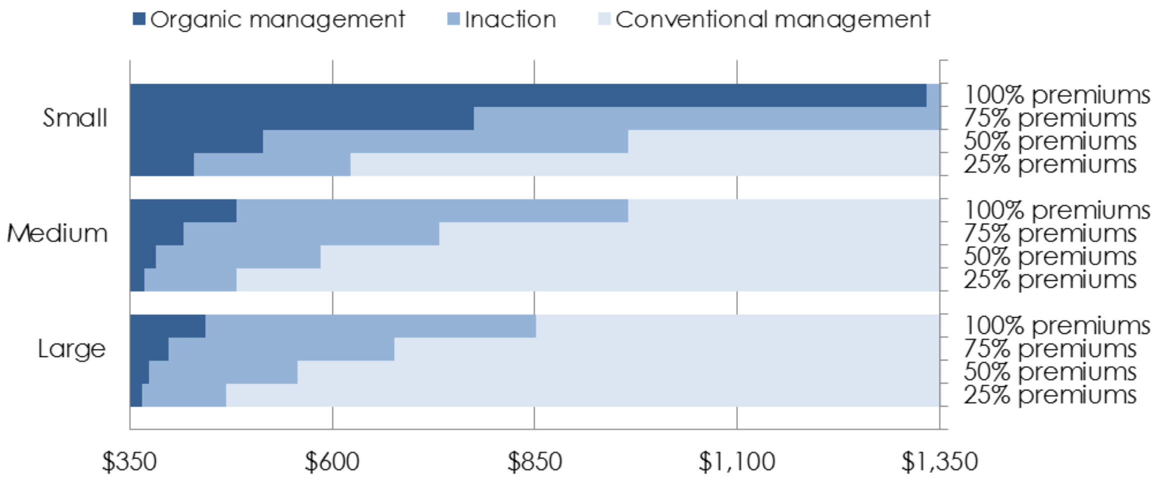

Figure 3.4: Critical gross return levels for different farm size scenarios with full trial yields and varying organic price premiums.

high, above $850, the optimal strategy 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 and this reduces the option value associated with the transition decision.

A closer look at the time series of detrended and inflation adjusted conventional returns in figure 3.1 helps to put these critical values into perspective. As explained above, organic transition on a large farm becomes optimal only if conventional gross returns fall below $443 per acre. In Redwood County, Minnesota, returns to the corn-soybean rotation have not been this low, on average, since 2005. Abandonment of organic management becomes optimal for the large farm when conventional gross returns surpass $850 per acre. It is noteworthy that average returns to a corn-soybean rotation surpassed this level in Redwood

County in 2012 for the first time in 30 years. The range of inaction, at least for the medium and large size farm scenarios, covers a large portion of the gross return levels observed in southwestern Minnesota in recent decades.

3.5.1 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 3.5 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%. This level is the reduction needed to bring the organic corn yield average to 75% of the conventional corn yield average, which is the level observed by partially transitioned farms in Minnesota that contribute to the FINBIN database (Delbridge and King, 2014). Organic soybean, oat, and alfalfa yields are not adjusted in the reduced yield scenario. A range of organic price premium reductions is also applied as they are in the full yield scenarios.

A comparison of Figures 3.3 and 3.5 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 86% when the observed organic price premiums are applied. In the larger farm size scenarios, the decreases in steady-state organic transition probabilities from the full yield scenario to the reduced yield scenario are from 30% to 14% for the medium farm and from 22% to 11% for the large farm. This suggests that the attractiveness of the organic system is fairly sensitive to the level of the

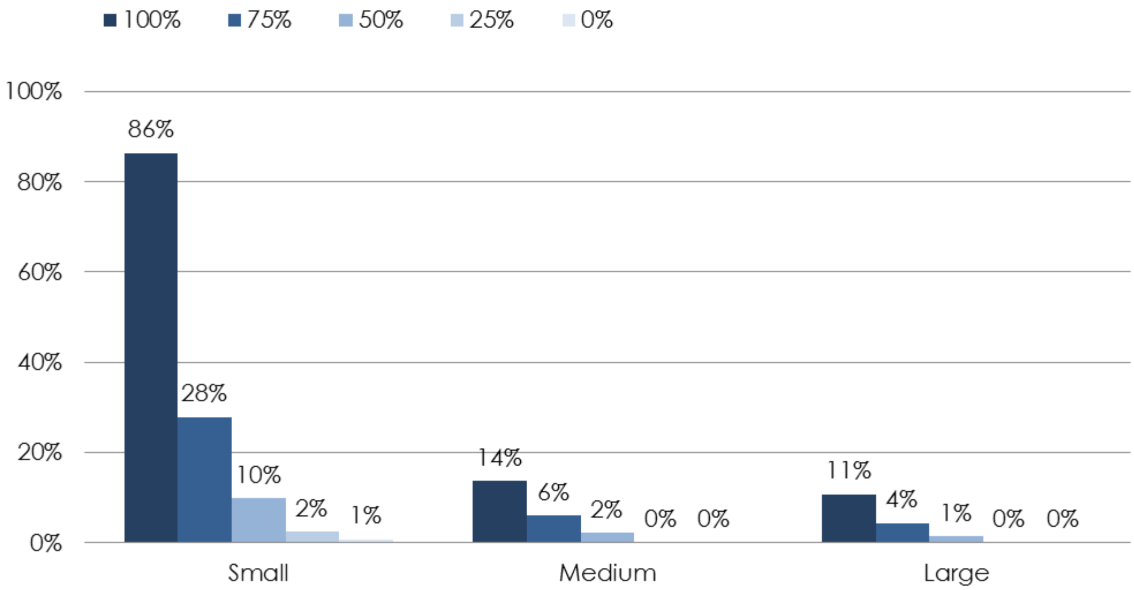

Figure 3.5: Steady state transition probabilities for each farm size scenario with reduced organic yields scenario and varying levels of organic price premiums (0%-100% of observed organic premiums).

organic corn yields that are expected following the transition period.

The threshold values that separate regimes of optimal organic management, inaction, and optimal conventional management are shown for the reduced yield scenario in figure 3.6. With the trial organic corn yields reduced by 20%, all threshold values are lower than in the baseline scenario. That is, conventional management becomes optimal at a lower level of gross returns and conventional returns must fall to lower levels for organic to become the optimal management strategy. The most striking difference in the critical values when organic corn yields are reduced is observed in the small farm-size scenario. With full organic price premiums, the level of conventional returns at which organic adoption becomes optimal falls by more than $500 per acre, from $1,330 to $785 per acre.

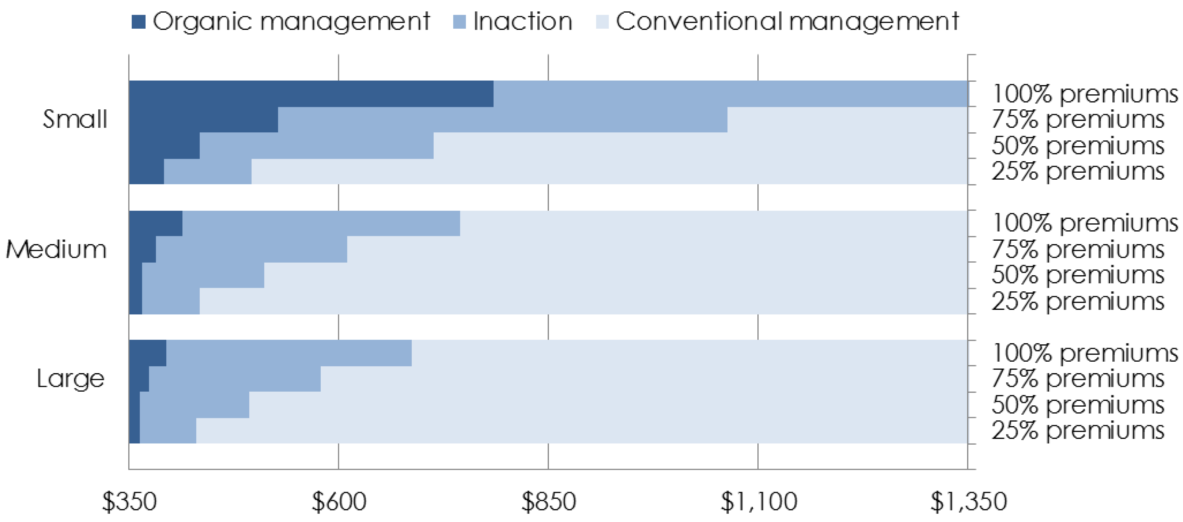

Figure 3.6: Critical gross return levels for different farm size scenarios with reduced organic yields scenario and varying organic price premiums.

3.5.2 Short-Term Transition

In recent years, high conventional commodity prices have resulted in large profits for conventional crop farms in Minnesota. The average gross return to a conventional corn-soybean rotation in Redwood County, Minnesota was above $700 per acre each year from 2010 to 2012 (USDA - NASS, 2013). Although organic crop prices have also been high, several midwestern states (including IA, IL, NE, WI) saw net decreases in certified organic crop acreage from 2010 to 2011[3.11], suggesting that a substantial number of organic crop producers have abandoned their certification and returned their acreage to conventional management (USDA-ERS, 2013). This raises the question of how the transition decision is impacted in the short-term by varying levels of conventional prices. To investigate this we reduce the period of the model simulation to ten periods (years) and vary the initial level of gross returns to conventional management (cr_0) from $400 per acre to $1000 per acre in increments of $200.

[3.11] Data from 2012 was not yet available as of early 2014.

Table 3.7: Short-term (10-year) organic transition probabilities with varying levels of initial per-acre gross returns to conventional management^a.

Farm Size	$cr_{t=1}$			
	400	600	800	1000
small	99%	95%	75%	50%
medium	37%	19%	12%	8%
large	24%	15%	9%	6%

a. For reduced yield scenario and full organic price premiums.

As cr_0 increases, the conventional gross return levels that define the ranges of organic transition, inaction, and reverse transition remain unchanged. However, the probability that the conventional returns fall low enough to induce organic transition before the end of the ten-year simulation decreases substantially. The probability of reaching organic certification by the end of the ten-year simulation is presented in table 3.7 for each farm size and varying levels of initial conventional return. These results reflect the model parameters from the reduced yield scenario with full organic price premiums. Although organic certification is likely for the small farm even with conventional returns at \$1000 per acre, for the larger farms the likelihood of organic certification drops to less than 10%. It is clear that organic transition is discouraged when conventional crop management is able to generate high returns.

3.6 Conclusions

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 (USDA-ERS, 2013). Delbridge et al. (2013) show that even when a transition to organic crop production is accompanied by a reduction in available crop acres, an organic crop rotation can be more profitable at the whole-farm level. The obvious question is: if organic crop production is more profitable than conventional production even when accounting for increased management requirements, why are more farmers not undertaking transition? This essay uses dynamic programming methods to model the transition decision itself and investigate whether or not the costly transition period and the 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 size is important given the increasing percentage of cropland controlled by large farms (MacDonald et al., 2013). If organic management is less attractive to large farms, it may be difficult to maintain high rates of growth in organic crop production. However, even within the large farm size scenarios, organic management is optimal in a fairly large percentage of simulated outcomes. Given the results derived from the baseline scenario, it appears that the option value related to the costly transition period may not fully explain low organic transition rates.

As discussed above, the organic crop yields achieved in the experimental trial on which these results are based were somewhat higher than the average yields achieved by certified organic crop farms in the region. 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 post-optimality simulation is shortened to 10 years and the starting value of conventional gross returns is varied, results show that in the short term, the probability of organic transition is highly sensitive to current returns to conventional crop management. When gross returns to conventional production are $400 per acre, the probabilities that organic certification is optimal within 10 years for medium and large farms are 37% and 24% respectively. When gross returns to conventional management increase to $1000 per acre, these probabilities drop to 8% and 6% respectively. This result is highly relevant given the climate of high commodity prices and robust profits to Midwest crop farms observed in recent years, and helps explain the decrease in organic transition rates since 2008. If conventional crop prices fall significantly below the levels seen in 2011 and 2012, we may see a return to higher rates of organic certification of midwestern cropland.

Given the model results, we can conclude that transition costs and uncertainty related to future returns to organic crop management lead to a substantial option value. This option value discourages organic transition, even for farms that could expect higher returns from an organic system. Though this model in particular, and the theory of investment under uncertainty in general, help to better understand the dynamics of the decision to adopt organic production methods, additional research is certainly needed. Two possible areas of focus are towards achieving a better understanding of the organic crop yields that conventional farms might expect, and the effect that further expansion of organic crop production might have on organic price premium levels.

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4 Investment in Organic Dairy Production: an Application of a Dynamic Panel Threshold Model

4.1 Introduction

Demand for organic dairy products has increased dramatically in recent years. While organic milk accounted for only 1.5% of total fluid milk products sold in the U.S. in 2006, by 2013 it had surpassed 4.5% of all milk sold (USDA-AMS, 2013a). Production has similarly increased. From 2000 to 2011, the number of certified organic milk cows increased from 38,000 nationwide to more than 250,000 (USDA-ERS, 2013; Figure 4.1). However, the rate of transition from conventional to organic production in the dairy sector has not been steady over this period. On a national level, the annual net increase in the number of organic dairy cows has been anywhere from less than 1% to 50%. Moreover, supply has not always matched demand, with organic producers forced to sell in the conventional market in some years and shortages of organic milk in others (Greene et al., 2009). This essay addresses the question of whether the organic certification of dairy cows in the U.S. exhibits hysteresis as predicted by the theory of investment under uncertainty for an investment decision with substantial sunk costs and uncertainty.

The transition from conventional to organic dairy production is not an easy one. Conventional dairy producers intending to achieve organic certification of their herd must complete a transition period of one year in which cows are managed organically but milk cannot be marketed as organic. All feed consumed by transitioning cows must be certified organic or produced on the transitioning farm from land in the final year of transition (USDA-AMS, 2013b). An organically managed dairy herd usually produces less milk per cow than a conventionally managed herd, and organic dairy feed is often much more expensive than conventional feed, making the transition a costly investment. Moreover, there is considerable uncertainty involved in organic dairy production. Though organic milk prices are

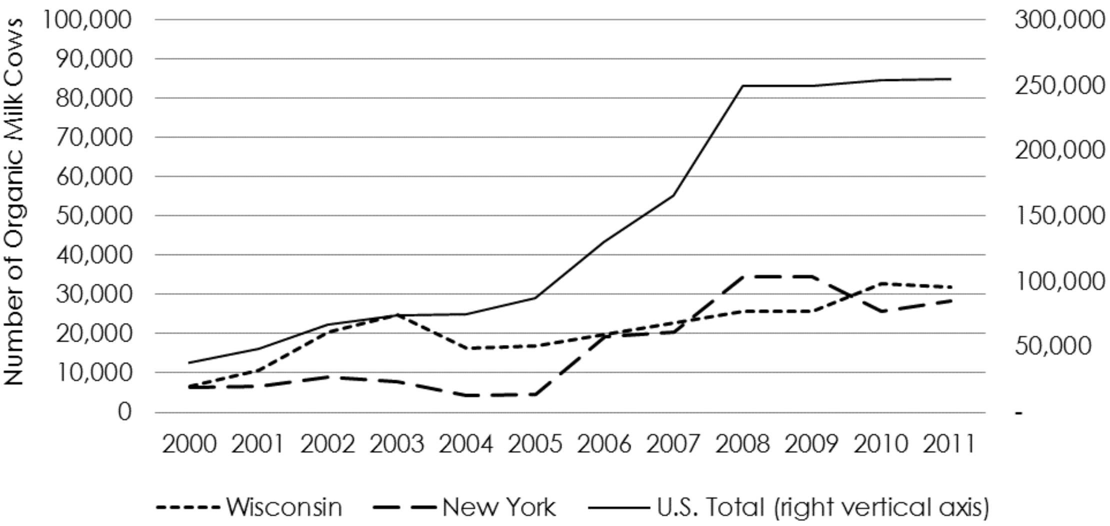

Figure 4.1: Number of certified organic dairy cows in NY, WI, and the U.S. from 2000 to 2011.

generally more stable than conventional milk prices (Figure 4.2), the volatility of organic grain and forage prices, combined with weather risk, makes returns to organic dairy quite variable.

An investment in an asset with uncertain returns and at least partial irreversibility (i.e. unrecoverable or "sunk" investment costs) has an option value (Dixit and Pindyck, 1994). That is, the option to delay investment and wait for additional information has a positive value. In the presence of a positive option value, investment in an income generating asset can be optimally forgone, even if the expected present value of the investment is greater than the present value of inaction. In agricultural production, as well as in other investment decision settings, this option value can lead to hysteresis, or a delayed response to changing market conditions. In the context of organic dairy production, hysteresis caused by significant option values could explain the uneven rates of organic transition over the past 15 years, despite steady growth in consumer demand for organic dairy products.

Though the scale of the option value of an investment depends on the size of the unrecov-

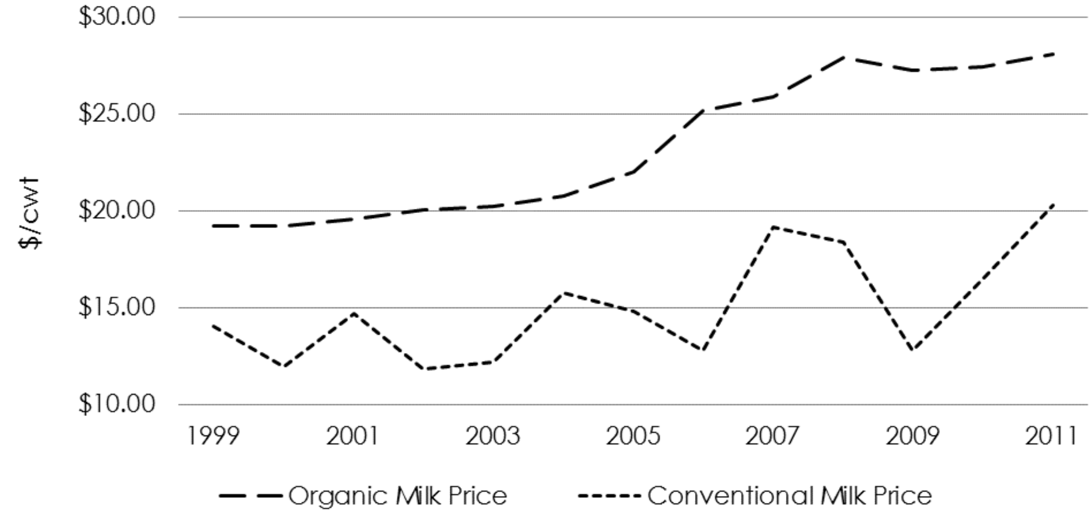

Figure 4.2: Average U.S. organic and conventional “mailbox” milk prices from 1999-2011.

erable investment cost and the riskiness of the investment, it has been shown in agricultural applications that the option value can be a significant barrier to technology adoption or land-use change. Purvis et al. (1995) found that uncertainty in dairy returns caused the rate of return required to trigger investment in technology improvements to be more than double the trigger rate in a net present value formulation of the decision problem. Tauer (2004) found that the price of milk at which dairy farmers optimally exit the industry is significantly lower than the variable cost of milk production and the price at which market entry is optimal is substantially higher than the variable cost of milk production. That is, there is a large range of prices for which neither entry nor exit is optimal. Although these studies focused on optimal investment/entry-exit behavior rather than observed management decisions, they show that the option value of delaying action could cause hysteresis in milk production.

Following the theoretical framework of investment under uncertainty (Dixit and Pindyck, 1994; Abel and Eberly, 1994), this study empirically estimates the supply response (i.e. transition) of organic dairy cows to organic and conventional milk and feed prices. Explicit allowance is made for distinct investment regimes, and investment thresholds are estimated in terms of the relative returns to organic and conventional dairy production. The threshold values are of particular interest because an accurate estimation will help predict future growth (or contraction) of domestic organic dairy production. Though Kuminoff and Wossink (2010) previously investigated the option value of waiting to convert conventional cropland to organic management, this study is the first to apply threshold estimation procedures to organic agricultural investment.

The estimation of investment thresholds and slope parameters within the distinct investment regimes is complicated by the dynamic nature of the investment decision. Since adoption rates of organic production technology are affected by the support and infrastructure supplied by existing organic farms, an appropriate estimation strategy must address the endogeneity and autocorrelation resulting from the decision model dynamics. To this end, this study adapts the threshold estimation procedure for use with endogenous regressors using a generalized method of moments (GMM) and instruments that are appropriate given the idiosyncrasies of the organic transition decision.

The essay continues with an explanation of the theoretical framework of investment under uncertainty and supply hysteresis needed to motivate the empirical analysis. The next section provides an explanation and discussion of the econometric model used to identify investment thresholds and estimate transition response within each regime. This is followed by discussion of the data and model specification, and then by a presentation of the model results. The essay concludes with discussion of the implications of the findings.

4.2 Conceptual Framework

Consider a conventional dairy farm manager who faces a decision of whether to manage the farm using organic or conventional methods. If organic management is chosen and the farm successfully navigates the organic transition period, the dairy herd can be certified as organic and the milk produced can be sold at higher prices than conventional milk (McBride and Greene, 2009). If a conventional dairy farm decides to initiate organic transition, the farm incurs transition costs, I. These costs may include the revenue lost due to a decrease in milk production during transition, the additional expense of purchasing certified organic feed, the cost of learning organic dairy management techniques, and the cost of making changes to the farm (e.g. increasing pasture area) necessary to satisfy organic regulations. Though there could be some salvage value associated with improved pasture, and some lasting value may be associated with the knowledge acquired in learning about organic management techniques, these costs are at least partially unrecoverable. It is important to note that these transition costs will vary across specific farms and different regions of the country. For example, it may be less costly for pasture based dairies in the Northeast and Upper Midwest to transition to organic production than confinement operations that have limited pasture land and a heavy reliance on purchased inputs.

It is also the case that individual dairy farms (both conventional and organic) may use different management techniques, and as a result have different levels of production per cow, ration formulations, and land requirements. However, for this simplified theoretical model these differences are unimportant and we need only assume that both organic and conventional dairy operations generate returns to management. We need not assume that these returns are independent processes but only that they are observable. Also, let us ignore the role of pasture and cropland in the provision of feed to a dairy herd and assume that all farms have access to sufficient pasture to satisfy National Organic Program rules and can thus feasibly use either production system. The decision to undergo organic transition can then be simplified to a maximization of discounted present value of the dairy operation.

Adopting the notation used by Song et al. (2011), let $V^i(\pi_c(t), \pi_o(t))$ denote the value of the dairy operation under management system i given the option of transitioning to system

j, where $\pi_c(t)$ and $\pi_o(t)$ are profits at time t to the conventional and organic systems[4.1] respectively. The dairy manager's problem can then be written as:

$$V^i(\pi_c(t), \pi_o(t)) = \\ max\left\{\pi_i(t)dt + e^{-rdt}EV^i(\pi_c(t+dt), \pi_o(t+dt)), V^j(\pi_c(t), \pi_o(t)) - I_j\right\} \quad (4.1)$$

where π_i is the current profits achieved by system i, r is the discount rate, E is the expectation operator, and I_j denotes the investment costs required to switch from system i to system j. Suppose the current state of the dairy farm is conventional management. Since the conventional dairy farmer is always free to initiate transition to organic management, the value of the conventional dairy farm is the maximum of the value of continued conventional operations and the value of organic operations net of the transition cost, I_o. The value of continued conventional operations is comprised of the flow of profits to the conventional dairy, $\pi_c(t)dt$, as well as the discounted expected future value of the farm, $e^{-rdt}EV^c(\pi_c(t+dt), \pi_o(t+dt))$. This second term is a function of both conventional and organic profits because if the conventional dairy decides not to transition at time t, it retains the option to transition in a later period. Likewise, the value of the organic dairy, $V^o(\pi_c(t), \pi_o(t))$, is a function of profits to both systems, because the organic dairy is always free to abandon organic management and revert to a conventional system. The abandonment of organic production is assumed to be costless.

The real options theory presented in Dixit and Pindyck (1994) explains that the option to transition to an alternative production system, along with transition costs and uncertainty in the return process, creates a range of conditions for which inaction is optimal regardless of the current production system. The inaction regime is bounded by an invest-

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[4.1] In reality, the profits from the transition period are distinct from organic farm profits. However, this formulation abstracts from the time dimension of the organic transition period and treats the transition as instantaneous. Decreased net returns during the transition period are included as part of the investment cost, I_o.

ment (i.e. organic transition) regime and disinvestment (i.e. organic abandonment) regime. To see this, let us assume that returns to both the organic and conventional systems follow independent processes of Geometric Brownian Motion of the form:

$$d\pi_c = \alpha_c \pi_c dt + \sigma_c \pi_c dz_c \tag{4.2}$$

$$d\pi_o = \alpha_o \pi_o dt + \sigma_o \pi_o dz_o \tag{4.3}$$

where α_i and σ_i are the drift and volatility parameters respectively for dairy production system i. The term dz_i is an increment of the Wiener process. Using Ito's Lemma, the equations that characterize a solution to the decision problem in equation (4.1) can be derived. Within the regime of inaction, in which the current production system is continued into the following period, the value function for each system must satisfy the equation:

$$\begin{aligned} rV^i(\pi_c, \pi_o) = \pi_i + \sum_i \alpha_i \pi_i \frac{\partial V^i(\pi_c, \pi_o)}{\partial \pi_i} + \sum_i \frac{1}{2}\sigma_i^2 \pi_i^2 \frac{\partial^2 V^i(\pi_c, \pi_o,)}{\partial \pi_i^2} \\ + \rho \sigma_c \sigma_o \pi_c \pi_o \frac{\partial^2 V^i(\pi_c, \pi_o)}{\partial \pi_c \partial \pi_o} \end{aligned} \tag{4.4}$$

This return equilibrium equation states that the return on an investment in the amount of the farm value when in system i (left hand side) must be equal to the returns from the optimal operation of system i (right hand side). An inequality in (4.4) would imply that gains could be made by transitioning from system i to the alternative system j.

There also must be a value-matching condition, which says that at the boundary between regimes the value of the option must be equal to the value of exercising the option. Given that the transition from a conventional system to an organic system requires transition cost I_o, the boundary between inaction and investment in organic transition the value-matching condition will be:

$$V^{c*}(\pi_c, \pi_o) = V^{o*}(\pi_c, \pi_o) - I_o. \tag{4.5}$$

However, because abandonment of organic production is costless (i.e. $I_c = 0$), at the boundary between the organic abandonment regime and the inaction regime the value matching condition will be:

$$V^{o*}(\pi_c, \pi_o) = V^{c*}(\pi_c, \pi_o) - I_c = V^{c*}(\pi_c, \pi_o). \tag{4.6}$$

Finally, the smooth-pasting condition, which requires continuity of value function slopes at the regime boundaries, is given by:

$$\frac{\partial V^c(\pi_c, \pi_o)}{\partial \pi_i} = \frac{\partial V^o(\pi_c, \pi_o)}{\partial \pi_j} \qquad \text{for } i, j \in [c, o] \text{ and } i \neq j. \tag{4.7}$$

This system of equations characterizes the solution to the dairy manager's maximization problem in equation (4.1) but it cannot be solved analytically for an application that is this complex. This conceptual model helps to illustrate how the relationship between organic and conventional dairy returns at time t will define the different regimes of investment in organic production. Letting $\rho_t(\pi_{ot}, \pi_{ct})$ denote the return to the organic system relative to the conventional system such that $\frac{\partial \rho_t(\pi_{ot}, \pi_{ct})}{\partial \pi_{ot}} > 0$ and $\frac{\partial \rho_t(\pi_{ot}, \pi_{ct})}{\partial \pi_{ct}} < 0$, there will be a threshold value of ρ_t^L below which $V^{c*}(\pi_c, \pi_o) > V^{o*}(\pi_c, \pi_o)$, and a manager of an organic dairy will revert to conventional management. There will be a second threshold value ρ_t^H above which $V^{c*}(\pi_c, \pi_o) < V^{o*}(\pi_c, \pi_o) - I_o$ and the conventional dairy manager will initiate organic transition. For $\rho_t^L < \rho_t < \rho_t^H$, equation (4.4) will hold and the manager's optimal decision will be to maintain the current system (Dixit and Pindyck, 1994). In the empirical sections that follow I will discuss the procedure for estimating the values of ρ_t^L and ρ_t^H.

4.3 Empirical Approach

There have been several studies that have estimated varying agricultural investment response within distinct regimes. Hinrichs et al. (2008) assigned data describing changes in hog stocks into regimes of investment, disinvestment and inaction and then used an ordered probit model to estimate determinants of investment behavior within the different regimes. Richards and Green (2003) use a similar method to analyze the hysteresis in California wine grape variety selection. Both studies define regimes of investment, disinvestment, and inaction and then separate their samples accordingly before estimating the investment response within each regime and testing for significance of the model relative to a model without distinct investment regimes. Alternatively, the threshold estimation procedure developed by Hansen (1999, 2000) and used by Boetel et al. (2007), Serra et al. (2009), and Adachi and Liu (2010) estimates the threshold levels directly, without having to divide the sample. This study estimates the rigidity of investment in certified organic dairy cows by drawing on the threshold estimation procedures developed for balanced non-dynamic panel data by Hansen (1999), and the extensions of this model for use with endogenous variables (Caner and Hansen, 2004) and for application to dynamic panel data (Kremer et al., 2013).

4.3.1 Threshold Estimation

The three-regime threshold model proposed by Hansen (1999) for use with non-dynamic panel data models[4.2] can be written for the case of a single regime dependent variable as:

$$\begin{aligned} y_{it} = \mu_i + \boldsymbol{\Gamma}'\boldsymbol{x}_{it} + \beta_1 z_{it} I(\rho_{it} < \rho^L) + \beta_2 z_{it} I(\rho^L \leq \rho_{it} < \rho^H) \\ + \beta_3 z_{it} I(\rho^H \leq \rho_{it}) + \epsilon_{it}. \end{aligned} \tag{4.8}$$

where y_{it} is the value of the dependent variable for cross-sectional unit i at time t, μ_i is the individual-level fixed effect, $\mathbf{x_{it}}$ is a vector of regime independent explanatory variables, and z_{it} is the regime dependent explanatory variable. Coefficient estimates for regime independent and dependent variables are denoted by $\boldsymbol{\Gamma}$ and β respectively. $I()$ is an indicator

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[4.2] i.e. a panel data model in which a lag of the dependent variable is not included as an explanatory variable.

function, ρ^H and ρ^L are the upper and lower thresholds respectively, and ρ_{it} is the value of the threshold variable for individual i at time t. The threshold variable, ρ_{it}, can also be included in the vector of explanatory variables, $\boldsymbol{x_{it}}$, or can itself be the regime dependent variable, z_{it}.

One drawback of Hansen's basic model for the application to organic dairy supply is that, with no restrictions on the regime-dependent coefficients ($\boldsymbol{\beta}$), the estimated investment response to the regime-dependent variable may be discontinuous. In particular, while the conceptual model outlined in the previous section predicts a non-negative continuous relationship between the relative profitability of organic dairy production and the stock of organic dairy cows, equation (4.8) allows a discontinuous response even if β_1, β_2, and β_3 are non-negative as expected. Given the nature of the organic transition decision, and this study's use of the number of organic milk cows as a dependent variable, it would make little sense to allow a "jump" (either upward or downward) in the predicted size of organic dairy herds as the relative milk price increases. Therefore, I impose continuity on this relationship by adapting the basic threshold model in equation (4.8) to:

$$\begin{aligned} c_{it} = \mu_i + \boldsymbol{\Gamma}'\boldsymbol{x}_{it} + \beta_1 z_{it} I(z_{it} < \hat{\rho}^L) \\ &+ \left[\beta_1\hat{\rho}^L + \beta_2(z_{it} - \hat{\rho}^L)\right] I(\hat{\rho}^L \leq z_{it} < \hat{\rho}^H) \\ &+ \left[\beta_1\hat{\rho}^L + \beta_2(\hat{\rho}^H - \hat{\rho}^L) + \beta_3(z_{it} - \hat{\rho}^H)\right] I(\hat{\rho}^H \leq z_{it}) + \epsilon_t \end{aligned} \tag{4.9}$$

where c_{it} is the number of certified organic dairy cows in state i in year t. The vector of regime independent variables, $\boldsymbol{x}_{it}$ includes a lag of the dependent variable, $c_{i,t-1}$ and the ratio of organic to conventional dairy returns serves as both the threshold variable, ρ_{it}, and the regime dependent variable, z_{it}. Note that by adding the constant term $\beta_1\hat{\rho}^L$ to the term interacted with the indicator function for the "middle" investment regime, the linear relationship between regime dependent variable z_{it} and dependent variable c_{it} is forced to

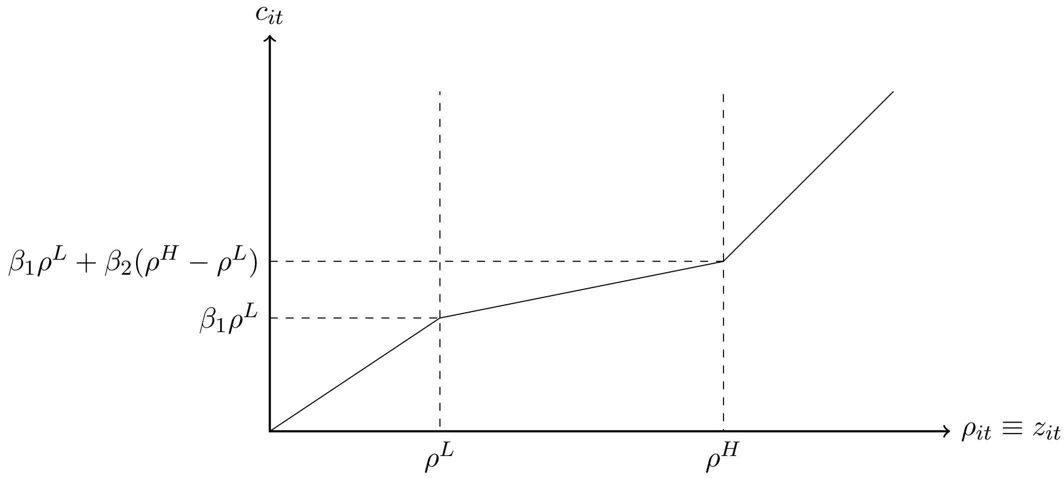

Figure 4.3: Demonstration of the imposed continuity in the double threshold model.

begin in the middle regime where the "low" regime investment left off at the threshold $\hat{\rho}^L$. This piecewise linear function has another kink at the upper investment threshold, $\hat{\rho}^H$, after which it continues at slope β_3. This is shown graphically in figure 4.3. A single threshold model can be similarly adapted to impose continuity across two regimes, and can be written formally as:

$$c_{it} = \mu_i + \mathbf{\Gamma}'\boldsymbol{x}_{it} + \alpha_1 z_{it} I(z_{it} < \rho) + [\alpha_1\rho + \alpha_2(z_{it} - \rho)]\, I(\rho \leq z_{it}) + \epsilon_t. \tag{4.10}$$

It should be noted that the conceptual model presented earlier predicts a regime of inaction in which the representative farm neither invests or disinvests in organic dairy production. Thus, at the farm level, the coefficent β_2 should be equal to zero and the segment of figure 4.3 where $\rho^L \leq \rho_{it} < \rho^H$ should be a horizontal line. At the state-level, we might expect some small changes in the aggregate organic dairy herd size, and we can think of this as a "sluggish investment regime" rather than a regime of "inaction". Further discussion of the model specification and explanatory variables will come in the following subsection.

The threshold values (ρ in the single threshold model and ρ^k for $k = L, H$ in the double threshold model) are estimated by choosing those from the set of unique values of the threshold variable that minimize the sum of squared residuals. The model is restricted to consider only thresholds that result in at least 5% of the sample in each regime. Once threshold estimates are obtained, they are tested for significance using a likelihood ratio test with a bootstrap procedure proposed by Hansen (1999). A test for the significance of the single threshold in equation (4.10) is simply the test of the null hypothesis:

$$H_0 : \alpha_1 = \alpha_2. \tag{4.11}$$

The hypothesis is tested using a likelihood ratio test in which (4.10) is compared to a model without a threshold, based on the test statistic:

$$F_1 : \frac{S_0 - S_1(\hat{\rho})}{\hat{\sigma}^2_{\hat{\rho}}} \tag{4.12}$$

where S_0 and $S_1(\hat{\rho})$ are the sum of squared residuals from the estimation of the zero and single-threshold models respectively, and $\hat{\sigma}^2_{\hat{\rho}} = \frac{S_1(\hat{\rho})}{n(T-1)}$ is the residual variance from the alternative hypothesis.

When a second threshold is added to the model, as in equation (4.9), the significance of the second threshold is tested by holding the first threshold constant and repeating the grid search procedure described above for a second threshold, choosing the second threshold that minimizes the sum of squared residuals. The test for significance of the double threshold model is performed much like that for the single-threshold model. The test statistic for the double threshold model is:

$$F_2 : \frac{S_1(\hat{\rho}_1) - S_2(\hat{\rho}_2)}{\hat{\sigma}^2_{\hat{\rho}_2}}. \tag{4.13}$$

Additional thresholds can be added, with the model significance tested in the same way, though this study considers only single and double threshold models.

As explained by Hansen (1996, 1999), because no threshold is identified under the null hypothesis in equation (4.11), the asymptotic distribution of the test statistic in equation (4.12) is non-standard and critical values for an F-test cannot be calculated. Hansen therefore suggests using a bootstrap procedure to obtain asymptotically valid critical values. The bootstrap method treats the regressors and threshold variable as constant, then draws repeated samples with replacement from the regression residuals, grouped by individual. Using these errors, many bootstrapped samples of the dependent variable are created and the LR test statistics are compared to that calculated using the threshold estimate (e.g. equation (4.12)). This bootstrap procedure is repeated 300 times for each threshold significance test.

4.3.2 Adaptation for Dynamic Panel Data

In Hansen's original formulation, the threshold model is estimated by least squares following the "within" transformation of panel data to remove the individual level fixed effects. The fixed effects transformation removes the within group mean from each observation, and is performed following the interaction of the regime dependent variables with the threshold indicator variables. The within transformation for equation (4.8) is given by:

$$(y_{it} - \bar{y}_i) = \mathbf{\Gamma}'(\boldsymbol{x}_{it} - \bar{\boldsymbol{x}}_i) + \beta_1(z^l_{it} - \bar{z}^l_i) + \beta_2(z^m_{it} - \bar{z}^m_i) + \beta_3(z^h_{it} - \bar{z}^h_i) + (\epsilon_{it} - \bar{\epsilon}_i). \tag{4.14}$$

where $z^l_{it} = z_{it}I(\rho_{it} < \rho^L)$, $z^m_{it} = z_{it}I(\rho^L \leq \rho_{it} < \rho^H)$, and $z^h_{it} = z_{it}I(\rho^H \leq \rho_{it})$. Given the least squares estimation procedure used to identify threshold estimates, Hansen's original method is limited to non-dynamic panel data to avoid violating the standard non-autocorrelation assumption: $\mathbb{E}[\epsilon_{it}\epsilon_{is}|\boldsymbol{x_{it}, z_{it}}] = 0$ for $t \neq s$. If a lag of the dependent variable is included in $\boldsymbol{x_{it}}$, as in a dynamic panel, the within transformation causes the correlation of not only ϵ_{it} and ϵ_{it-1}, but of ϵ_{it} and ϵ_{is} for all $t \neq s$ through the transformed error term, $\bar{\epsilon}_i$.

Previous research on organic dairy transition has shown that the maturity of the local organic industry positively impacts transition rates through a "neighbor effect" (Lewis et al., 2011). One would also expect institutional support and organic supply chains to be more robust in states with more existing organic dairy cows. Thus, state wide organic dairy transition is best modeled as a dynamic process, in which the growth or contraction of the state's organic dairy industry responds to market conditions and the size of the state's existing herd. To avoid the inconsistent estimators that would result from using the within transformation to eliminate the fixed effect in a dynamic panel, I follow Kremer et al. (2013) and Arrelano and Bover (1995) and apply a forward orthogonal deviations transformation in place of the within transformation. The forward orthogonal transformation subtracts the individual mean of future observations rather than the mean of all observations, which removes the individual fixed effect while avoiding autocorrelation of the transformed error terms. The forward orthogonal deviations transformation of the error term for group i at time t is given as:

$$\epsilon^*_{it} = \sqrt{\frac{T-t}{T-t+1}}\left[\epsilon_{it} - \frac{1}{T-t}(\epsilon_{it+1} + \cdots + \epsilon_{iT})\right] \tag{4.15}$$

where the first term is a weighting function, required to equalize the variances.

Although the forward orthogonal deviations transformation allows the removal of the individual fixed effect from the dynamic panel without introducing autocorrelation, there remains endogeneity introduced by the lagged dependent variable on the right hand side. Caner and Hansen (2004) developed a technique to use instrumental variables (IV) in a cross-sectional threshold model with an endogenous explanatory variable and an exogenous threshold variable. This was then adapted for use in a dynamic panel by Kremer et al. (2013). Following these authors I estimate the threshold values using a 2SLS estimation, in which the endogenous lagged dependent variable is regressed on an all exogenous vari-

Table 4.1: Summary statistics for dependent and independent variables ($n = 23$, $T = 10$).

Variable	Obs	Mean	Std. Dev.	Min	Max
Organic cows in state	230	6,914	9,817	0	57,809
Net change in organic cows	230	871	4,127	-11,618	47,387
Organic milk price ($/cwt)	230	24.48	3.48	18.99	30.04
Conv. milk price ($/cwt)	230	15.44	3.06	10.88	22.00
Organic:Conv. milk price ratio	230	1.62	0.28	1.20	2.42
Organic IOFC ($/cow/day)	230	5.88	1.14	3.90	8.89
Conv. IOFC ($/cow/day)	230	5.39	1.25	2.79	8.11
Organic:Conv. IOFC ratio	230	1.16	0.37	0.61	2.41

ables, including regime dependent variables and an excluded instrument, then replace the lagged dependent variable in the structural equation with the fitted values from the first stage regression. Both stages of the estimation procedure are repeated with each unique value of the threshold variable, and the threshold value that minimizes the sum of squared residuals in the second stage is selected as the threshold estimate. Once the thresholds are estimated, the model is re-estimated using a more efficient GMM procedure to obtain the slope estimates (Roodman, 2006, Kremer et al., 2013).

4.3.3 Data and Model Specification

To estimate the organic dairy transition response to organic and conventional market conditions we need a measure of investment in organic dairy production, data describing the relative returns to the two production systems, and information to account for other contextual issues or exogenous shocks that may affect the rate of transition. This study uses publicly available panel data on the number of certified organic dairy cows in each state from 2000 to 2011 to represent investment in organic dairy production (USDA-ERS, 2013). The dependent variable is the number of organic dairy cows in each state, c_{it}. A complication in estimating the investment in organic dairy production at the aggregated state level is that many states have very small organic dairy industries. Five states had not had any certified

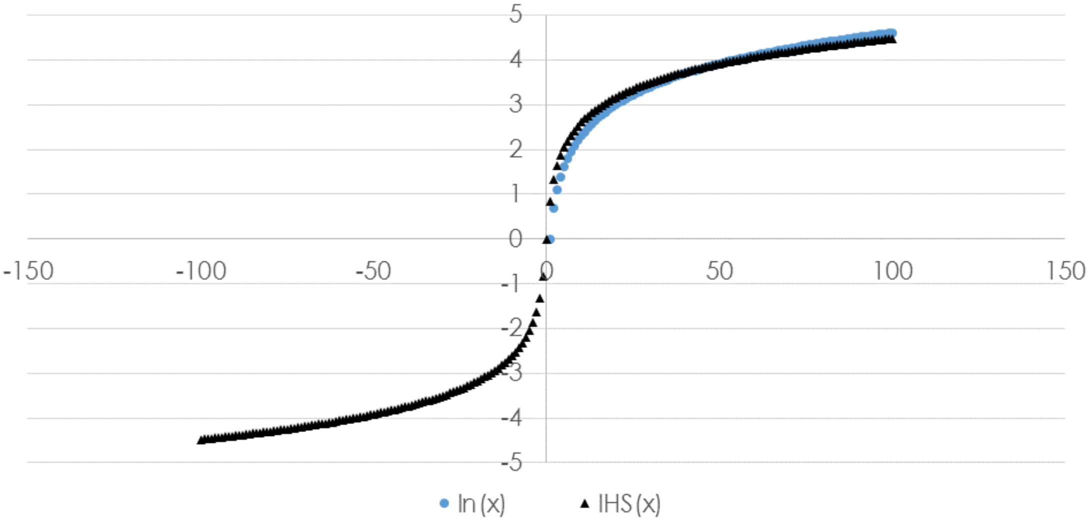

Figure 4.4: Inverse hyperbolic sine (IHS) and log transformations for values -100 to 100.

organic milk cows as of 2011, and 27 states had fewer than 1,000 organic milk cows in every year from 2000 to 2011. All 27 of these states are excluded from the sample. Even across the remaining 23 states with relatively robust organic dairy industries, there is a large range of industry size (see summary statistics in Table 4.1). While a log transformation of c_{it} helps to normalize the distribution of the model's error term, it also requires the removal of an additional 8 states from the sample that have zero cows in at least one year, leaving only 15 states. An alternative transformation that would allow the retention of all 23 states in the sample is the inverse hyperbolic sine (IHS) transformation, proposed by Johnson (1949) and re-examined by Burbidge et al. (1988). The IHS transformation is given for y with parameter θ as:

$$g(y_{it}, \theta) = \frac{\ln\left(\theta y_{it} + \sqrt{\theta^2 y_{it}^2 + 1}\right)}{\theta}. \tag{4.16}$$

The IHS transformation can be applied to positive, negative, and zero values, and except for small values of $|y|$, mimics $\ln(y)$ and -$\ln(|-y|)$ for positive and negative y, respectively. The transformation also has the property of mapping 0 to 0. A comparison of the log and

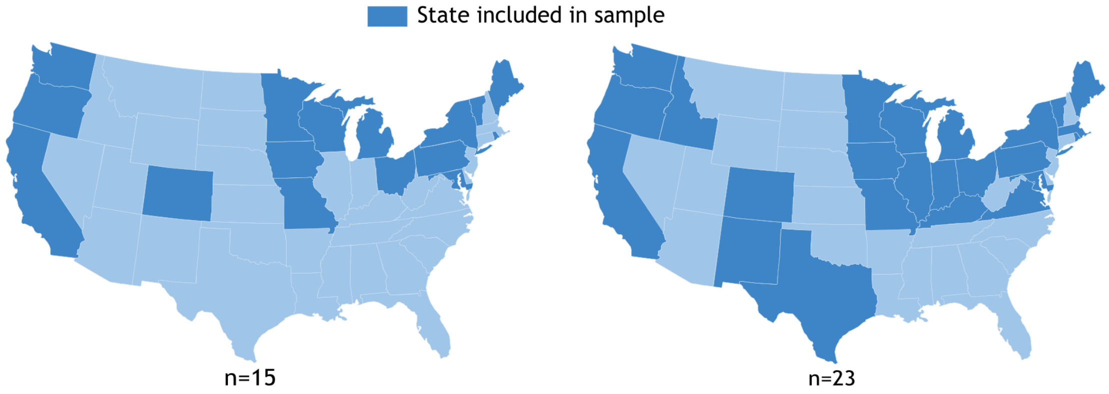

Figure 4.5: Map of states included in reduced ($n = 15$) and full ($n = 23$) samples.

IHS transformations is presented graphically in figure 4.4. For this application, θ is chosen so that $g(\widetilde{cows}_{it}, \theta) = \ln(\widetilde{cows}_{it})$ where $\widetilde{cows}_{it}$ is the median number of organic cows across all states and years. I present the results from the IHS transformation (with larger sample) in the results section that follows and the log transformation (with smaller sample) in the appendix. The states included in the full and reduced samples are shown in figure 4.5. The explanatory variable of primary interest is the relative returns to organic and conventional dairy production. One widely used measure of dairy profitability is the daily income over feed cost (IOFC) per cow (Wolf, 2010). The IOFC measure is calculated using the daily quantity of milk produced per cow along with the market prices of a standard feed ration and the average milk price received by the farmer. Though this measure can provide a reasonable representation of average dairy profitability, it obscures farm-level differences in feed rations and productivity per cow. Since organic dairy farms are more likely than conventional dairy farms to graze their herds and feed a ration with a higher proportion of hay and pasture, an IOFC calculation using the standard ration is not appropriate for organic dairy farms, even if organic prices are used. However, significant heterogeneity of organic dairy farms makes it difficult to settle on an alternate representative ration. An alternative to using a ratio of organic to conventional IOFC is to simply use the ratio of organic milk price to conventional milk price. Since many dairy farms that decide to transition to organic production grow a significant amount of their own feed, they are likely less concerned with feed costs than they are with the prices that they can receive for their milk production. Thus, one would expect organic transition rates to be more closely related, at least at the aggregate state level, to the relative milk prices than to the IOFC measure. I use the milk price ratio as the threshold variable and the regime-dependent variable (ρ_{it} and z_{it}) in the baseline model, and I report the results using the organic to conventional IOFC ratio in the appendix.

An understanding of the timing of an organic transition decision is necessary to accurately model investment in organic production. It is certainly intuitive that the dairy manager's transition decision is made for year t based on the market conditions experienced prior to year t. The technical and financial planning required for a successful organic transition is complex, and farmers likely actively consider and research organic production systems for several years before they are finally certified. However, because cropland must be managed organically for three years and livestock must be managed organically for one year before organic certification can be achieved, the years $t-3$ and $t-1$ are particularly relevant to the decision to adopt an organic dairy system. Although many farms take three years to transition both their cropland and dairy herds, others may transition their cropland only to decide not to transition the dairy herd if market conditions are no longer favorable. In these cases, the conditions in year $t-1$ are more relevant to the transition decision. Moreover, since there is no delay in the abandonment of certified organic management, market conditions in $t-1$ are more relevant than those in $t-3$ for the abandonment decision. Therefore, I use the one-year lag of the milk price ratio as the primary explanatory variable in the baseline model but also include a three-year lagged value as a regime-independent explanatory variable. One would expect a positive sign on both of these variables, which would indicate that transition rates increase as organic dairy production becomes more profitable relative to conventional production.

Dummy variables for the years 2008, 2009, and 2010 are also included as regime-independent explanatory variables. I include a dummy variable for 2008 because this year saw the expiration of the "80-20" rule, which allowed transitioning farms to feed 20% conventional feed during the first nine months of the year long transition (USDA-AMS, 2006). Since the expiration of this rule caused transition costs to increase, many farms rushed to transition before the rule expired, and a positive sign is expected on the 2008 dummy variable. Years 2009 and 2010 saw decreased consumer demand for organic milk as a result of the economic recession. In response, most organic dairy processors introduced supply controls during this time and temporarily ceased enrolling new farmers in their production pools (Li et al., 2012). Moreover, the organic cow data is unavailable for 2009. Based on discussions with USDA officials and organic dairy industry experts, I have set the number of organic cows in each state in 2009 equal to the number observed in 2008, reflecting no net change in organic dairy herds in 2009. I expect negative coefficient estimates on both of these years' dummy variables. Again, a one year lag of the number of organic cows in the state is included to account for the maturity of the local organic dairy industry. As with the dependent variable, this variable is transformed by the IHS transformation in the baseline model. As discussed in the preceding section, this variable is endogenous by construction and will be replaced in the structural model by the fitted values from the first-stage regression.

4.3.4 Endogeneity and Dynamics of Organic Transition Decision

It is common in some applications using dynamic panel data to instrument a lagged dependent variable with a larger lag of the same variable. Under the assumption that the further lagged dependent variable, say $c_{i,t-2}$, is uncorrelated with subsequent error terms from the structural model, $u_{i,t-1}, u_{it}, \ldots, u_{iT}$, this technique will yield consistent estimates (Bond, 2002). In our application however, this is not an attractive option. Given that cropland requires a three-year transition period before organic certification can be achieved, even a three-year lag of the dependent variable ($c_{i,t-3}$) would likely be at least weakly endogenous, and would therefore not be a valid instrument. Using a larger lag, say $c_{i,t-4}$, as an instrument for $c_{i,t-2}$ may be valid, but would require the discard of an additional two years of data, leaving only 2004-2010[4.3].

Instead, the lagged number of conventional dairy cows in the state is used as an instrument for the lagged number of organic dairy cows (USDA-NASS, 2014). Organic and conventional dairy industries are effected by similar commodity market and dairy industry forces and the size of state herds of organic and conventional milk cows are likely correlated. The validity (i.e. exogeneity) of this instrument is also likely, as there is no reason that changes in the size of a state's conventional dairy herd would significantly affect the size of the state's organic dairy herd. Although most newly certified organic milk cows were previously conventional milk cows, the small number of cows certified each year relative to conventional herd sizes is small enough that endogeneity is unlikely.

4.4 Results

This section presents the threshold estimation results and the slope estimates for the zero-threshold, single-threshold, and double-threshold models. I will first address the results from an OLS estimation that avoids autocorrelation by removing the state fixed effect with a forward orthogonal transformation, but ignores the endogeneity introduced by the lagged dependent variable, $c_{i,t-1}$. These results will be compared to that of the baseline GMM estimation which controls for this endogeneity by instrumenting for the endogenous variable with the number of conventional milk cows in the same year, $t-1$. The appendix includes threshold and slope estimates for additional specifications that use i) the log transforma-

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[4.3] The final year, 2011, is dropped as a result of the forward orthogonal transformation.

tion with a reduced sample rather than the IHS transformation on the full sample, ii) the organic:conventional IOFC ratio as the threshold variable rather than the milk price ratio, and iii) a GMM estimation using lags of the endogenous variable beginning with $c_{i,t-4}$ to instrument for $c_{i,t-1}$ lag in the structural equation.

Table 4.2 reports the results of the OLS fixed effects estimation of the zero-threshold, single-threshold, and double-threshold models. The regime-independent coefficient estimates are largely consistent across threshold specifications. In the zero-threshold model the coefficients on both the one-year and three-year lagged milk price ratios are positive, and the coefficient on the one-year lag is significant at the 0.10 level. This suggests that, as expected, higher organic milk prices, relative to conventional milk prices, encourage organic transition in subsequent periods. The yearly dummy variable coefficient estimates also have the expected signs: positive and strongly significant for 2008, and negative though not statistically significant for the recession years of 2009 and 2010. The coefficient on the lagged dependent variable is 0.644 and highly significant, suggesting that only 60% of the state's organic dairy cow herd can be attributed to the size of the herd in the previous year. Given the earlier discussion of the positive network effects on organic transition rates and the findings of Lewis et al. (2011), one might expect a coefficient greater than 1.0 on the lagged number of cows, suggesting exponential growth. It is likely, however, that these coefficient estimates reflect the slowing growth rate and even reductions in the size of state-wide herds in latter years of the sample, especially in states with larger industries. Indeed, the more cows that are certified as organic in a state, the more cows that can be transitioned back to conventional management.

Table 4.2 also presents the OLS threshold estimates for the single and double threshold models. The results from the single threshold model imply that when the organic to conventional milk price ratio surpasses 1.303 there is a break in the relationship between the milk price ratio and the size of the state's organic dairy herd. The theory is ambiguous

Table 4.2: OLS estimation of zero-threshold, single-threshold, and double-threshold models; $g()$ = IHS transformation.

Dependent Variable: Number of Organic Milk Cows in State, $g(c_{it})$			
	Zero threshold	Single threshold	Double threshold
Threshold estimates			
$\hat{\rho}$	–	1.303	–
$\hat{\rho}^L$	–	–	1.250
$\hat{\rho}^H$	–	–	1.303
Regime-independent variables			
$g(c_{i,t-1})$	0.644$***$	0.653$***$	0.655$***$
	(0.077)	(0.077)	(0.076)
Milk price ratio $(t-3)$	0.914	0.986	1.030
	(0.680)	(0.674)	(0.674)
2008	0.808$***$	0.857$***$	0.832$***$
	(0.295)	(0.298)	(0.291)
2009	−0.092	−0.062	−0.045
	(0.399)	(0.398)	(0.391)
2010	−0.079	−0.189	−0.238
	(0.337)	(0.343)	(0.340)
Milk price ratio $(t-1)$	0.918$*$		
	(0.475)		
Regime-dependent variables			
α_1		−7.554	
		(6.132)	
α_2		1.219$**$	
		(0.518)	
β_1			20.538
			(20.100)
β_2			−21.004$***$
			(7.627)
β_3			1.370$***$
			(0.526)
Threshold significance (P-value)			
Against H_0 of zero thresholds	–	0.387	–
Against H_0 of one threshold	–	–	0.157
Observations	207	207	207

Standard errors in parentheses

* p<0.1, ** p<0.05, *** p<0.01

as to whether the effect should be stronger above or below this threshold, but the effect should be non-negative in both regimes. Although the slope below the threshold, $\hat{\alpha}_1$, is not significantly different from zero and the slope above the threshold, $\hat{\alpha}_2$, is positive, the lower portion of table 4.2 shows that the threshold model itself is not close to significantly different from the zero-threshold model (P-value: 0.387). Similarly, with a P-value of 0.157, the double threshold model is not significantly different than the single threshold model and the regime dependent slopes (β_1, β_2, and β_3) are not meaningful.

As noted earlier, the OLS estimates are biased and inconsistent because of the endogeneity and autocorrelation introduced by the lagged number of organic cows on the RHS of equation (4.9). To obtain consistent threshold and coefficient estimates, the model is estimated using a GMM procedure in which the lagged number of conventional milk cows is used to instrument for the endogenous variable. The GMM threshold estimation results for the zero-threshold, single-threshold, and double-threshold models are presented in Table 4.3. As with the OLS estimation, results for the regime-independent variables do not change substantially across threshold specifications and the signs of the coefficient estimates in the zero threshold model are as expected. In contrast with the OLS estimation, the primary explanatory variable (lagged milk price ratio) is not significant at even the 10% level in the GMM model, and the 2008 dummy variable is significant only at the 5% level. One advantage of the GMM estimation procedure over a 2SLS framework, in addition to the efficiency gains had by including additional instruments, is the ability to test for the validity of instruments. A Sargan over-identification test based on the GMM estimation fails to reject the null hypothesis of exogenous instruments, supporting the validity of the identification strategy.

Also like the OLS model, the GMM estimation results provide no support for either a single or double threshold in the organic dairy supply model. The threshold estimate for the single threshold model is an organic to conventional milk price ratio of 1.853, which falls

Table 4.3: GMM estimation of zero-threshold, single-threshold, and double-threshold models; $g() =$ IHS transformation.

Dependent Variable: Number of Organic Milk Cows in State, $g(c_{it})$	Zero threshold	Single threshold	Double threshold
Threshold estimates			
$\hat{\rho}$	–	1.853	–
$\hat{\rho}^L$	–	–	1.303
$\hat{\rho}^H$	–	–	1.853
Regime-independent variables			
$g(c_{i,t-1})$	0.722$***$	0.726$***$	0.747$***$
	(0.078)	(0.078)	(0.079)
Milk price ratio $(t-3)$	0.742	0.684	0.691
	(0.681)	(0.691)	(0.687)
2008	0.670$**$	0.680$**$	0.757$**$
	(0.317)	(0.319)	(0.317)
2009	−0.153	−0.138	−0.076
	(0.401)	(0.403)	(0.401)
2010	−0.145	−0.030	−0.013
	(0.353)	(0.412)	(0.409)
Milk price ratio $(t-1)$	0.752		
	(0.492)		
Regime-dependent variables			
α_1		0.875	
		(0.542)	
α_2		0.138	
		(1.228)	
β_1			−10.755$**$
			(5.357)
β_2			1.471$**$
			(0.598)
β_3			−0.370
			(1.247)
Threshold significance (P-value)			
Against H_0 of zero thresholds	–	0.640	–
Against H_0 of one threshold	–	–	0.180
Observations	207	207	207

Standard errors in parentheses

* p<0.1, ** p<0.05, *** p<0.01

in the top half of price ratio values (Table 4.3). While positive in sign, neither of the regime dependent slopes is statistically significantly different from zero. Moreover, with a P-value 0.640, the null hypothesis in equation (4.11), that there is no threshold, cannot be rejected. Boetel et al. (2010) argue that even if the null hypothesis of no single threshold cannot be rejected, it might be because the double-threshold model is the true model, resulting in inconsistent estimates in the single threshold model. Thus, I proceed to test the double-threshold model against the single-threshold model. In this application, however, the second likelihood ratio test also results in failing to reject the null hypothesis (P-value = 0.180) and two of the three regime dependent slope coefficient estimates are of the wrong sign. With this specification and estimation strategy there is no evidence of distinct organic transition regimes in terms of organic to conventional milk price ratio. The alternative specifications, whose results are presented in the appendix, are broadly consistent with the results of the OLS and GMM estimation results presented here.

4.5 Discussion and Conclusion

The objective of this study is to frame the decision to transition from conventional to organic dairy management in the context of the theory of investment under uncertainty, and to estimate the investment thresholds that bound the regime of inaction that is predicted by the theory. Although organic dairy supply has seemed slow to respond to past changes in consumer demand, and organic transition has been previously discussed in the context of real options theory, this is the first study to apply threshold estimation techniques to the investment in organic certification. The estimation of the transition thresholds in particular, and the organic transition response to changing market conditions in general, is complicated by the complex timing of the organic transition decision and the dynamic nature of the organic industry's growth. Thus, adaptations of the threshold estimation methods for use with dynamic panel data are used to estimate the proposed organic investment models.

This study is not the first to apply real options theory to management decisions in the U.S. dairy industry. Tauer (2004) showed that conventional dairy farmers' optimal entry and exit decisions can entail forgoing more profitable options in the short-term due to the uncertainty of future returns. Purvis et al. (2005) used simulations to show that optimal capital investments on dairy farms also fall into distinct regimes consistent with real options and adjustment cost theory. Despite the predictions of established theory and previous applications to investment in dairy production, this study finds no evidence of distinct regimes in the transition from conventional to organic dairy production. This suggests that there may be fundamental differences between the organic transition decision and other investment decisions that dairy farmers face.

There are several issues relevant to the organic transition decision that are likely to pull aggregate investment in organic certification away from theoretically predicted outcomes. First, there is a fairly complex relationship between organic milk producers and processors that may serve to blur the causal relationship between dairy profitability and transition rates. Not only must farmers want to produce organic milk, but one of the small number of organic dairy processors must also be willing to purchase their organic milk. Since organic dairy processors must sell any surplus milk for a loss on the conventional milk market, supply is tightly controlled. Even if farmers decide to seek higher milk prices by transitioning their dairy herds to organic status, they may have to wait to initiate transition, for several months or longer until an agreement has been made with an organic processor. While this doesn't necessarily weaken the relationship between organic dairy profitability and transition, it may make the relationship harder to detect in empirical data.

Second, there are some farmers who pursue organic certification for reasons other than profit maximization. Of course, organic dairy farms seek profits, and this study's results confirm a positive effect of organic profitability on transition rates in subsequent years. However, social science research has repeatedly shown that perceived environmental, health, or other benefits are also important factors in many farmers' organic transition decisions (e.g. Lapple and Rensburg, 2011; Duram, 2000). Similarly, many conventional farmers may not consider organic production as a viable alternative, despite potential financial gains, because of social pressures or philosophical objections to organic management in general (Brock and Barham, 2013). This suggests that, even if encouraging further organic transition remains a policy goal, there are few easy options that would result in additional organic production in the near term.

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5 Barriers to Organic Transition

The essays is Chapters two, three, and four have something in common; they highlight ways in which the optimal outcome of the organic transition decision seems to differ from the observed transition behavior of farms in the United States. Chapter two shows that an organic cropping system can outperform a conventional system even when managed on fewer acres. This result is surprising given the relatively low percentage of the nation's cropland that has been certified as organic. The analysis in Chapter three focuses on the option value created by the cost and uncertainty associated with the transition decision itself, and shows that this is a significant barrier to organic adoption, especially for large farms. Although this study provides some explanation for the growing difference between consumer demand for organic foods and organic production, results show that organic management is still optimal in a fairly large percentage of simulated outcomes. Chapter four uses empirical data on the number of organic milk cows over time to try to identify organic adoption behavior consistent with the theory of investment under uncertainty (i.e. distinct regimes with varying transition response). While simulated outcomes of the organic transition decision in Chapter three are consistent with the theoretical predictions, the analysis in Chapter four returns no evidence of distinct regimes of disinvestment, inaction, and investment.

Although there has been little previous research on the economics of transition to organic agriculture, there have been more studies that have focused on the attitudes and motivations of organic and conventional farmers with respect to organic adoption. Many studies have addressed the environmental and health focus of organic farmers, the perceptions of organic systems held by conventional farmers, and the institutional and production challenges faced by transitioning and established organic farms (e.g. Constance and Choi, 2010; Cranfield et al., 2009; Duram 2000; Fairweather 1999). These qualitative analyses, many from the field of rural sociology, do not compete with the economic analyses presented in this dissertation to explain sluggish organic transition. Rather, they add context that can enrich the economic models and the interpretation of the results offered here. The objective of this chapter is to tie together the quantitative studies of risk, returns, and transition costs from Chapters two through four with the broader literature on organic adoption. The result will be an improved understanding of the organic transition decision and the complex factors involved in modeling the economics of organic adoption.

5.1 Skepticism regarding the Sustainability of Organic Returns

Though some organic farmers have environmental or health motives for managing their farms with diverse crop rotations and without synthetic chemical inputs, many farmers also do so to receive organic price premiums (Läpple and Van Rensburg, 2011; Padel, 2001). For these farms, the attractiveness of the organic system is dependent on the organic prices and the organic yields that can be expected once transition is complete. Although there are some recent data available on organic price premiums received by existing organic farms, given the relatively small size of the organic sector, these data might not accurately describe the full distribution of possible price outcomes. Moreover, there may be a higher probability of fundamental shifts in organic prices than in conventional prices in the long term. If consumer preferences change away from organic foods[5.1], organic prices could fall, eroding the attractiveness of an organic system to a profit-maximizing farmer. Indeed, Constance and Choi (2010) report that more than half of the conventional farms that did not consider organic transition believe that organic markets are unreliable.

Other sources of uncertainty faced by conventional farmers considering transition to organic production are related to the lack of familiarity with technical aspects of organic production methods and concerns about the sustainability of crop yields without chemical pest control. Multiple studies of survey and interview data from conventional farmers report that many do not consider organic agriculture to be "technically feasible" (Khaledi et al.,

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[5.1] For example, there is considerable concern in the organic community regarding food labels promising "natural" or "GMO-free" products, which may act as substitutes for certified organic products.

2007; Fairweather, 1999; Constance, 2010). Furthermore, there is evidence to suggest that some farmers believe that organic farms benefit from their conventional neighbors' pesticide applications through reduced pest populations (Fairweather, 1999). Implicit in this belief is the view that observed organic yields would not be sustainable if organic production became widespread.

Skepticism of the long-term financial returns to organic production fits quite well with the dynamic programming model of organic transition developed in Chapter three. In that study, the relative profitability of organic crop production is uncertain and varies over time, but the range of possible return outcomes is constructed using empirical price and yield data. The concerns discussed in this subsection represent organic price and yield uncertainty that is not necessarily captured by existing data. Because greater uncertainty makes the option to delay transition more valuable, and thus increases the level of expected organic returns needed to induce adoption, the results presented in Chapter three may overstate the probability that organic management is optimal for skeptical farms.

5.2 Lack of Accessible Organic Network

In regions with relatively high concentrations of organic farmers, it may not be difficult to find others with whom to discuss production methods, marketing, and regulatory challenges related to organic production. In fact, Lewis et al. (2011) found that the number of neighboring organic dairy farms has a positive and significant effect on the probability that a conventional dairy farm initiates organic transition. The authors attribute this effect to the assistance and support that is available when nearby farms have experience in complex organic methods. Institutional support, in the form of university-based agricultural extension programs and state transition assistance efforts, may also be more robust in states that have a higher number of organic producers (Duram, 2000). Research suggests that this extension support can help induce further transition (Lohr and Salomonsson, 2000) and that a lack of institutional support poses a serious challenge for existing organic producers (Cranfield et al., 2010).

Thus, farms that are located in areas that have few established organic farms likely experience the underdeveloped organic sector as a barrier to organic transition. The barrier posed by a small or non-existent local network of organic farming neighbors is closely related to the uncertainty regarding the sustainability of organic production discussed in the previous subsection. The uncertainty of organic price and yield outcomes is likely perceived as greater by a farm with little interaction with organic growers than by farms with many organic neighbors. Furthermore, areas with few organic farms are perhaps more likely to experience social opposition to organic farming in general. Padel (2001), in her application of diffusion of an innovation theory to organic adoption, concludes that early opposition to organic production within the larger agricultural community likely slowed the diffusion of the production system.

5.3 "Hassle Factor"

Achieving organic certification involves a significant amount of paperwork and record keeping that is not required of conventional growers. Organic growers, and farms in the process of organic transition, must keep detailed records on all inputs that are applied to their cropland, as well as crop rotation information and plans to avoid commingling of organic and conventional crops. Organic farms have to allow annual inspections to maintain organic certification, and must report any issues with pesticide drift which might impact certification status (USDA-AMS, 2013). Organic livestock producers must also source organic feed for their animals, which can be difficult in times of poor local yields or in areas with few organic crop farms. Not only is acquiring inputs more difficult for organic farmers, so too is marketing organic outputs. Because the infrastructure and markets are less robust for organic commodities, organic farmers report spending much more time and effort marketing their crops than they did when they farmed conventionally (Sierra et al., 2008).

These management requirements can all be considered part of the "hassle factor"[5.2] associated with maintaining organic certification. In surveys of farms in California that abandoned their organic certification, regulatory hurdles were the most commonly cited reason to revert to conventional production (Sierra et al., 2008). In Canada, organic farmers reported that challenges related to marketing organic farm products were more serious than production related challenges (Cranfield et al., 2010). It is clear that the prospect of navigating unfamiliar regulatory hurdles and marketing processes could push the marginal farm to forgo organic transition. Though the "hassle factor" quite clearly represents additional management expenses that should be considered in a comparison of system profitability such as those presented in Chapters two and three, defining and quantifying management costs is difficult due to the current lack of detailed data on organic management. It is likely that the exclusion of these costs from the comparative profitability studies results in an overstatement of the attractiveness of organic crop production.

5.4 Institutional Barriers

Real or perceived differences in institutional support for conventional and organic production may act as additional barriers to organic adoption. These differences include federal programs such as the Federal Crop Insurance Program, as well as production support via public and private research and extension. Federally subsidized crop insurance products have become a significant source of support for conventional crop farmers (Coble and Barnett, 2013). Although published loss-ratios for conventional crop insurance have been below 1.0 for most of the past decade, suggesting that collected premiums exceed paid indemnities, these figures exclude premium subsidies intended to make insurance products more affordable for farmers. In fact, crop producers usually receive a positive net return on insurance

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[5.2] I borrow this phrase from Carmen Fernholz, University of Minnesota Organic Coordinator for Research Management and long-time organic crop producer.

policies, making the crop insurance program not only a risk management tool but also a farm subsidy program (Sherrick and Schnitkey, 2013). While organic crop producers are also eligible to purchase organic crop insurance policies, participation rates are much lower than among conventional crop farms. This is partly due to the fact that diverse organic rotations often include crops for which attractive insurance options are not available, but also because many organic farmers believe that the organic policies are too expensive or provide inadequate coverage (Singerman et al., 2010). Thus, as federal farm policy has shifted away from direct payment subsidies, for which organic producers were eligible if their land had a history of commodity program participation, to indirect subsidies through the crop insurance program, organic farmers may be receiving (or believe that they are receiving) a smaller slice of the "subsidy pie".

Another potential institutional barrier is the disparity in research and outreach to which organic and conventional producers have access. Although there have recently been significant increases in grant funding directed towards public research in organic agriculture[5.3], there is a common feeling in the organic community that too little practical research has been directed towards improving crop varieties and production practices for organic farmers (Kuepper and Gegner, 2004; Organic Farming Research Foundation, 2014). Although I am aware of no studies that systematically compare funding for organic and conventional crop production research, a perceived lack of research support may contribute to concerns about the long term viability of organic systems.

5.5 Philosophical Objections

"Can organic agriculture feed the world?" is a question that has been often asked by skeptics of organic production methods (Borlaug, 2000) and directly addressed by recent research (Badgley et al., 2007; Ponti et al., 2012). It is clear that the world's population is increasing

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[5.3] Much of my graduate study was funded by USDA-NIFA grant #2010-51300-21401.

and that people in many developing countries are consuming an increasing amount of animal protein (Godray et al., 2010). It is often argued that if these trends continue, the world's farms will need to become more productive than they are now. As the argument critical of organic production goes, now is no time to adopt methods that may result in lower yields. The idea that the role of an individual farmer is to "help feed the world" and the role of government is to help maximize agricultural output may be considered antithetical to organic farming in general. Farmers that hold these beliefs likely do not consider a transition to organic production as a reasonable option.

In a study of survey data from conventional and organic farms in Texas, Constance and Choi (2010) found that more than 25% of conventional farmer respondents reported that they "disagreed with 'the philosophy of organic farming'". A higher percentage disagreed that organic is a "feasible long-term production method". In a series of interviews with farmers in the United Kingdom, Sutherland (2013) found that traditional views of "good farming" often included achieving high yields and keeping tidy fields, which many consider to be at odds with organic production systems. Given these findings, it is clear that there are farmers for whom their philosophy, or a perceived philosophy of organic agriculture, presents a significant barrier to adoption.

These ideas and objections relate to the analyses presented in previous chapters not because they pose additional transition costs or sources of uncertainty, but because they directly limit the set of farms to which the analyses apply. In both the whole-farm profitability comparison in Chapter two and the dynamic programming model of a crop farm's transition decision in Chapter three, we are modeling the outcomes of a representative farm in the Midwest. Although the results from Chapter three provide a probability that the representative crop farm will find organic transition optimal, the probability that any particular farm will actually adopt organic management may be much lower than results suggest. This is because the reported probability of adoption is conditional on the probability that the farm believes organic production is a viable option worthy of further consideration. As pointed out by Brock and Barham (2013), it is useful to view the organic transition decision within the framework of bounded rationality theory, as the organic transition decision is complex and farmers (especially those with limited exposure to successful organic systems) face very real informational constraints.

5.6 Policy Implications

It is now a stated goal of the USDA to support the further growth of organic agricultural production in the U.S. (USDA, 2013). The barriers to transition identified here and in the earlier chapters of this dissertation can provide some guidance as policy makers move to improve organic crop insurance policies, organic data collection, and certification procedures. The paucity of data on organic production outcomes presents a problem not only for farms attempting to plan a successful organic transition but also for insurance rate-makers and lenders. The funding of data collection from organic producers in different parts of the country, and preferably from the same producers year after year, would improve the understanding of organic production risk and differences in outcomes across farms.

Since increased management requirements and paperwork have been reported as a serious barrier to organic adoption, efforts could be made to streamline certification procedures and facilitate marketing and input sourcing. This would reduce the time cost of transitioning to an organic system and would reduce the level of organic profitability required to induce adoption. There are currently efforts underway to create viable organic futures markets, and there have long been organic marketing cooperatives that have helped growers market their organic crops. Further research could help identify how these options can be most efficiently used by organic growers.

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6 Conclusion

The objective of this dissertation was to analyze the economics of the farm-level decision to transition from conventional to organic agricultural production. Previous research on the profitability of organic crop production has shown that organic systems can often achieve higher net returns than conventional systems. However, only a relatively small portion of the cropland in the U.S. has been certified as organic. Each essay in this dissertation approaches the issue of organic adoption from a different angle, and each makes a unique contribution to the existing literature on organic agricultural production in the United States.

The first essay shows that because of the increased management requirements of an organic cropping system, a conventional corn-soybean rotation can often be managed on a larger farm than can an organic rotation before experiencing yield penalties from delayed planting, weed control, and harvest. This farm-size difference provides a partial explanation for why relatively little cropland in the Midwest has been certified as organic despite research showing that organic systems can be more profitable on a per-acre basis. However, stochastic dominance analysis shows that risk-averse individuals would still prefer the organic rotation over the conventional rotation for each machinery size scenario (i.e. SSD), and when comparing farms of similar size, all individuals who prefer more to less would prefer the organic rotation (i.e. FSD).

The second essay hypothesizes that the cost and risk associated with the organic transition period may present a barrier that keeps conventional farms from adopting organic management, despite the possibility of increased farm profitability. The optimal organic transition decision for a representative crop farm is modeled as a problem of investment under uncertainty and solved using dynamic programming methods. Results show that although organic transition is an attractive alternative, it is less so for large farms than for small farms. Moreover, when organic yields are reduced from the high levels achieved in the experimental trial, the probability that organic adoption is optimal drops substantially. An analysis of the transition decision in the short term shows that high current returns to conventional crop production dramatically reduce the probability that a farm will find it optimal to transition to organic management within ten years. This essay demonstrates that the organic transition period acts as a significant barrier to organic adoption, but does not fully explain low transition rates.

The third essay seeks to identify the organic adoption patterns predicted by the theory of investment under uncertainty in empirical data on state-level organic dairy herds over time. Using threshold estimate techniques for dynamic panel data, I estimate the levels of relative organic to conventional dairy returns that define regimes of investment, inaction, and disinvestment in organic dairy production. Although the theory of investment under uncertainty predicts that such supply hysteresis will result from an investment problem like the organic transition decision, no evidence is found in support of the threshold model of organic dairy adoption.

The fourth essay provides a brief discussion of the broader literature on organic adoption and its relationship to the economic analyses presented in the previous chapters. A more complete understanding of the organic transition is achieved by considering research on the motivations and characteristics of organic, transitioning, and conventional farmers within the framework of the organic transition as an investment decision with uncertain returns.

In summary, this dissertation makes a substantial contribution to the understanding of the organic transition decision at the farm-level, and provides a useful basis for further study as more farm-level yield and financial data become available. Future research may investigate the impact of specific policies, such as insurance and conservation programs, on the attractiveness of the organic alternative. It would also be helpful for research to address the optimal organic transition strategy, including timing with respect to commodity price fluctuations, and the use of partial farm transitions to mitigate variations in returns during the transition period.

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A Organic Dairy Threshold Model: Supplementary Tables

Table A.1: GMM Estimation Using Reduced Sample and Log Rather than IHS Transformation, i.e $g() = \ln(x)$

Dependent Variable: Number of Organic Milk Cows in State, $g(cows_{it})$			
	Zero threshold	Single threshold	Double threshold
Threshold estimates			
$\hat{\rho}$	–	1.931	–
$\hat{\rho}^L$	–	–	1.314
$\hat{\rho}^H$	–	–	1.931
Regime-independent variables			
$g(cows_{i,t-1})$	0.700$***$	0.681$***$	0.691$***$
	(0.106)	(0.105)	(0.105)
Milk price ratio $(t-3)$	-0.239	-0.250	-0.233
	(0.416)	(0.419)	(0.415)
2008	0.203	0.237	0.285
	(0.213)	(0.212)	(0.210)
2009	0.198	0.218	0.255
	(0.239)	(0.239)	(0.237)
2010	-0.230	-0.127	-0.130
	(0.208)	(0.239)	(0.237)
Milk price ratio $(t-1)$	0.445		
	(0.311)		
Regime-dependent variables			
α_1		0.559$*$	
		(0.326)	
α_2		-0.159	
		(0.855)	
β_1			-4.771
			(2.972)
β_2			0.842$**$
			(0.349)
β_3			-0.438
			(0.867)
Threshold significance (P-value)			
Against H_0 of zero thresholds	–	0.423	–
Against H_0 of one threshold	–	–	0.307
Observations	135	135	135

Standard errors in parentheses

* p<0.1, ** p<0.05, *** p<0.01

Table A.2: GMM Estimation Using Organic:Conventional Income Over Feed Cost (IOFC) Ratio as Threshold and Regime-Dependent Variable; $g()$ = IHS Transformation

Dependent Variable: Number of Organic Milk Cows in State, $g(cows_{it})$			
	Zero threshold	Single threshold	Double threshold
Threshold estimates			
$\hat{\rho}$	–	1.514	–
$\hat{\rho}^L$	–	–	1.192
$\hat{\rho}^H$	–	–	1.514
Regime-independent variables			
$g(cows_{i,t-1})$	0.795***	0.777***	0.783***
	(0.076)	(0.074)	(0.074)
IOFC ratio (t-3)	0.517	0.545	0.567
	(0.662)	(0.661)	(0.657)
2008	0.502	0.604*	0.491
	(0.334)	(0.336)	(0.337)
2009	−0.208	−0.120	−0.237
	(0.454)	(0.448)	(0.448)
2010	0.024	0.093	0.040
	(0.333)	(0.331)	(0.330)
IOFC ratio $(t-1)$	0.192		
	(0.417)		
Regime-dependent variables			
α_1		0.559	
		(0.509)	
α_2		−0.553	
		(0.748)	
β_1			−0.655
			(0.771)
β_2			2.446**
			(1.035)
β_3			−1.265
			(0.816)
Threshold significance (P-value)			
Against H_0 of zero thresholds	–	0.233	–
Against H_0 of one threshold	–	–	0.037
Observations	207	207	207

Standard errors in parentheses

* p<0.1, ** p<0.05, *** p<0.01

Table A.3: GMM Estimation Instrumenting With Further Lags of Endogenous Variable; $g()$ = IHS Transformation

Dependent Variable: Number of Organic Milk Cows in State, $g(cows_{it})$			
	Zero threshold	Single threshold	Double threshold
Threshold estimates			
$\hat{\rho}$	–	1.872	–
$\hat{\rho}^L$	–	–	1.364
$\hat{\rho}^H$	–	–	1.872
Regime-independent variables			
$g(cows_{i,t-1})$	0.506***	0.499***	0.510***
	(0.125)	(0.124)	(0.124)
Milk price ratio ($t-3$)	0.583	0.713	0.556
	(1.139)	(1.142)	(1.140)
2008	0.562	0.637	0.613
	(0.392)	(0.398)	(0.394)
2009	−0.057	−0.103	0.055
	(0.448)	(0.449)	(0.453)
2010	−0.053	0.088	0.127
	(0.327)	(0.357)	(0.353)
Milk price ratio ($t-1$)	0.596		
	(0.851)		
Regime-dependent variables			
α_1		0.942	
		(0.916)	
α_2		−0.240	
		(1.215)	
β_1			−5.739*
			(3.068)
β_2			1.550*
			(0.894)
β_3			−0.889
			(1.260)
Threshold significance (P-value)			
Against H_0 of zero thresholds	–	0.203	–
Against H_0 of one threshold	–	–	0.823
Observations	161	161	161

Standard errors in parentheses

* p<0.1, ** p<0.05, *** p<0.01