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The Potential Supply of Cellulosic Biomass Energy Crops in Western Massachusetts

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THE POTENTIAL SUPPLY OF
CELLULOSIC BIOMASS ENERGY CROPS
IN WESTERN MASSACHUSETTS

A Dissertation Presented

by

DAVID SELKIRK TIMMONS

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DEDICATION

To my wife Robin, who endured much keyboard clacking.

ABSTRACT

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Most energy sources are derived from the sun, directly or indirectly. Stopping the increase of heat-trapping carbon dioxide in the atmosphere will likely require more reliance on current rather than ancient terrestrial solar input. Yet which forms of renewable energy are most appropriately used is a significant question for the twenty-first century. This dissertation concerns the potential supply of biomass energy crops as a renewable energy source in Massachusetts. Biomass represents a low-efficiency solar collector, and supplying society with an important portion of its energy from biomass would require a great deal of land. The cellulosic biomass crop evaluated in this research is switchgrass, among the most studied of possible biomass crops.

The study looks at biomass energy crop potential from three perspectives. First, a biomass crop supply function is developed for switchgrass by 1) using a GIS model to estimate land availability by current land use and soil type; 2) using

a crop-growth simulation model to estimate potential switchgrass yields; 3) estimating marginal production cost by land parcel; and 4) calculating a supply function from marginal production costs. Total technical potential is estimated to be about 1.3 million dry metric tons of switchgrass per year, though financial constraints would likely limit production to some portion of the estimated 125,000 metric tons per year that could be produced on existing grasslands.

Next, the study examines circumstances under which landowners might opt to make land available for biomass crop production. The social challenge of minimizing biomass energy cost is described. Potential biomass crop landowner decisions are characterized in a theoretical utility maximization model, with results suggesting that non-price attributes of crop production are likely important to landowners.

Finally, an empirical study using a landowner survey assesses interest in growing biomass crops, and uses contingent valuation (CV) to estimate landowner willingness to accept (WTA) land rent for biomass crops. The median estimate is $321/ha/yr, with a much-higher mean estimate of $658/ha/yr (based on a parametric estimator).

While the realistic potential for biomass crops is some fraction of technically feasible potential, there are other potentially important roles for biomass crops in Massachusetts, for example in preserving unused farmland that would otherwise revert to forest.

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a	amenity values…………………………………………………...	3
AVC	average variable cost…………………………………………	2
b	bid amount (hypothetical rent payment)……………………..	3, 4
B_{fs}	switchgrass budget fixed costs, supplies……………………	2
B_{fm}	switchgrass budget fixed costs, machinery…….................	2
B_v	switchgrass budget variable costs…………………………...	2
BH	bordered hessian matrix……………………………………...	3
BM	Crop biomass, Mg..……………………………………………	2
c	consumption goods expenditure……………………………..…	3
CN	optimal crop nitrogen concentration…………………………	2
d	downtime for farm equipment………………………………...	2
D	switchgrass yield, Mg/ha……………………………………...	2
e	field efficiency…………………………………………………..	2
EC	energy cost……………………………………………………..	3
f	switchgrass supply function…………………………………..	2, 3
g	production possibilities function………………………………	3
h	random WTA function…………………………………………	4
H	hectares of biomass crop production………………………..	3
i	producer index………………………………………………….	2
j	bid level index…………………………………………………..	4
J	number of bid levels…………………………………………...	4

k	vector of land characteristics……………………………………	4
K	field capacity, ha/hr………………………………………………	2
l, L	location index…………………………………………………….	2
L	Lagrangian equation………………………………………..	3
m	exogenous income……………………………………………	3
MC	marginal switchgrass cost, $/Mg……………………………..	2
n	number in sample……………………………………………...	4
N	number rejecting bid…………………………………………...	4
o	vector of landowner characteristics………………………….	4
p	biomass crop price……………………………………………..	2, 3
Pr	probability………………………………………………………	4
pb	pooled bids……………………………………………………..	4
q	firm or location production quantity………………………….	2
Q	market production quantity……………………………………	2, 3
r	field proportion cost adjustment per hectare………………..	2
s	vector of landowner attitudes…………………………………	4
SN	nitrogen stress factor…………………………………………..	2
SNS	nitrogen stress scaling factor………………………………….	2
t	trucking cost per hectare……………………………………...	2
T	tractor turning time, seconds………………………………….	2
TC	total cost………………………………………………………....	2
TP	total product of land (crops and amenities)…………………	3
TR	total revenue……………………………………………………	2

CHAPTER 1

INTRODUCTION

Most current and historic energy sources are derived from the sun. Solar photovoltaic and solar thermal systems convert the sun's radiation directly to usable energy. Hydropower requires solar-driven evapo-transpiration for precipitation and water flow. Wind energy comes from differential solar heating of the earth's surface. Plants use solar energy in photosynthesis, turning CO_2 and H_20 into new biomass hydrocarbons. Fossil fuels are hydrocarbons from ancient biomass, and thus from ancient solar energy. Most energy is solar, directly or indirectly.

Given that fossil fuels are finite, the world will depend on renewable, carbon-neutral energy sources in the long run. Stopping the increase of heat-trapping carbon dioxide in the atmosphere will also require more reliance on current rather than ancient terrestrial solar input. Yet which forms of renewable energy are most appropriately used is a significant question, and answering this question represents one of the great challenges of the 21st century. Biomass energy is one of several candidate renewable energy sources. Its potential rests in part on economic realities of its available quantity and cost compared to other renewable energy alternatives. This study looks at cellulosic biomass crop potential in the western Massachusetts, which includes Berkshire, Franklin, Hampden, Hampshire, and Worcester Counties.

Biomass energy can be derived from many sources: natural forests, managed tree plantations, wood waste, crops and crop residues, and animal wastes. Crops are projected to be the largest source of biomass energy, both in the United States (Perlack, Wright et al. 2005) and globally (Berndes, Hoogkijk et al. 2003). This is in part due to yield potential; some studies report agricultural biomass yields in the range of three to four times more per unit area than for natural forest biomass (calculated from Duffy and Nanhoue 2002; Tharakan, Volk et al. 2005; Innovative Natural Resource Solutions 2007).

In Massachusetts as in the New England region as a whole, farming has become less practiced over the last century. Indeed Massachusetts land use has changed continuously since colonial settlement: land that was deep forest at settlement was slowly cleared for agriculture, and the specific crop mix changed significantly over the centuries (Russell and Lapping 1982). As the country expanded and better farmland became available in the West, many farms were abandoned. Much potential agricultural land is no longer farmed, with a large portion of this land having reverted to forest (Foster, Motzkin et al. 1998).

A frequently cited problem of biomass energy crops is their potential for adverse welfare impacts related to food prices: if land is withdrawn from food production in order to produce energy, food prices will increase as a result. Abandoned farmland as now found in Massachusetts is thus of particular interest for biomass crop production, as it has the potential to increase renewable energy production without impacting food prices.

In a review of the potential for using abandoned agricultural land for biomass energy crop production, Campbell (2008) reports a high concentration of former cropland in the eastern United States. This can also be seen from the quintennial Census of Agriculture. In western Massachusetts at the 1905 census, 47 percent of total land area was cropland and pastureland. By the 1954 census, the agricultural proportion had dropped to 24 percent, and by 2007, to only five percent of land area (USDA 2009). Thus 89 percent of the 1905 farmland base is no longer in use for commercial agriculture.

Yet the land base still exists. While some former farmland has reverted to forest, land cover estimates based on satellite images indicate that farmland not counted in the Census of Agriculture (i.e. not in use for commercial agriculture) totals some 24,000 hectares (1 hectare ≈ 2.5 acres) across the five western Massachusetts counties (Timmons, Damery et al. 2008). This represents a land resource that could be used for biomass energy production, without affecting food supply. A similar pattern of land use likely exists in many parts of the eastern United States, and in other parts of the world where historic agriculture has declined.

How much of this land could or should be used for agricultural biomass production is a significant question, one that this study begins to answer. Some former farmland is ecologically sensitive. Some has been developed for urban and suburban use. And much of the earlier farmland base has now reverted to forest. The prospect of a new biomass crop industry in the region raises the possibility of reconversion of existing forest to farmland. While this could increase the available quantity of renewable energy, there would be environmental costs of land-use change. Forests provide ecosystem services like carbon sequestration, soil formation, water and air purification, wildlife habitat and genetic diversity. Agricultural land, depending on use and management, may provide similar services but to different degrees.

Environmental pollution from potential biomass crop production may also need to be considered. Switchgrass, for example, is native to North America and can be grown without any soil amendments. Yet where total cost as a function of fertilizer inputs has been studied, profits are maximized with significant fertilizer use (Brummer, Burras et al. 2001; Nelson, Ascough et al. 2006; Lemus, Brummer et al. 2008). The findings from this study are consistent with earlier ones, as described below.

A number of studies have assessed how the United States and the world might transition to a renewable energy basis, given available technologies and current energy demand (e.g. Hoffert, Caldeira et al. 2002; Pimentel, Herz et al. 2002; DeFries, Foley et al. 2004; Teske, Biel et al. 2009). Generally these studies consider the potentials for hydroelectric, wind, solar, biomass, and geothermal energy. Some studies also consider nuclear energy to be a renewable source.

Given the large amount of solar radiation falling on the earth's surface, the question of renewable energy availability is in some ways trivial. Turner (1999) shows that an area of solar photovoltaic panels approximately 161 km square (25,900 km^2; 100 mi square or 10,000 mi^2) could supply the entire energy requirement of the United States (assuming appropriate energy transmission and storage infrastructure). Turner notes that this is less than one fourth of the national area covered by roads and streets, and that the area could be reduced with the use of wind, hydroelectric, and other renewable energy sources. Similarly, Denholm and Margolis (2008) calculated the solar electric "footprint" for the United States as a whole and for each state, finding that in a base-case scenario, the country would need 0.6 percent of its land area to meet all of its energy requirements from photovoltaic energy (about twice the area estimated by Turner), with somewhat higher and lower requirements for other scenarios. At the state level, New Jersey had the highest land requirement on a percentage basis, at 8.8 percent of land area, while Alaska had the lowest, at 0.01 percent. Massachusetts was estimated to need 5.9 percent of its land area to supply all its energy from photovoltaics, or 3.7 times the estimated roof area in the state.

Yet the renewable energy supply problem is not only about land requirements; cost is the more significant question. A study considering world potential for wind, solar, and biomass electricity (de Vries, van Vuuren et al. 2007) estimated biomass electricity (converting biomass to electricity in a power plant) to have the lowest cost of the three, at 10 percent of current solar photovoltaic cost and 42 percent of estimated photovoltaic cost in 2050 (based on midpoints of projected cost ranges). Pimentel (2002) estimated biomass electricity cost to be 36 percent of photovoltaic cost (based on midpoint of photovoltaic range). And biomass for thermal applications is much less expensive than biomass electricity.

Yet biomass represents at best a low-efficiency solar collector, and to take advantage of its lower cost, much more land area is required than for solar photovoltaics, or for other renewables. Pimentel (2002) estimated that biomass electricity production (including energy losses in a power plant) required 71 times more land area than photovoltaic electricity.

While biomass crop feedstocks can in principle produce any kind of energy—heat, electricity, ethanol or other liquid fuels—the energy efficiency, land area requirements, and final cost of biomass energy vary greatly based on the final form of biomass energy required. For example, using biomass to produce electricity, as in the Pimentel (2002) study, requires about three times more land area per unit energy than in biomass combustion for thermal energy.

Even using the most efficient energy conversion technologies, supplying society with an important portion of its energy from biomass would require a great deal of land, with the potential to change the face of a region. For example in Massachusetts, for switchgrass yielding 9.5 metric tons per hectare (see Chapter 2) at 18.4 gigajoules per metric ton (McLaughlin, Samson et al. 1996), it would take about 89,000 square kilometers of switchgrass to meet all of Massachusetts' current energy demand (Energy Information Administration 2009), or 4.4 times the land area of the Commonwealth.

Though assessment of biomass energy demand is beyond the scope of this project, potential uses for biomass energy clearly exceed the potential availability of this relatively low-cost renewable resource. While biomass is not a complete energy solution for a populous state like Massachusetts, a single renewable source is not required. Feasible renewable energy portfolios include multiple energy sources, as well as energy conservation.

Considering both energy costs and available quantities, de Vries (2007), projected that biomass could comprise 1.8 percent of a 2050 renewable energy portfolio for the United States. In other studies, Pimentel (2002) calculated the potential biomass contribution at 10.9 percent of U.S. renewables in 2050, and a recent report by Greenpeace estimated biomass could contribute 30.2 percent of 2050 renewable energy production in the United States (Teske, Biel et al. 2009). There is uncertainty about total energy requirements, about the portion of total energy that might be renewable by 2050, and about the cost and availability of the various renewable energy alternatives. As renewable energy portfolios will likely show geographic variation, there is need for more information about renewable potential at state and regional levels.

In western Massachusetts, the finite nature of the biomass resource was recently brought into the public eye by debate about possible biomass electric power plants. The debate led the state to commission the wide-ranging Manomet report on biomass sustainability (Walker, Cardellichio et al. 2010). Among other issues, the report looked at carbon impacts of forest biomass harvest. While confirming the conventional wisdom that forest biomass is nearly carbon neutral in the long run, the report demonstrated that in the shorter term (e.g. 50 years) forest biomass use can result in net carbon emissions, depending in part on biomass use efficiency and on forest harvest practices. Carbon dynamics are complicated by the fact that forests, if not harvested for biomass, could otherwise be sequestering carbon, at least until they reach carbon saturation. Net carbon impacts also vary depending on the biomass technology used and the energy source replaced, with biomass electric plants clearly having the greatest carbon impacts, due to low energy conversion efficiency. The Manomet report suggested that biomass crops "deserve more attention", based on carbon advantages over forest biomass, as well as the report's finding that the forest biomass supply may be significantly less than found in other studies (Walker, Cardellichio et al. 2010, p. 36).

The Massachusetts biomass energy supply identified in this study is not restricted to any particular use. While as noted above, it is technically possible to convert biomass to thermal, electrical, or chemical (liquid fuel) energy, conversion efficiencies vary greatly. For example, the Manomet report calculates net efficiency of green wood-chip biomass to electricity at 25 percent, while the same biomass can be used to create thermal energy at 75 percent efficiency (Walker, Cardellichio et al. 2010). Useful energy available from a given quantity of biomass is thus three times higher when used for heat than when used to generate electricity. In the context of a Massachusetts renewable energy portfolio, efficiency differences together with limited biomass availability suggest that biomass may be best used for thermal applications, with electricity-producing renewables like hydroelectric, wind, and solar photovoltaic power used to meet electric-energy portions of a renewable-energy portfolio. This conclusion might be different in areas with higher ratios of biomass to energy consumption (e.g. Maine), or in areas with high biomass potential but lower thermal energy demands (e.g. Georgia).

Compared to other renewables, biomass represents energy conveniently stored for use on demand (unlike wind and solar energy, and more so than hydropower). In cold climates like Massachusetts the marginal value of this stored energy may be very high. For example, on a cold, still, winter morning with high thermal demand and little solar or wind energy available, the marginal value of biomass energy for heating buildings may be extremely high, given that the renewable-energy alternatives available in such situations are few and costly. This again suggests a thermal role for biomass in a renewable energy portfolio.

This study looks at the extent to which biomass crops may contribute to a renewable energy portfolio in Massachusetts, with a particular interest in potential biomass crop cultivation on abandoned farmland. The research builds on a smaller study that identified key questions around biomass crops in the Commonwealth (Timmons, Damery et al. 2008). The biomass crop modeled is switchgrass, one of the most studied of the grassy biomass crops (Wright and Turhollow 2010). While switchgrass is a crop for which modeling data are readily available, a number of other crops also have potential in the region.

This study first estimates direct financial costs of biomass production in Massachusetts, and also suggests likely external costs that should be the subject of future research. The potential land base is then evaluated in detail, first using a theoretical model exploring possible landowner motivations for biomass cropping decisions, and then in an empirical study based on a survey of western Massachusetts landowners. Specific research objectives include:

- Develop supply functions for switchgrass production in western Massachusetts, as a basis for understanding the potential contribution of agricultural biomass to renewable energy in the Commonwealth;
- Evaluate supply functions for different levels of fertilizer use, as a basis for future research on possible fertilizer-use impacts;
- Assess supply functions for different land uses (cropland, grassland, and forestland), so the potential for land-use change can be evaluated; and
- Understand by theoretical and empirical means the probability of landowners electing to use land for biomass crop production, along with their likely compensation requirements.

Information from this study provides both a stronger basis for renewable energy policy decisions in Massachusetts, and identification of additional research needs in this area.

CHAPTER 2

ESTIMATING A TECHNICALLY FEASIBLE SWITCHGRASS SUPPLY FUNCTION

Introduction

Many studies have looked at the potential availability and cost of biomass energy in the United States, and specifically at the potential supply of switchgrass as a biomass energy crop (e.g. Duffy and Nanhoue 2002; Bransby, Smith et al. 2005; Qin, Mohan et al. 2006; Bangsund, DeVuyst et al. 2008; Khanna, Dhungana et al. 2008). There are also a number of studies from outside the United States, particularly from Europe (e.g. Christian, Elberson et al. 2003; Larsson 2003; Lovett, Sunnenberg et al. 2009) and Canada (Samson 2007). However, in New England as in most of the country, there is not currently a biomass crop industry in the region from which to draw data, or even large-scale field trials with results that might be extrapolated.

Compounding the problem with lack of regional biomass crop data, there is clear heterogeneity of the area's land resources. Some farmland of excellent quality exists, particularly in river valleys, though most of the available, unused farmland is likely among the thinner soils of the area's hill country. Weather conditions also vary significantly with topography, and crop success may depend to some extent on elevation and other topographic conditions. In these circumstances, biomass crop yields and production costs cannot be assumed to be constant, as might be assumed in other parts of the country. This study develops a methodology to accommodate the variety of production conditions found across the western Massachusetts region, and to estimate a supply function for the region as a whole. The method is easily extendable to other regions.

Since cellulosic biomass crops are just one of a number of potential renewable energy sources for the region, attention should also be given to potential non-market costs and benefits of a new biomass crop industry. This study looks in particular at the dependence of switchgrass on fertilizer inputs, which if used, could have impacts beyond increasing crop yields (e.g. on water and air pollution).

Finally, as suggested in the dissertation introduction, inherent in the biomass cropping decision are consequences for land use in the region. Forest is the natural vegetative cover in western Massachusetts, and over the centuries much of the region has moved in and out of forest cover (Foster 2003). Cultivating land for biomass crops keeps land out of forest, which would also produce biomass, though of a different quality and quantity. Conversely, in many places retaining existing forest cover implies withholding potential agricultural land from production. This study sheds light on the type and extent of land-use consequences that might accompany introduction of cellulosic biomass energy crops as a new renewable energy resource.

Previous Research

The most prominent quantification of U.S. biomass availability, a study commissioned by the U.S. Department of Agriculture (USDA), described the possibility of supplying a billion tons of biomass annually (Perlack, Wright et al. 2005). While noting that about 75 percent of existing utilized biomass comes from forests, the study estimated that future biomass supply would be dominated by agricultural sources: 907 million metric tons (megagrams, or Mg; 1 Mg = 1.1 short tons) could be produced annually from agricultural crops and crop residues, and 335 million Mg from forestlands. Though broad in its coverage of potential biomass feedstocks, the "Billion Ton" study did not address the question of biomass energy cost.

In Massachusetts, there have been several previous efforts at quantifying biomass energy availability. An early attempt combined estimates from multiple studies to arrive at estimates for biomass in categories of municipal solid waste (MSW), construction and demolition debris (C&D), primary and secondary wood manufacturing residues, urban wood residues, and unutilized net forest growth (Massachusetts Biomass Energy Working Group 2002). Unutilized net growth was defined as net forest growth in excess of harvest, damage, and clearing. Quantities were summed for an annual total of 4.0 million Mg (at various moisture contents). After adjusting for dry weight, and with MSW and C&D excluded (the typical practice), total biomass availability was 2.2 million dry Mg annually. Of this, unutilized net forest growth accounted for 1.2 million dry Mg, or 54 percent of the total available biomass. It should be noted that the forest growth estimate was based only on U.S. Forest Service data for all forests in Massachusetts, and did not consider net land availability after excluding environmentally-sensitive areas, parks and other restricted areas, or consider likely harvest rates by owners; a realistic estimate of quantity supplied would thus be less than unutilized net growth.

A later study commissioned by the Massachusetts Department of Energy Resources (DOER) used a similar framework for the five western counties of Massachusetts, but updated data sources and estimation procedures, and considered biomass in surrounding "buffer" counties (Innovative Natural Resource Solutions 2007). Net forest growth was estimated at 1.2 million dry Mg annually for the core western Massachusetts counties (not including buffer counties), as in the earlier study. Wood residues were more carefully defined and quantified than in the earlier report, and added 0.3 million dry Mg to the available biomass. A final biomass availability estimate of 1,073,652 annual Mg from the core counties included land clearing, existing biomass residues, and 50 percent of net forest growth (accounting for likely harvest feasibility and non-harvest decisions). In all cases the fourteen buffer counties were found to have significantly higher biomass quantities than the five core counties, emphasizing the need for a regional approach to biomass availability assessment.

At about the same time, a different report also commissioned by DOER looked more carefully at forest ownership patterns and likely harvest rates, arriving at an estimate of 808,000 dry Mg of forest biomass available annually for Massachusetts as a whole (Kelty, D'Amato et al. 2008). The study also looked at ecological implications of harvesting biomass, for example removal of soil nutrients, and recommended management practices to minimize harvest damage.

More recently, the Manomet study of biomass sustainability also looked at the question of Massachusetts forest biomass supply (Walker, Cardellichio et al. 2010). Unlike earlier studies, the Manomet report estimated two points in a forest biomass supply function. Only 94,000-157,000 dry Mg of additional forest biomass was estimated to be available at current landowner payments of $0.76-$1.52 per dry Mg, the low-price scenario. In a high-price scenario, a stumpage price of $15.17 per dry Mg of biomass would effectively double landowner total income from forest harvest (including timber income), and was estimated to raise new forest biomass availability to 408,000-533,000 dry Mg. These quantities were significantly lower than earlier estimates, though they included only incremental quantity increases, excluding existing quantities supplied. It was assumed that marginal cost increases would stem from increasing forest landowner payments, with other marginal production costs assumed to be constant. Estimates of landowner supply elasticity were based only on the minimal empirical data available, and there is room for more research in this area.

None of the Massachusetts studies cited above considered dedicated biomass crops as part of a potential supply. Two other reports did review biomass crop potential in general terms (Herbert, Prostak et al. 2008; Timmons, Damery et al. 2008), looking at biomass crop production budgets and the potential land resource. Data and methodological constraints limited the robustness of conclusions from these reports, and neither study considered how marginal costs would likely rise with increasing quantities. These limitations motivated the current study.

Graham described the problems inherent in biomass supply estimation: "Forecasting the magnitude of sustainable biofeedstock supplies is challenging because of 1) myriad potential feedstock types and their management; 2) the need to account for the spatial variation of both the supplies and their environmental and economic consequences; and 3) the inherent challenges of optimizing across economic and environmental considerations" (Graham 2007, p. 255). And of course there is a challenge simply in defining "sustainable." Yet as Graham described, over time research methods have been developed that satisfy more of these needs, though perhaps not completely.

Haq (2002) developed biomass supply curves for evaluating biomass electricity production potential in the United States, and estimated separate supply functions for different biomass sources. To different degrees, all supply curves displayed the same characteristic shape, with costs climbing steeply initially, reaching a relatively level plateau, then rising sharply again near the maximum available quantities. Available quantities in descending order were from: 1) agricultural residue, with the highest quantity and lowest plateau-level price, 2) forest residue, 3) energy crops, and 4) urban wood waste with the lowest available quantity.

In total, the study found 375 million dry Mg available for less than \$4.74/Gigajoule (GJ). Energy crops started to contribute significantly to the supply at about \$2.18/GJ; at \$2.37/GJ, energy crops made up 13 percent of the estimated supply, and at $4.74/GJ accounted for 21 percent of the total supply (Haq 2002). By contrast, the U.S. Energy Information Administration (EIA) reports that powerplant-purchased coal averaged $1.18/GJ in 2002 (Energy Information Administration 2010).

Haq's (2002) study used the Policy Systems Analysis (POLYSYS) model to generate energy crop supply curves. POLYSYS is a crop-switching model developed by the Agricultural Policy Analysis Center at the University of Tennessee. Based on the production costs of biomass crops and other crops, prices at which it would be more profitable for farmers to switch to biomass crops were calculated. Rising biomass prices would motivate farmers to switch more land from conventional crops, and biomass quantities would thus rise with prices. POLYSYS is also a general-equilibrium model, allowing prices of other crops to rise as quantities produced decline.

In Oklahoma and Tennessee, researchers used two approaches to estimate switchgrass supply (Epplin, Clark et al. 2007). First, a model assuming a land-lease ownership structure was used to estimate likely production costs, which totaled $53.77/Mg and $71.82/Mg for assumed eight- and two-month harvest seasons respectively. A two-month harvest significantly increased harvest cost, as more capital investment was required to harvest the crop in a shorter time. Second, under the federally funded Tennessee Switchgrass Project, actual bids were sought from farmers to produce switchgrass. Since the quantity being procured was limited, preference was given to farmers who proposed smaller acreages, the average production area being about four hectares. Bids were made on a per-acre basis, with per-weight equivalents ranging from $48.25/Mg to $213.00/Mg, assuming a 12.4 Mg/ha yield. Actual contracts were awarded for 37 hectares with winning bids ranging from $50.00/Mg to $78.51/Mg. The lowest bidder was disqualified based on a large minimum acreage requirement; the authors note that the small acreage sizes requested may have increased bid levels.

Since a supply curve is a marginal cost curve, a supply function can also be generated by directly estimating marginal costs. Walsh (2000) used this approach for estimating biomass energy crop supply. Walsh first identified appropriate land in ten bioenergy crop production regions, a total of 130 million hectares in the central and eastern United States. She then estimated biomass crop yields on those lands. Production functions were assumed to be the same across regions, but input costs for labor, land rent, etc., varied by region. Price per biomass ton in each area was then calculated as total cost divided by total yield in each area. These costs were sorted from low to high, cumulative quantities were tallied at each cost point, and a supply function was generated. Since biomass crops are typically perennials grown in multi-year rotations, future costs and yields were discounted to arrive at a present value cost per ton. The procedure used was equivalent to annualizing the initial planting cost at a given discount rate (a 6.5 percent rate in the Walsh study).

Walsh (2000) also noted that this was a partial-equilibrium approach, maintaining a ceteris-paribus assumption that other parameters (notably the prices of other crops) did not change as biomass energy crops were introduced.

On the national scale, this assumption would clearly be unrealistic: a significant shift from food to biomass crops would tend to raise the prices of food crops, with feedbacks to land rent and ultimately back to biomass crop cost. The Walsh study made an adjustment for this, but the inherent limitations of a partial equilibrium model in a national study led to adapting the general-equilibrium POLYSYS model described above for subsequent biomass crop studies. The limited scale of the current Massachusetts study suggests that the partial equilibrium approach used by Walsh is reasonable, and this study will assume no feedback into food prices and land rents.

Graham et al. (2000) used a similar approach to Walsh, but without estimating actual supply functions. Other notable differences from the Walsh study included:

- a Geographic Information System (GIS) model was used to map cost and yield data for 1 km^2 pixels, a much finer degree of resolution than Walsh used.
- the EPIC model (Erosion-Productivity Impact Calculator) was used to estimate yields at the soil-group level for each pixel.
- the EPIC model also provided some output used in estimating environmental effects.
- land rent estimates were based on returns to land from current crop mixes.
- a biomass transportation cost module was included.

The current project combines the methods of Walsh (2000) and Graham (2000), with additional modifications for the Massachusetts context. The procedure is described below. Since the method assumes all suitable land could be brought into production for a constant land rental rate (which is unlikely to be the case; see Chapters 3 and 4), the resulting supply function represents only technically feasible supply. This provides an upper bound on possible market quantities.

Compared to previous studies, the current one uses a much finer resolution of 15 meters (225 m^2, or 0.000225 km^2). Crop yields are estimated at this resolution for specific soils, at different elevations, and with weather data from each county. This high-resolution study is appropriate in a region like New England, with heterogeneous land resources and weather, and represents a natural development from the broader and necessarily more general studies conducted earlier. This study also models switchgrass production with different fertilizer treatments, finding significant differences that suggest other potential environmental costs of biomass production.

Methods and Data

Estimating a technically feasible supply function for switchgrass in western Massachusetts is conceptually uncomplicated, yet there are important nuances, detailed below. Major steps include:

1. defining the area's potential land resource;
2. developing a switchgrass enterprise budget;
3. estimating switchgrass yields on potential production land;

4. making other spatially explicit cost adjustments; and
5. combining these into supply functions for the region.

Short-run supply function derivation

The theoretical basis for a supply function in a competitive economy is a familiar economic concept. Assume a market where producers have strictly concave production functions (at least in the neighborhood of profit maxima), and where each producer *i* chooses a production quantity (q_i) to maximize profit (π_i), the difference between total revenue (TR_i) and total cost (TC_i):

$$\pi_i = TR_i(q_i) - TC_i(q_i) \qquad \text{(2-1)}$$

Further assuming a competitive market where price (*p*) is exogenous for each producer:

$$\pi_i = pq_i - TC_i(q_i) \qquad \text{(2-2)}$$

Assuming for the moment interior solutions only, the first-order condition for the profit-maximizing quantity is:

$$\frac{d\pi_i}{dq_i} = p - \frac{dTC_i}{dq_i} = 0 \qquad \text{(2-3)}$$

Calling the first derivative of total cost the marginal cost (*MC*):

$$p - MC_i = 0 \qquad \text{(2-4)}$$

$$p = MC_i \qquad \text{(2-5)}$$

This says that each firm *i* produces quantity q_i such that the firm's marginal cost equals the market price. Two further conditions apply. First, for the first-order condition to describe a profit maximum, the second-order condition must hold, or marginal cost must be increasing at this point:

$$\frac{d^2\pi_i}{dq_i^2} = -MC_i{}' < 0 \quad (2\text{-}6)$$

$$MC_i{}' > 0 \quad (2\text{-}7)$$

Second, for a producer to stay in the market in the short run, total revenue must exceed variable costs, so market price must be greater than average variable costs (*AVC*):

$$TR_i \geq VC_i \quad (2\text{-}8)$$

$$pq_i \geq VC_i \quad (2\text{-}9)$$

$$p \geq \frac{VC_i}{q_i} \quad (2\text{-}10)$$

$$p \geq AVC_i \quad (2\text{-}11)$$

Since these conditions must hold for every producer of biomass crops, the total market quantity supplied (*Q*) is the sum of quantities supplied by each firm:

$$Q = \sum_{i=1}^{I} q_i \quad (2\text{-}12)$$

where $MC_i = p$, $MC_i' > 0$ and $p \geq AVC_i$ for all producers $i = (1,\ldots,I)$ in the market.

In practice, individual producers may not have continuous, well-behaved production functions, and each producer may not be able to increase production to precisely the quantity where $MC_i = p$. We thus modify this condition to $MC_i \leq p$; producers supply biomass crops to the market as long as their marginal costs are no more than the market price.

For the case of biomass crops, it may also be necessary to relax the assumption of interior solutions, as corner solutions likely exist as well. The optimum quantity of biomass crops is likely zero for many farmers, if for example, profits are higher for alternative crops. For non-farmer landowners, the profit-maximizing quantity may be greater than zero even if profit is zero, given that landowners would incur an expense (a negative profit) simply to mow fields and prevent them from returning to forest. For such cases the Kuhn-Tucker conditions apply:

$$\frac{d\pi_i}{dq_i} \leq 0 \qquad (2\text{-}13)$$

Marginal profit can be zero (the typical case) or negative (for a corner solution where the quantity produced is zero).

$$q_i \geq 0 \qquad (2\text{-}14)$$

The quantity produced may be zero, or greater.

$$q_i \frac{d\pi_i}{dq_i} = 0 \qquad (2\text{-}15)$$

At a profit maximum, either marginal profit must be zero (for an interior solution or a corner solution with a positive quantity and zero profit) or the quantity produced is zero (for a corner solution where marginal profit is negative).

While this is the usual description of behavior in a competitive market, it is not typically used as a basis for an empirical supply estimate, which would more often be based on an econometric study of changes in market quantities and prices over time. Yet the theory implies that if we can estimate marginal costs, we can estimate a supply function directly. This is precisely the approach recommended by Walsh (2000), and is appropriate for cases like biomass crops in Massachusetts, where no market yet exists for an econometric study.

For this study, the cost function to be estimated is:

$$MC_l = \frac{\{B_{fs} + [(B_{fm} + B_{vl}) \cdot (1 + r_l)] + x_l\}}{D_l} + t_l \qquad (2\text{-}16)$$

where:

MC_l = switchgrass marginal cost in dollars per dry metric ton ($/Mg) for location l. Cost is calculated at a 15-meter resolution, i.e. cost is estimated for each 15 m square location.

B_{fs} = budgetary fixed costs per hectare for supplies and other non-machine work expenses, from the enterprise budget described below. These costs are assumed to be constant for all locations and all producers.

B_{fm} = budgetary fixed costs per hectare for machinery.

B_{vl} = budgetary variable cost per hectare (baling) in location l.

r_l = production cost adjustment for field proportion in location l.

x_l = cost adjustment per hectare for proximity of production field l to closest field in a potential enterprise.

D_l = yield in location l, in Mg/ha.

t_l = transportation cost/Mg for moving biomass from production location l to a hypothetical processing center.

As detailed below, since $B_{fm} \cdot (1+r_l)$ is decreasing in field length (up to mean field length) and x_l is decreasing in field area, the cost function exhibits increasing returns to field size, which could suggest increasing returns to scale.

Estimated costs and yields for all locations l are sorted in ascending marginal cost order. Cumulative quantities Q_L are calculated for each marginal cost point (MC_l, q_l):

$$Q_L(MC_L) = \sum_{l=1}^{L} q_l \qquad (2\text{-}17)$$

The resulting (MC_L, Q_L) points provide an estimate of the supply function:

$$Q = \hat{f}(MC) \qquad (2\text{-}18)$$

where MC represents both marginal cost and price (as described above). This function gives the total biomass quantity Q_L produced at each price-marginal cost point MC_L.

This process, as detailed below, results in a technically feasible supply function, i.e. a function that describes the quantity of switchgrass that could be produced if all available resources were used for this purpose. This technically feasible supply function represents a first, important step in understanding the potential for switchgrass production in the region, and is an upper bound on the potential market-supply function.

Land area and identifying production locations

Western Massachusetts is typically defined as the five western counties of Berkshire, Franklin, Hampden, Hampshire, and Worcester. These counties comprise approximately 56 percent of Massachusetts land area, and are generally more rural in character than eastern Massachusetts, though several urban centers also exist in the west.

While the area of interest is the five western counties, at the time of the study the core soil survey data for Franklin County are not yet available in Geographic Information System (GIS) format, and the estimates presented here are thus based on only the four western counties of Berkshire, Hampden, Hampshire, and Worcester (Figure 2-1). To account for the missing Franklin County data, quantities at each marginal cost point are inflated in proportion to the quantity of missing Franklin County land. This process assumes that land in Franklin county shares the same yield and cost characteristics as the other four counties studied.

Presence of agricultural soils is the first criterion for including potential switchgrass production land. Soil agricultural potential is defined using the Natural Resource Conservation Service's (NRCS) Soil Survey Geographic (SSURGO) maps and associated data tables, which are available in GIS format. The SSURGO data tables include approximate yield estimates for crops that are common in an area. In Massachusetts, for example, yield estimates are provided for corn, hay, potatoes, etc. on many soil types. For this study, soils that have a yield estimate for any crop are included as potential switchgrass soils (though the yield estimates themselves are not used). Gray areas in Figure 2-2 indicate soils included in the study.

Next, land-use criteria are applied to the potential soil areas. GIS layers with land-use classification data are available from MassGIS. These are produced from 2005 aerial photography. Three categories of land use are evaluated in this study:

- cropland: land-use code 1
- grassland: land-use codes 2 (pasture), 6 ("open" land, a general category), 24 (powerline/utility), 40 (brushland/successional, likely representing recent pasture)
- forestland: land-use code 3

All other land is excluded. For example, residential and commercial development is excluded, even though soils in these areas might be agricultural. This process also screens wetlands, as wetlands are in separate land-use classifications.

Grasslands are the primary areas of interest, as abandoned pastures may represent the most promising areas for biomass crops. Existing croplands are included, though it is not clear that biomass crops at foreseeable prices can compete economically against other crops grown in the region. Forestland is included for study, as much of the former farmland of interest has reverted to forest (Foster, Motzkin et al. 1998). Though there are both economic and environmental obstacles to utilizing forestland for biomass crops, as discussed below, in the interest of providing a complete technically feasible supply function, currently forested land is included.

Also excluded are priority habitats of rare species, as defined by the Natural Heritage and Endangered Species Program (NHESP), and as mapped in data obtained from MassGIS. Assuming that priority habitats would not be suitable for biomass crops may be overly restrictive, since priority habitats do include some existing croplands and grasslands. Yet whether biomass crops would significantly alter important habitats in these areas is felt to be best assessed on a case-by-case basis, which is beyond the scope of the current project. In the four-county study area, a total of 24,800 hectares of otherwise-suitable land are excluded based on this priority habitat criterion, accounting for 15% of otherwise-suitable land area.

Finally, contiguous areas of less than one hectare are excluded. While it is clear that there is some economic minimum production area, it is impossible to establish a precise minimum size. The one hectare criterion is thus somewhat arbitrary, though it is much smaller than areas typically seen in commodity crop production in much of the country. In total, the screening described above removes about 58 percent of the potential area with agricultural soils.

Note that these land selection criteria relate to physical characteristics of the land and environment only, and not to land ownership, political jurisdiction, etc. For a technically feasible supply function, all resources that could be used in production should be included, though whether such resources would in fact be used is another important question. For example, the land-use criteria do not exclude parks or preserved areas, which are unlikely to be utilized unless their preservation status should change. Yet characteristics like preservation status do change over time, while inherent characteristics like soil type do not change; thus, only physical land attributes are considered in the technically feasible supply function.

Budgets

A number of switchgrass production budgets are published in different parts of the United States, though to date none has been identified in the Northeast region. An enterprise budget is a common form, where switchgrass production is assumed to be one enterprise of many on a farm. Hourly rates are used for personnel and equipment, based on typical farm costs. While actual cost for each farm will depend on specific equipment used, these rates are indicative of actual costs for the required tasks. An enterprise budget is equally valid under different ownership and management alternatives, i.e. the enterprise could be conducted by an owner-farmer, by an owner-manager with farming contracted to others, or by a farmer who leases the production area from a landowner. Also, with an enterprise budget the size of the enterprise is easily scalable based on assumptions regarding returns to scale.

Several published switchgrass enterprise budgets are compared in Table 2-1. (Duffy 2008; Haque, Epplin et al. 2008; Mooney, Roberts et al. 2008; Perrin, Schmer et al. 2008). Expected production costs clearly vary by study, with the highest cost per ton (Duffy 2008) about 2.3 times greater than the lowest (Haque, Epplin et al. 2008). Some of this discrepancy stems from differing cost assumptions that are explicit in the studies; however, even after adjusting for assumptions about discount rate, yield, and land rental cost, the highest estimate is still 59 percent greater than the lowest (calculations not shown). Estimates may thus reflect basic regional differences in production methods, scale, and costs. Also, unlike the first three budgets, the Perrin (2008) figures reflect results from empirical trials, and there may be important differences between field trial data and enterprise budget estimates.

The current study relies on the Duffy (2008) budget from Iowa as a primary source, since this budget appears to be well researched, is conservative in its cost estimates, and provides adequate detail to allow for adaptation to Massachusetts. A number of modifications and additions are made to this budget, as detailed below.

Since switchgrass is a perennial crop, an initial investment must be made in its establishment, an investment that is repaid by a subsequent series of harvests. Duffy also assumes a 25 percent probability of needing to reseed in the second year of establishment. Initial and reseeding costs are annualized by amortization, i.e. by calculating the equal annual payments needed to repay the investment with interest over an assumed ten years of harvest after the establishment year. Duffy uses an eight percent real interest or discount rate (no inflation is calculated for costs or revenues over the project life). Because establishment costs are a relatively small portion of total costs, final cost is not especially sensitive to discount rate choice. For example, at an eight percent rate, Duffy's final cost estimate is $90.45 per metric ton (Mg). At a four percent rate, this becomes $88.41/Mg, and at 12 percent becomes $92.67/Mg. This study retains Duffy's method and choice of discount rate.

For machinery costs, the most recent and comprehensive rates identified for the Northeast come from the USDA and the Pennsylvania Department of Agriculture (2009). Where available, Pennsylvania rates are substituted for the

Iowa rates in the Duffy budget. As shown in Tables 2-2 and 2-3, the Pennsylvania rates are in general somewhat higher, and suggest more expensive production in the Northeast than in Iowa.

Most supply costs from the Duffy budget are used directly, but fertilizer costs are adjusted to match each of three fertilizer scenarios modeled (as described below). In addition to other impacts discussed below, nitrogen fertilizer use has a significant cost impact: in the Duffy budget, purchased nitrogen accounts for nine percent of total switchgrass cost.

While the Duffy budget assumes a constant yield of about 9.0 Mg/ha, this study estimates yield by soil type, and thus finds that final costs per ton differ by soil type. Harvest cost is a significant budget element, and for this study, harvest is split into fixed and variable costs, with variable costs again based on yield. Specifically, mowing and raking costs are assumed to be fixed (a single tractor pass for each operation, regardless of yield). Costs for baling and staging (moving bales to truck loading point) are assumed to be proportional to yield, and comprise B_{v}, the variable costs per ton in the cost function above (Equation 2-16).

Based on an Iowa perspective, the Duffy budget assumes production on existing cropland, with only initial disking and harrowing operations to be performed before planting. This study also considers the possibility of producing on existing grassland and on agricultural soils that have reverted to forest cover. For production on grassland, cost of an initial plowing operation is added to the budget, so initial operations include plowing, disking, and harrowing. This adds only slightly to total costs.

For planting on existing forestland, the additional operations of clearing and grubbing stumps represent a major expense. Timber suitable for sawlogs, pulp, or biomass can often be removed at no net cost to a landowner in a clearing operation, but with stumps and other residue typically being left behind. While some net revenue from timber sales can often be obtained as well, since such revenue could be obtained whether land were then cleared for crops or not, timber revenue obtained does not reduce economic costs of land clearing (though timber revenue might present a way to fund land clearing).

The $13,714/ha ($5,550 per acre) clearing cost used comes from a reliable construction cost index (RS Means 2010), and is consistent with more anecdotal sources found. Even assuming a long amortization period (30 years) and low discount rate (three percent), this land clearing cost adds an annual cost of $700/ha, nearly doubling the final cost of switchgrass over growing on cropland or grassland. This cost might be offset by revenue from timber or biomass sales, and a landowner wishing to convert forest back to cropland might explore avenues other than hiring heavy equipment (e.g. owning equipment for the duration of the project, clearing timber and then pasturing animals amongst stumps for an extended period, etc.). Yet the $13,714/ha figure is used as a reliable full-cost clearing estimate, being reflective of the various opportunity and time costs that would be inherent in other approaches. As discussed below, land clearing costs cast serious doubt on the financial viability of reconverting forestland to cropland to increase biomass production, even before environmental costs of removing forest are considered. Clearing cost is also a reminder of the value of the agricultural land legacy bequeathed to us by previous (and more patient) generations, perhaps making a case for using biomass crops at least as an agricultural "placeholder" to prevent unused farmland from reverting to forest.

Finally, an assumption must be made about land rent, or return to the landowner. This is assumed to be a long-run rental rate, i.e. a rate that should in principle cover both fixed and variable costs of owning land (though in practice agriculture in some regions may not cover fixed costs of land ownership). Land rents should also be reflective of land purchase prices and opportunity costs of not using land for other purposes, e.g. for raising crops. For putting idle farmland to work in Massachusetts, any amenities provided to owners by land in its idle state may be the main opportunity cost of use for biomass crops, as discussed in Chapter 3.

In the Iowa budget, Duffy uses a land rental rate of \$198/ha. This is close to average cropland cash rental rate of \$222/ha for the lower 48 states (USDA 2009). Landowner interest in biomass production and likely Massachusetts biomass cropland rental rates are the main subjects of the Chapter 4 study. This includes a landowner survey using a contingent valuation approach to establish likely land rent requirements. Based on that study, the median land rent requirement of \$321/ha is used in the Massachusetts production budget, though this is a high figure for the Northeast. Using a single land rental rate represents a simplifying assumption, since actual land rent would likely vary by parcel and by owner, as suggested by the Chapter 4 results.

According to the USDA (2009), cropland rental rates average $130/ha in the Northeast, and just $67/ha for Northeast pastureland. While no state-level figures are reported for New England, 2009 cropland rates in the Northeast range from $101/ha in New York to $173/ha in Maryland and Delaware. To find the $321 median rent required by Massachusetts landowners, one would have to go to the Corn Belt ($361/ha) or the Pacific coast ($484/ha). The highest USDA reported state-level cropland rent is for irrigated land in California, at $890/ha (USDA 2009).

Though high by regional standards, the $321/ha is used here, since the Chapter 4 empirical study reveals that half of Massachusetts landowners would in fact plant biomass crops for this level of payment. As shown in Tables 2-2 and 2-3, this accounts for 45% of total switchgrass production cost (including land rent during establishment, reseeding, and production), so landowner payment requirements are a significant determinant of final biomass crop energy cost.

Yield estimates: ALMANAC model

This study uses the ALMANAC (Agricultural Land Management with Numerical Assessment Criteria) model developed by the USDA (Kiniry, Williams et al. 1992) to estimate switchgrass yield for each soil of interest in the region. This provides accurate yield estimates at a fine degree of resolution, and is appropriate for Massachusetts, where there is currently no commercial-scale switchgrass production from which reliable yield estimates can be obtained. The ALMANAC model is one of a family of simulation models developed by the USDA at its Grassland Soil and Water Research Laboratory in Temple, Texas (Williams, Arnold et al. 2008). ALMANAC is based on the earlier EPIC model, and is designed specifically to model competing plant species, e.g. a crop and weeds. ALMANAC is used in this project because of its previous use and success in modeling switchgrass yields (Kiniry, Cassida et al. 2005; Kiniry, Lynd et al. 2008; Kiniry, Schmer et al. 2008). The ALMANAC model is publicly available from USDA, and Dr. James Kiniry, the model's developer, provided guidance on using ALMANAC for the current study.

ALMANAC is a bio-physical crop growth simulation model with a daily time step. It includes hundreds of equations and parameters related to the crop of interest (switchgrass, in this case), soil, weather, and crop management practices. The model estimates plant growth for each simulated day, based on the current values of many variables, e.g. plant leaf area, soil moisture, hours of sunlight, air temperature, etc. Plant growth accumulates through a simulated season, and the model provides a yield estimate at the end of each season. For multi-year simulations, the model carries forward stocks of some variables from one year to the next, e.g. soil organic matter and nutrient levels.

Initial soil parameters are loaded directly from Soil Survey Geographic (SSURGO) tables. A random weather generator produces daily simulated weather, based on National Oceanic and Atmospheric Administration (NOAA) weather-station data. Three stations are used for the three project areas in this study: Pittsfield (Berkshire County), Amherst (Hampshire and Hampden counties), and Worcester (Worcester County).

The ALMANAC model uses a number of different randomization processes to simulate daily weather. For example, occurrence of a simulated precipitation day is modeled using a first-order Markov chain, based on NOAA-estimated probability of a wet day following a dry day, and a wet day succeeding another wet day (Sharpley and Williams 1990). In the event of precipitation, simulated precipitation quantity is modeled from the NOAA mean and variance of precipitation amount, using a skewed-normal probability distribution. Wind speed is modeled using a two-parameter gamma distribution. Temperature and solar radiation follow still other randomization processes. The ALMANAC weather model has been extensively tested, and generally results in weather simulations comparable to actual weather in any particular area (Sharpley and Williams 1990). In this study, 30-year simulations are used, in part to minimize the probability of unrepresentative weather conditions. Though the initial model weather pattern is random, the same pattern is retained through all subsequent modeling runs, to isolate the effects of changing independent variables.

Switchgrass is a warm-season (C4) grass (Parrish and Fike 2005), and is more often evaluated as a biomass crop in areas south of Massachusetts, though a number studies have examined switchgrass production in the northern Great Plains (e.g. Kiniry, Schmer et al. 2008; Perrin, Vogel et al. 2008). A question, then, is whether and to what extent switchgrass yields might be sensitive to temperature, and whether elevation differences between individual fields and NOAA weather stations might create temperature differences large enough to affect yields. This would be more of an issue in areas with more topographic variation. Sensitivity testing indicates that such elevation-induced yield differences are likely significant, so a process is included to estimate these.

The temperature adjustment procedure rests on the idea that temperatures vary systematically and predictably with elevation, all else equal. Two recent papers (Peterson 2003; Gallo 2005) cited and used figures from Landsberg (1945), who calculated a lapse rate for summer mean temperatures of 6.56˚C per kilometer of elevation increase, or 0.66˚C per 100 m increase. Using a MassGIS 1:250,000, 30' contour elevation layer, the project study area is divided into seven 100 m elevation bands. Monthly mean temperatures from weather station data are manually adjusted for these elevation differences, in effect creating seven weather zones for each of the three project weather stations. Temperature variances are not adjusted.

For example, for the Amherst NOAA station, at 67 m elevation, the unadjusted mean temperature data are used for the 100 m band, for the 200 m band mean temperatures are reduced 0.66˚C, reduced 1.32˚C for the 300 m band, etc. ALMANAC yield estimates are then generated for all soils in all elevation bands. Finally, soil-elevation yield estimates are matched to actual soils areas in the appropriate elevation bands.

All ALMANAC simulations in this study are 33 years in length, with data from the first three years dropped to allow simulated initial soil conditions to stabilize (Kiniry, Cassida et al. 2005). Yield means, standard deviations, minima, and maxima are then calculated for the remaining 30 years of each simulation.

As noted above, the ALMANAC model incorporates many variables, including parameters specific to each crop. Default parameters for switchgrass (and many other crops) are included with the ALMANAC model software. Two parameters have been shown to be of primary importance in adjusting switchgrass simulation for northern regions (Kiniry, Schmer et al. 2008): potential heat units (PHU), or heat days to plant maturity, and plant potential leaf area index (DMLA). Values of 900 PHU and 3.0 DMLA are used in this study. In addition, based on results of initial simulations, the default value of DLAI (fraction of the growing season when leaf area declines) is adjusted from the default value of 0.7 to 0.6. These values are based on Kiniry's previous work in northern areas (Kiniry 2010). All other crop parameters are defaults provided in ALMANAC for northern upland switchgrass (representing variety Cave-in-Rock, a variety being tested with success at the University of Massachusetts Crop Research and Education Center).

Nitrogen availability enters the ALMANAC model as a possible constraint on crop growth. ALMANAC first evaluates crop nitrogen demand, based on an optimal concentration of nitrogen for a crop's growth stage. A net nitrogen demand is calculated from crop demand and nitrogen supply, with supply defined as the sum of nitrogen absorption in prior growing days. This net nitrogen demand is absorbed from the soil, if the nitrogen is available (Sharpley and Williams 1990).

Any estimated nitrogen deficiency is then evaluated as one of several possible stress factors. Other potential stress factors include water deficiency, temperature, phosphorous deficiency, and aeration stress (caused by water saturation of the soil). While a crop not subject to any of these stresses would follow a theoretical maximum growth curve, the stress factors act as growth constraints in ALMANAC, with only the greatest stress factor as a binding constraint. Thus, nitrogen availability does not impact estimated growth unless nitrogen stress is more severe than stress from water shortage, temperature extremes, phosphorous deficiency, and lack of root aeration (Sharpley and Williams 1990).

The nitrogen stress function in ALMANAC generates a sigmoid curve, with a no-stress plateau at high nitrogen availability (Figure 2-3). A nitrogen-stress scaling factor is given by:

$$SNS_{\tau} = 2\left(1 - \frac{\sum_{\kappa=1}^{\tau} UN_{\kappa}}{CN_{\tau} \cdot BM_{\tau}}\right) \qquad (2\text{-}19)$$

where *SNS* is the nitrogen-stress scaling factor in day τ, *UN* is nitrogen uptake in kg, *CN* is optimal crop nitrogen concentration in kg/Mg, and *BM* is Mg of crop biomass. The scaling factor is thus based on the ratio of crop nitrogen supply to crop nitrogen demand. The scaling factor is then used in calculating the nitrogen stress factor, *SN*:

$$SN_{\tau} = 1 - \frac{SNS_{\tau}}{SNS_{\tau} + exp\{3.39 - (10.93 \cdot SNS_{\tau})\}} \qquad (2\text{-}20)$$

Equation 2-20 generates the sigmoid stress function shown in Figure 2-3, where the stress factor represents the proportion of maximum crop growth that can be achieved based on nitrogen stress. Nitrogen supply- to-demand ratios below about 0.6 generate stress factors at or near zero, precluding further crop growth. Stress factors increase rapidly with nitrogen supply-to-demand ratios up to ratio of about 0.9, where the stress factor reaches a plateau. At a nitrogen supply- to-demand ratio of 1.0, the stress factor is also 1.0, meaning that nitrogen deficiency does not constrain growth. And nitrogen deficiency would not constrain growth at lower nitrogen supply-to-demand ratios, if another stress factor were less than the nitrogen factor, and therefore binding (Sharpley and Williams 1990).

Limited data are available to compare ALMANAC estimates with yields actually obtained in experimental plots of switchgrass established in 2007 at the University of Massachusetts Crop Research and Education Center. In testing consistency between ALMANAC estimates and actual yields, actual weather data since 2007 were used in the ALMANAC simulation. Since the Crop Research and Education Center is located in Franklin County (for which soil data are not available), soil parameters for a similar soil in nearby Hampshire County are used. The parameters given above provide ALMANAC estimates consistent with observed yields (Table 2-4). Note that estimated and actual yields with no nitrogen fertilizer are relatively high for the experimental plots. ALMANAC results suggest that these high yields are possible because of residual nitrogen in the soil, and that yields with no nitrogen additions will be declining over time. As discussed below, this is a key result, and one that should be empirically verified when possible. Results for additional years of harvest and for the actual Franklin County soil will be of interest, when such data become available.

Switchgrass is often promoted as a biomass crop because of its ability to grow on marginal lands, and its relatively minimal input requirements (Duffy and Nanhoue 2002; Wright and Turhollow 2010), for example compared to corn. Yet switchgrass is also known to respond positively to nitrogen fertilizer applications, and previous studies have suggested that some level of nitrogen fertilizer use is economically optimal (Nelson, Ascough et al. 2006; Lemus, Brummer et al. 2008). Since many costs per hectare are constant regardless of yield level (land rent, planting, etc.), higher yields tend to reduce total cost per ton, despite fertilizer expenditure. Brummer (2001) estimated that a yield plateau for switchgrass occurred between 56 and 112 kg/ha of nitrogen on the soils studied.

In this study switchgrass yields are estimated with no added nitrogen and with two levels of nitrogen fertilization: 67 and 135 kg/ha of nitrogen (60 and 120 lb/ac), representing moderate and moderately high nitrogen application levels. These fertilizer levels are being tested at the University of Massachusetts Crop Research and Education Center (Herbert 2010). The Duffy (2008) switchgrass enterprise budget (discussed above) assumes 112 kg/ha, while the default switchgrass nitrogen level in the ALMANAC model is 200 kg/ha.

Nitrogen is the only soil amendment evaluated in this study, which again corresponds to the experimental treatment at the University of Massachusetts. The Duffy (2008) budget assumes 9 kg/ha of added phosphorous, while the default ALMANAC input is 50 kg/ha of phosphorous. In sensitivity testing with a few western Massachusetts soils, no yield increases are observed with modeled addition of phosphorous, though its inclusion would likely increase yields on at least some of the soils in the region. It can thus be assumed that phosphorous use may lower costs on some soils, if the marginal cost of phosphorous is less than the value of its marginal product. The Duffy budget also uses 102 kg/ha of potassium (included in the production budget), while ALMANAC does not model any growth limitations due to potassium deficiencies.

Other spatially explicit adjustments

Since a supply function is needed, i.e. marginal costs of production for increasing cumulative quantities, it is appropriate to assess how spatial aspects of production affect marginal costs. The GIS model used in this study provides a means to do so. Three such spatial cost adjustments are made, based on: 1) proportions of production field, 2) proximity of production field to other production fields, and 3) trucking cost based on distance from farm gate to plant gate, assuming biomass must be used in a central facility or at least processed in a central facility. In all cases, adjustments made represent the minimum additional costs that could be expected based on the information available. In many cases actual costs would be higher.

Field proportion adjustment:

A cursory look at the western Massachusetts landscape reveals that production fields are smaller than in many other parts of the United States, and especially compared to areas more oriented toward agricultural commodity production. The mean plot size for the four-county study area is 7.6 ha, and the median 2.6 ha. Excluding forestland, which has some large contiguous areas, the mean plot size for existing crop and grasslands is 5.0 ha, and the median again 2.6 ha. Here, a plot is defined as a contiguous area with the same land-use classification. Note that this represents maximum field size; ownership boundaries or other barriers not apparent at the land-use level likely create smaller working parcels.

In Ireland, an area perhaps more agriculturally similar to New England than are other parts of the United States, Deverell et al (2009) assessed the impact of field size on biomass crop production cost. The study's particular aim was assessing costs of the country's characteristic stone wall and hedge field boundaries, as compared to the ecosystem benefits those provide. The study divided Ireland into ten different zones, with mean zone field size ranging between one and ten hectares. The Deverell study used methods of Hunt (2001) to calculate machine time as a function of field proportions. The same methods are used in the current study.

As noted above, the intent of this study is to estimate conservative minimum cost adjustments. Hunt's methods, for example, rely on the assumption of a rectangular field, and it can easily be shown that any field shape with a non-constant width results in higher costs (Hunt 2001). Adjusting for rectangular shape thus represents the minimum additional cost.

As shown below, machine cost is primarily a decreasing function of field length. Initial testing of the field-proportion adjustment process described below revealed that GIS polygon length was not a good reflection of likely working dimensions. Many land-use polygons have unusual (e.g. branching) shapes, resulting in large length/area ratios and low cost estimates, despite obvious machine-use planning problems. Consequently, the square root of field area is calculated as a pseudo field length, i.e. the length of a square field of given area, and this pseudo length is used in the calculations shown below.

Hunt (2001) describes field capacity as the area a machine can work in a given amount of time, measured in hectares per hour. The general capacity (*K*) formula is:

$$K = 0.1\, z\, w_e\, e\, \left(\frac{ha}{hr}\right) \qquad \text{(2-21)}$$

where:

z = machine speed in km/hr

w_e = effective width of machine in meters (rated width less required overlap for successive passes)

e = field efficiency, the ratio of theoretical field time to the actual time.

The field efficiency factor is key, as this can vary significantly between fields of different proportions. Hunt lists five kinds of time that might be used in the field efficiency calculation:

1. theoretical time to perform the operation
2. time to turn at the ends of fields
3. loading and unloading (if the machine must be stopped)
4. machine adjustment
5. in-field maintenance and repair

These efficiency parameters then used in an explicit formula for field capacity (Hunt 2001, p.6):

$$K = \frac{Sw_e y}{10y + 2.78\, zT + d\, zw_e y} \left(\frac{ha}{hr}\right) \tag{2-22}$$

where:

y = field length in meters

T = turning time in seconds

d = other downtime, in hr/ha

and other variables are as above.

While Hunt (2001) does not include the derivation of the formula, this is provided below for reference, where by including all measurement units, it can be seen that the constants in the formula (10 and 2.78) arise simply from unit conversions. The general capacity formula (from above, including measurement units) is:

$$\begin{aligned} K &= \frac{z\, km}{hr} \cdot w_e\, m \cdot e \cdot \frac{1000\, m}{km} \cdot \frac{1\, ha}{10{,}000 m^2} \\ &= 0.1\, z\, w_e\, e \left(\frac{ha}{hr}\right) \end{aligned} \tag{2-23}$$

The efficiency factor (*e*) is:

$$e = \frac{theoretical\ time}{theoretical\ time + turning\ time + other\ time} \tag{2-24}$$

Standardizing the theoretical time to 1:

$$e = \frac{1}{1 + turning\ time + other\ time} \tag{2-25}$$

Assuming a rectangular field with headlands for turning, the turning frequency can be derived from machine speed and field length. This is multiplied by the time for each turn:

$$turn\ time = \frac{1\ turn}{y\ m} \cdot \frac{z\ km}{hr} \cdot \frac{T\ sec}{turn} \cdot \frac{1000\ m}{km} \cdot \frac{1\ hr}{3600\ sec}$$
$$= \frac{0.278\ zT}{y} \qquad (2\text{-}26)$$

Hunt's expression for other time losses (#3 - #5 from above) is simply the per-hectare hours lost in these activities multiplied by theoretical hectares per hour:

$$other\ time\ = \frac{d\ hrs}{ha} \cdot \frac{0.1\ zw_e\ \ ha}{hr} = 0.1\ dzw_e \qquad (2\text{-}27)$$

Putting the expressions for turning time and other time into the field-efficiency formula (2-23):

$$e\ = \frac{1}{1\ +\ \left(\frac{0.278\ zT}{y}\right) + 0.1\ dzw_e} \qquad (2\text{-}28)$$

Substituting back into the field-capacity formula:

$$K = 0.1\ zw_e \left(\frac{1}{1\ +\ \left(\frac{0.278\ zT}{y}\right) + 0.1\ dzw_e} \right) \left(\frac{ha}{hr}\right) \qquad (2\text{-}29)$$

$$K = 0.1\ zw_e \left(\frac{y}{y\ +\ 0.278\ zt + 0.1\ dzw_e y} \right) \left(\frac{ha}{hr}\right) \qquad (2\text{-}30)$$

$$K = 0.1\ zw_e \left(\frac{y}{0.1[10y\ +\ 2.78\ zT\ +\ dzw_e y]} \right) \left(\frac{ha}{hr}\right) \qquad (2\text{-}31)$$

$$K = \frac{zw_e y}{10y\ +\ 2.78\ zT + dzw_e y} \left(\frac{ha}{hr}\right) \qquad (2\text{-}32)$$

This is Hunt's final capacity formula (Hunt 2001, p. 6).

The inverse of *K*, hours per hectare, provides the expression needed to adjust production budgets for field size:

$$\frac{1}{K} = \frac{10y\ +\ 2.78\ zT + dzw_e y}{zw_e y} \left(\frac{hr}{ha}\right) \qquad (2\text{-}33)$$

For the purpose of adjusting production cost for field size, constant values are assumed for all parameters except *y* (length), and shown in Table 2-5. Speed values (*z*) for different operations are taken from Hunt (2001, p. 5), and a weighted average speed is calculated based on the frequency of each operation. Values for effective machine width (w_e) and turn-around time (*T*) are from examples provided by Hunt (2001). Downtime (*d*) is assumed to be 0.1 hours per hectare. Mean field length *y* is calculated for the study region, and assumed to be the same in the Massachusetts study area as in Pennsylvania, where the machine rates used in the production budget were estimated.

Inverse *K* is then calculated for the mean field length and for fields of all other lengths, and percent changes in inverse *K* (hr/ha) are established. The machine-expense portions of the production budgets are then adjusted by these percentages for all field lengths less than the mean; expense is adjusted upwards for shorter fields, but no adjustment is made for longer fields. This distinction is based on the likelihood that many working field sizes are actually smaller than suggested by sizes of land-use polygons, as described above, and are not necessarily less expensive production areas than fields of mean length.

The field proportion adjustment factor is then:

$$r_l = \frac{\left(\frac{1}{K_m}\right) - \left(\frac{1}{K_l}\right)}{\left(\frac{1}{K_m}\right)} = 1 - \frac{K_m}{K_l} \qquad \forall \ K_l > K_m \qquad (2\text{-}34)$$

where:

K_m is factor *K* for mean field length, and

K_l is factor *K* in location *l*.

Field proximity adjustment

All fields in the region are likely smaller than the optimum size for a cellulosic biomass crop production enterprise, as the area's maximum non-forest land-use polygon size is 171 ha (and as noted above, the mean is just 5 ha). In North Carolina, Rizzon (2009) found declining switchgrass production costs per hectare of $2118, $1418, and $1063 for enterprise sizes of 101, 202, and 404 hectares (250, 500, and 1000 acres) respectively. While the optimum enterprise scale in Massachusetts may be different than in North Carolina, it is safe to assume that all enterprises will include multiple fields, and travel time between these fields will be a cost of production.

Areas where fields are more widely scattered will be more expensive for production than areas where fields cluster in tighter proximity. To accurately model this cost, one would need to make assumptions about optimum enterprise scale, about utilization of potential biomass crop fields (not all landowners will participate in production), and about the extent of overlapping between different enterprises in the same area (producers will not likely have firm geographic boundaries).

Since there are no known empirical data on these variables, this study instead makes the simpler assumption that minimum travel distance is from any field to its nearest neighbor field: if all enterprises include multiple fields, the least travel would be to the nearest field (if that field were part of the same enterprise). On average, one trip of at least this length would be made for each machine operation on a field. For example, assume a farmer has two fields located at points *A* and *B*, with the farm operation center located between *A* and *B* at point *C* (Figure 2-4). In order to conduct any field operation (e.g. mowing), the farmer must travel line segments *CA, AB,* and *BC*. Total travel distance for each operation in the two fields is then 2(*AB*), or on average for each field, *AB*, regardless of where farm center *C* is located between the fields.

Total proximity cost is the number of such trips (based on the production budget) multiplied by road travel time at 32 km/hr (Wehrspann 2000) at $35.40 hourly tractor cost (USDA and Pennsylvania Department of Agriculture 2009).

Proximity cost is divided by field size to arrive at a proximity cost per hectare. This procedure assigns a somewhat higher cost to remote fields that have no near neighbor fields, and higher cost per hectare to fields with smaller area (since a trip to a field is a fixed cost, divided by the area of the field). As with other cost adjustments in this study, the assigned value is the likely minimum: configurations differing from that shown in Figure 2-4, which are probable, result in higher field-proximity costs.

Trucking cost adjustment

Compared to other energy sources, biomass is relatively expensive to transport (Epplin, Clark et al. 2007), and a number of studies have examined the logistics problems inherent in biomass transportation. Graham et al (1995) analyzed biomass movement in Tennessee, comparing delivery cost in different regions of the state and for different sized facilities. They found cost of biomass transportation ranged from $8 to $18/dry Mg, accounting for 18 percent to 29 percent of delivered biomass fuel costs for different locations. Graham's group later (1996) developed a GIS model to analyze differences in biomass supply locations (with an emphasis on biomass crops).

A Danish study used GIS technology to model optimal delivery of woodchips to 35 woodchip-burning plants, noting that "transport costs are a major determinant of fuel price flexibility" (Moller 2003, p. 187). Moller and Nielsen (2004) observed that Denmark's forest cover is unevenly distributed, and mostly in small scattered stands. Their study found delivery costs from $12 to

$28 per dry Mg, for four different study areas and for supply volumes ranging from 5,000 to 50,000 Mg per year.

Langholtz et al (2006) also used a GIS model to estimate transportation cost of biomass energy, but argued that calculating delivery cost in terms of time (minutes driving time per delivery) rather than distance gave a more accurate cost picture. The GIS model calculated total transportation time based on posted speed limits and an operational time allowance for each delivery route.

This study makes a final spatial cost adjustment from farm-gate price to a plant-gate price. Biomass, particularly in grass form, is not as easily used on a small scale as for example cordwood. We thus assume that the grass crop must either be transported to a large scale user, for example a district heating system or electric power plant, which could be equipped to burn grass, or transported to a processing facility that could turn grass into a product like grass pellets (for home heating) or ethanol. Both of these possibilities would likely operate on medium to large scales, though examples of farm-scale pelletizing technology do exist.

For this study one large industrial plant or processor is assumed in each project area: in Pittsfield for Berkshire County, in Northampton for Hampshire and Hampden Counties, and in Worcester for Worcester County. County seats are chosen in each case, since they are typically well located on transportation networks. Though the choice of a hypothetical processing location is somewhat arbitrary, wherever a plant is located, there will be lower-cost biomass supplies nearby and higher-cost supplies at a distance. This is the cost element modeled here.

Road networks are added to the GIS model, based on 2008 data layers produced by the Massachusetts Executive Office of Transportation - Office of Transportation Planning (EOT-OTP) and obtained from MassGIS. Road attributes provided include speed limits for many roads; roads missing speed limit values are assigned a default speed limit of 56 km/hr (35 mph). To create a cost surface in GIS, areas lacking roads (e.g. fields) are also assigned a travel speed, in this case 14 km/hr (8.5 mph), an average of typical tractor field speed given in Hunt (2001). The ArcGIS cost distance function is then used to calculate travel time over the quickest route (i.e. following the best roads) from every map grid cell to the designated plant center. The portion of a full 30-short-ton truckload accounted for by each hectare is calculated, based on yield, and trucking cost is calculated from travel time, truck portion, and a tractor-trailer truck and driver rate of $85/hr obtained from published values for Minnesota (http://www.dli.mn.gov/LS/PrevWageTR10.asp). This cost per ton is then added to total switchgrass production cost. Note that unlike the Duffy (2008) budget, switchgrass producers are assumed to incur no storage or handling costs, but rather that any storage costs required are borne by plant owners (since no storage requirement results in the minimum cost).

Summary of production cost and supply function development

To calculate the supply functions, three project areas are first established for Berkshire, Hampden-Hampshire, and Worcester counties. In each project area, ArcGIS is used to identify potential agricultural soils. These soil areas are further classified by land use (crop, grass, forest) and by 100m elevation band. Priority habitat areas are removed. Polygons smaller than one hectare are removed.

NOAA temperature data are adjusted for elevation difference from a weather station. The ALMANAC model is used to provide yield estimates for all soils in all elevation bands. Three fertilizer scenarios are estimated: no nitrogen, 67 kg/ha N, and 135 kg/ha N. Yield batch results are compiled in a spreadsheet. Yield estimates for all nitrogen scenarios are then joined to the data for their corresponding soil-use-elevation polygons in ArcGIS.

In the soil-use-elevation polygon data tables, polygon pseudo length is calculated and used in the formula for Hunt's (2001) inverse-*K*, which is used to calculate a field-proportion cost adjustment factor for each polygon.

At this point all vector (polygon) data are converted to raster (grid) format, for use in ArcGIS Model Builder processes, as shown in Figure 2-5. Inputs and final output are on the top row (labeled in capital letters); other boxes and ovals are intermediate processes and outputs. Budgets per hectare for each land-use-type/fertilizer-level combination are input manually. Model Builder calculates all costs per hectare and costs per ton of switchgrass. The Euclidean allocation and zonal fill tools are combined to generate values for nearest neighbor polygon (nearest neighbor field to each field), for use in the proximity cost adjustment. In a separate model, the cost distance tool estimates trucking time from each raster cell to a processing center (generating the TRUCK COUNTY input). The model then calculates field proportion, field proximity, and trucking cost adjustments and adds these to total costs.

Final cost per metric ton rasters are combined with yield rasters for each project-area/land-use/fertilizer-scenario combination (3 x 3 x 3 = 27). These are exported and are combined in spreadsheets for the three project areas. Each of the nine land-use/fertilizer scenarios is sorted by cost/Mg from lowest to highest. Calculating cumulative quantities at each marginal cost point completes the estimated supply function. For graphing, every 100th marginal-cost cumulative-quantity point is selected, to avoid exceeding the spreadsheet graphing record limit.

Results

A total of 330,725 ha of soils with crop potential are identified in the study area, representing 34 percent of four-county land area. After screening for environmental, use, and minimum-size attributes, 138,039 hectares of technically feasible biomass crop growing area remain, or 14 percent of land area. Table 2-6 shows totals by project area and current land use. Approximately 16 percent of the feasible biomass crop area is currently cropland, 10 percent is grassland, and 74 percent is currently forestland.

ALMANAC provides yield estimates for 380 soil types, covering 116,490 hectares in the 4-county western Massachusetts region. However, no estimates are provided on 26 soils of interest, accounting for 21,549 hectares or 16 percent of the soil areas meeting all criteria for inclusion in the study. Staff at the USDA Grassland Soil and Water Research Laboratory (developers of the ALMANAC model) examined several of the soils for which ALMANAC failed to provide estimates, and in all cases examined, found soil parameter values outside of ALMANAC's acceptable range for calculation. This suggests that such soils may require additional conditioning or soil amendment to be suitable for switchgrass cultivation, which in some cases could be cost effective. Since such individual soil analysis is beyond the scope of the current effort, soils without a yield estimate are removed from consideration in the supply functions.

As shown in Table 2-7, yield estimates range widely. With no nitrogen (i.e. under natural conditions), soils in the study area yield a mean of 2.05 Mg/ha, with a standard deviation of 0.59 Mg/ha, and a range of 0.90 to 5.17 Mg/ha. With more nitrogen, yields are both higher and relatively less variable across soils.

Yields range from a low of 0.90 Mg/ha (minimum zero nitrogen) to a high of 11.2 Mg/ha (maximum 135 kg/ha nitrogen). There are clearly large yield differences between different soils and between fertilizer treatments; it is hardly meaningful to discuss "typical" Massachusetts switchgrass yields without including more particulars. Area-weighted average yields (calculated separately) are within 0.05 Mg/ha of the mean values shown, at 2.1, 6.2 and 9.5 Mg/ha, for the 0, 67, and 135 kg/ha N scenarios respectively. Clearly, added nitrogen plays a major role in switchgrass productivity. As shown above in Tables 2-2 and 2-3, fixed production cost per hectare is relatively constant. Thus, yield variation is a primary component of final cost per ton variation.

Table 2-8 shows statistics over the 30-year simulation runs. Mean yield with 67 kg of nitrogen is 6.19 Mg/ha (the same as calculated across soils), but the standard deviation over time is 1.39 Mg/ha, almost twice the standard deviation across soils: farmers can expect considerable year-to-year variation in yields. Note that Table 2-8 does not show the time-series variance, minimum, and maximum statistics for the no-nitrogen scenario. Because of the way ALMANAC calculates annual nitrogen accumulations in the soil, the model generates an oscillating yield prediction when no nitrogen is applied; while mean yield values over a simulation of several years are believed to be reliable, annual values are not reliable estimates (Kiniry 2010).

In Figure 2-6, the zero-nitrogen (natural condition) yield estimates by soil type are arranged from lowest to highest soil productivity. Adding 67 or 135 kg/ha of nitrogen increases yields in all cases, but the impact of additional nitrogen varies, especially for the 135 kg/ha N treatment. Cases of less-than-typical increase with nitrogen likely represent situations where some non-nitrogen soil component is limiting. A soil-by-soil analysis might suggest remedies (specific soil amendments) and result in cost-effective yield increases, at least in some cases.

Figure 2-7 shows that for given soils, temperature change associated with elevation change also has a significant impact on yield. Though field elevation is not a parameter that one can control, the yield variations suggest that there may be elevation thresholds at which other biomass crops (cool-season grasses, short-rotation woody crops) outperform switchgrass. On a regional or national scale, such thresholds may exist at latitude-elevation boundaries.

The spatial cost variables included in the model have varying effects on total cost. Mean adjustments are modest. For example, for the 67 kg/ha N treatment on grasslands in Berkshire County, the average spatial cost adjustment per hectare is $21.44. This cost on the mean 67 kg/ha N yield of 6.2 Mg/ha results in only a $3.46/Mg spatial cost adjustment.

Yet spatial cost adjustments are much higher at the extremes. The maximum total adjustment in the Berkshire grassland 67 kg/ha N treatment is $85.87/ha, four times the mean. Maximum field proportion adjustment is $40.44/ha, maximum proximity adjustment $39.69/ha, and maximum trucking charge $49.94/ha (note that individual maxima do not occur in the same location). The per-ton cost impact of the spatial adjustments is also higher where yields are low, which is particularly prevalent in the no-nitrogen scenarios.

Figures 2-8, 2-9, and 2-10 show the results above combined in supply functions. The functions for all the land-use areas exhibit the same characteristic shape, similar to that found by Haq (2002). Costs initially rise steeply, reach a plateau (more distinct in some scenarios than others), then rise rapidly again for the last, highest-cost production. Two factors drive this shape: 1) the yield curves also exhibit this shape, with relatively little of the least and most productive soils, and 2) the spatial cost adjustments become high in a few of the most expensive production areas—those with small, isolated fields, located at a distance from assumed processing facilities.

In Figure 2-8, with no nitrogen applied, biomass costs on grassland and cropland start around $150/Mg, rise and then level around $275/Mg, then rise rapidly again to around $600/Mg until all land is in use. The cropland curve lies to the right of grassland curve, because there is more cropland and available quantities are higher. Forestland exhibits a similar (albeit less well-defined) shape, but at much higher costs and quantities. Higher costs reflect the clearing expense, as discussed above, while higher quantities reflect the preponderance of forestland in the western Massachusetts region, even on soils suitable for agriculture. The aggregate supply function in Figure 2-8 includes a steep cost increase at about $300/Mg, where the cost of biomass from grassland and cropland increases steeply, and where switchgrass from forestland begins to enter the supply.

Figures 2-9 and 2-10 show similar characteristics, but as nitrogen is added, quantities increase and costs decline. For example, with nitrogen fertilizer, costs start near $100/Mg, about $50/Mg lower than without nitrogen. Maximum cost on cropland and grassland is less than one-third of the cost without fertilizer. The cost jump where forestland enters the supply is also more pronounced in Figures 2-9 and 2-10, where the use of nitrogen reduces other (non-land clearing) production costs.

The impact of nitrogen fertilizer use is seen most clearly in Figure 2-11, with the aggregate supply functions for three different nitrogen levels shown on the same graph. Fertilizer use dramatically increases yield and reduces cost per ton, even though fertilizer expense increases cost per hectare. Nitrogen fertilizer also flattens the supply functions, i.e. differences in natural soil productivity are diminished as fertilizer levels increase. In addition, there appears to be a diminishing return on fertilizer use, as would be expected: the difference between no nitrogen and 67 kg/ha is much more pronounced than the difference between 67 and 135 kg/ha N. There is an economic optimum, where the marginal cost of additional nitrogen equals the value of its marginal product (though the economic optimum for a producer may not be the same as the social optimum, as discussed below).

The technically feasible supply functions shown in Figures 2-8 to 2-11 suggest significant expansion potential for biomass. In Figure 2-11, the aggregate switchgrass quantity supplied from using 135 kg/ha N extends to about 350,000 dry Mg/year before costs rise sharply. This would include most of the available biomass from grassland and cropland (the quantity available from the lower cost plateau in Figure 2-11). Figure 2-11 also shows that using higher-cost biomass, primarily from agricultural soils that have now reverted to forests could increase switchgrass quantity supplied to about 1,250,000 dry Mg/yr before steep cost increases. But in the case of utilizing forestland for biomass crops, the forest biomass quantity would also be reduced, so the net gain would be less than the new switchgrass quantity.

Discussion

As noted above, a recent study at the University of Massachusetts estimated the sustainable woody biomass availability to be approximately 809,000 dry Mg/yr. Since this estimate is for the Commonwealth as a whole, if we assume that the sustainable woody biomass is distributed the same as forest cover, the Berkshire, Franklin, Hampden, Hampshire, and Worcester County portion of the sustainable woody biomass quantity supplied would be approximately 533,159 dry Mg/yr. The 350,000 dry Mg/year shown in Figure 2-11 thus represents a 66 percent increase from the woody supply.

Yet these potential increases in biomass supplied would come at a cost. A regional reference for delivered wood-chip biomass prices is the New Hampshire Timberland Owners' Association Timber Crier quarterly market report. For the fourth quarter of 2009, the reported price was $29 per green ton, equating to approximately $46/dry Mg. By comparison, switchgrass using 135 kg/ha N runs from $91/dry Mg up to $213/Mg for a quantity of 1,250,000 dry Mg. Switchgrass thus appears to cost from 97 percent to 363 percent more than current woody biomass.

From technically feasible to market supply

The supply numbers presented above reflect only the technically feasible supply, and there is likely a significant gap between what is technically feasible and what actually occurs in the market. While projecting a market supply is beyond the scope of the current study, it is clear that differences between technically feasible and actual production would likely be based on:

1) Profit opportunities available from other crops: switchgrass represents a relatively low-value commodity, while much of the cropland in western Massachusetts is cultivated for high-value products like vegetables. Switchgrass prices are unlikely to reach levels providing sufficient profit for switchgrass to replace such high-value crops. On existing grasslands, switchgrass would compete most directly with hay, and Massachusetts hay prices have recently been relatively high, at $243/Mg in 2008 (New England Agricultural Statistics Service 2009). The process described above for the switchgrass supply estimate could also be used to model a technically feasible hay supply function on existing grasslands. Prices at which profit-maximizing farmers might switch from growing hay to supplying biomass crops could then be calculated. As noted in the section on previous research, several studies of biomass supply have used this profit-maximizing crop-switching principle to estimate market supply.
2) Non-profit-maximizing behavior by non-farmer landowners. As agriculture has declined in the region, much of the land base has been acquired by people or institutions that are not actively involved in farming. Unlike farmers, we cannot assume that such owners seek to maximize the value of commodities produced for the land; they may instead value other land attributes or services. A significant quantity of such privately owned land is likely to be withheld from production. In Chapters 3 and 4 this question is

considered in detail, and Chapter 4 includes a survey of Massachusetts landowners about their attitudes toward biomass crops.

3) Use of restricted and conserved areas: as noted above, the current study looks only at the physical land base of western Massachusetts, and not at ownership or restrictions that may prevent raising crops. Determining whether and under what circumstances various parks, preserves, or conservation lands might be used for crop production represents a significant challenge, but it is safe to assume that much land with physical attributes suitable for biomass crop production would not actually be used for that purpose.

As shown above, biomass crop production on forestland is unlikely for financial reasons, even before considering environmental costs of land-use change. Chapter 4 also suggests that biomass crop production on existing cropland is unlikely, given the values of alternative crops. The most likely current landuse for cellulosic biomass crop production is thus grasslands. Figure 2-12 shows the supply function for switchgrass using 135 kg/ha N on grassland only. A linear regression fits this function very well for quantities between 5,000 and 125,000 Mg/year (R^2 = 0.99). The regression line equation is:

$$p = 95.28 + 0.09Q \qquad (2\text{-}35)$$

where *p* is the price of biomass in dollars per ton, and *Q* is the quantity of biomass in thousands of metric tons (to a maximum quantity of 125 thousand Mg). A realistic supply function for switchgrass in western Massachusetts would include some portion of this available quantity, perhaps half, given that the

Chapter 4 study finds half of landowners willing to accept a biomass crop planting proposition at the $321/ha land rent used in the supply calculation, and given other supply constraints noted above.

Note also that while the study area is western Massachusetts, the borders of the Commonwealth are not closed. With high biomass transportation costs, the biomass market is perhaps more local than most, but biomass supply and demand in the region as a whole will ultimately impact market prices and the quantity of biomass produced in western Massachusetts.

Use of unproductive lands

In Massachusetts there has been some interest in using otherwise unproductive lands for biomass crop production; utility corridors and highway medians are frequently mentioned as examples. The attraction of such lands is clear: if nothing has to be given up to obtain a useful new product, there is unambiguous gain. But a review of the potential of such lands reveals that total production potential is not large.

Land used for utility corridors is included in this study (land-use code 24). Given soil criteria and other screens used, 811 hectares of utility corridor are included in the feasible supply area. This represents 0.59 percent of the total feasible land area identified in the study; clearly inclusion or exclusion of utility corridors does not greatly affect biomass crop supply.

Highway medians are classified as transportation land, which is not included in the study. But a review of these areas reveals that the total supply potential is again small. Using the 2008 road data layers produced by the Massachusetts Executive Office of Transportation - Office of Transportation Planning (EOT-OTP), the database shows 119.2 km of rural limited-access roads in the four-county study area. These include rural sections of Interstates 90 and 91, along with segments of Route 2 and several other highways. Using the median width provided in the EOT-OTP database, and assuming the total tillable width is double this (to include land on sides of roads), a total of 989 hectares might be available. This assumes, of course, no other vegetation in these areas, and that all soils are suitable or could be made suitable for switchgrass cultivation. Even with these generous assumptions, the highway median and side areas add only 0.71 percent to the feasible production area identified in the study. While there may be substantial educational and promotional value in having highly visible land in highway medians used for renewable energy production, there would likely be significant safety issues to address in such places as well.

Perhaps the land of greatest interest is idle farmland that has not yet reverted to forest. Biomass crop production on such lands could both provide a renewable energy source and maintain agricultural land for future use, without the financial and environmental costs of removing existing forests, and without disrupting existing agriculture. Former dairy farms, for example, would be areas of interest. But identifying such land is difficult.

In an earlier study, the author (Timmons, Damery et al. 2008) calculated the difference between agricultural land as seen on GIS maps (based on satellite images) and as counted in the USDA Census of Agriculture. Since the census only counts land on active commercial farms, the difference between the census and the GIS data could represent abandoned agricultural land. It is, of course, difficult to assess degree of abandonment from a satellite view; land not in use by commercial farms could still be actively used for home production, for example. The 2008 study found 69 percent of pastureland was not counted in the USDA Census, and was thus potentially unused. If this same percentage held for the grasslands identified in this study, 9,936 hectares of grasslands might be idle.

In addition, farmers completing the census classified 888 hectares of cropland as idle. The total of 10,824 hectares represents 7.8 percent of the total suitable area identified in this study. Thus, perhaps as much as 7.8 percent of the supply identified in this study could be construed as coming from unused farmland, though the actual total is likely less than this, especially given use by active but non-commercial farmers.

Ecosystem service impacts

Beyond the marginal production costs of biomass crops, significant environmental externalities could arise as unintended consequences of that production, consequences that would not be reflected in the market price of biomass energy. In the case of biomass crop production, many of these externalities fall in the general category of ecosystem services.

Mooney and Ehrlich (1997) trace the origin of the ecosystem services concept to 1864, when *Man and Nature* was published by George Perkins

Marsh. The idea was not formally developed for some time, though, and the first use of the term "ecosystem services" was by Erlich and Erlich (1981), mostly in connection with biodiversity loss (Mooney and Ehrlich 1997). Sixteen years later, the ecosystem services paradigm emerged as a more general approach to incorporating nature in financial calculus, with the publication of *Nature's Services* (Daily 1997), and an article by Robert Costanza and company (1997) that attempted to estimate the value of seventeen major ecosystem services for the entire planet. In the year 2000, U.N. Secretary-General Kofi Annan called for "a comprehensive global assessment of the world's major ecosystems" launching the Millennium Ecosystem Assessment.

This study identifies likely ecosystem service impacts of increased biomass crop production, though without attempting to estimate economic values of these services.

Nitrogen fertilizer

Based on the technically feasible supply functions derived above, use of nitrogen fertilizers appears likely in any biomass crop production that might occur. Previous studies have also shown that some use of fertilizer is economically optimal for farmers (Nelson, Ascough et al. 2006; Lemus, Brummer et al. 2008).

Nitrogen fertilizer in various forms is produced primarily from natural gas (composed chiefly of methane, CH_4), used both for its hydrogen in synthesizing ammonia (NH_3), and for process energy (Gellings and Parmenter 2004). The world average energy requirement for nitrogen production is 69.53 MJ/kg; when packaging, transportation, and application energy are considered, the total is 78.23 MJ/kg (Helsel 1992). Yet based on the yield numbers shown above, nitrogen application has a positive impact on net energy yield.

Assuming dry switchgrass has an energy content of 18.4 GJ/Mg (McLaughlin, Samson et al. 1996), switchgrass gross energy per hectare can be calculated, and from this, energy required to produce nitrogen fertilizer can be deducted. As shown in Table 2-9, the yield effect of nitrogen dominates the nitrogen production energy requirements, at least for soils and nitrogen application levels modeled in this study. The 67 kg/ha N rate provides a 182 percent net energy improvement over no nitrogen, and the 135 kg/ha N treatment also provides a positive 51 percent improvement over 67 kg/ha N, though apparently at a declining rate.

While natural gas is typically used to produce nitrogen fertilizer, it is chemically possible to produce nitrogen fertilizer directly from electricity, which can be generated renewably (Gellings and Parmenter 2004). A recent project in Minnesota, for example, aims to produce nitrogen fertilizer from wind-generated electricity (Lammers 2010). Use of nitrogen fertilizer could thus be consistent with a renewable energy criterion.

Beyond yield and energy impacts, nitrogen fertilizer has several other effects, including release of nitrous oxide (N_2O, a greenhouse gas) when used, and nitrate (NO_3) pollution of groundwater and waterways. Some of these impacts are regional; the Connecticut River is a major source of nitrogen in Long

Island Sound, for example (Rideout, Craig-Nicolson et al. 2005). A full accounting of nitrogen's benefits and costs should consider all of these impacts.

Since biomass crops respond positively to nitrogen application, and are not food crops, fertilizing with waste products like municipal sewage sludge may be appropriate. This could be a positive ecosystem service from increased biomass crop production, as sewage sludge could otherwise be a pollution concern.

Forest change

As described above, the cost of converting forest to farmland may preclude any such land-use change for the foreseeable future. Yet this is possible. As noted above, 101,719 ha or 75 percent of the potential biomass crop land identified is now forested. Given the presence of agricultural soils, and historic extent of farming in the region, this is likely former farmland. The 101,719 ha of forest on soils with agricultural potential represent approximately 16 percent of the total forestland in the four-county study area. This land undoubtedly provides a range of ecosystem services that would be absent or provided to a lesser extent by cropland. For example:

- Carbon storage: a significant amount of stored carbon would be released initially if forests were removed, incurring a "carbon "debt" (Fargione, Hill et al. 2008). This debt would be minimized by using harvested forest biomass to substitute for fossil fuels, and by ensuring maximum potential energy utilization of the biomass, e.g. by burning wood only after drying to low moisture content. The carbon debt would eventually be repaid by increased renewable energy production from biomass energy.

- Water retention: grassland in general has higher runoff and less evapotranspiration than forest, which can impact downstream hydropower generation as well as flood control and other services (Zhang, Ricketts et al. 2007; Turner and Daily 2008). For example, a study of land cover impacts on hydroelectric production on the Yangtze River in China found that grassland had only 35% of the water conservation capacity of mixed forests (Guo, Xiao et al. 2000).
- Soil formation and retention: forest cover may be superior in both respects, though perennial crops like switchgrass have much less adverse soil impact than row crops (Graham 2007), for which the soil is regularly disturbed.
- Ecosystem services impacted by herbicide application, since herbicide is frequently used for establishing switchgrass. For example, herbicide use may curtail pollination services provided by beneficial insects, or pollute domestic water supplies.
- Other ecosystem services such as aesthetic, cultural and spiritual attributes, recreation, education, biodiversity, refugia, etc., though the marginal values of these may be low in a region that is predominantly forested. In some parts of the world, for example, any loss of forest could result in significant biodiversity reduction. Yet in western Massachusetts, the marginal cost of biodiversity loss from forest loss would likely be small,

at least unless forest cover were significantly reduced from its current level, or fragmentation of forest cover increased.

As shown in Table 2-10, this list of relevant ecosystem services is consistent with previous studies of biomass energy crop environmental impact (Ranney and Mann 1994; Graham, Downing et al. 1996) and agricultural externalities in general (Pretty, Brett et al. 2000).

To better assess whether and under what circumstances there might be incentive to convert forestland to cropland, an experiment is conducted using the tools described above. The question is how biomass yields from native forest compare to biomass yields from a switchgrass crop: are crop yields actually higher, and if so, how much? The ALMANAC model is used to generate switchgrass yield estimates on all forestland in Berkshire, Hampden, Hampshire, and Worcester Counties, as though the forest had been removed and replaced by switchgrass. Yield estimates are obtained for approximately 75 percent of the forestland area. These yield estimates are then compared to forest-growth data obtained from the USDA Forest Service, Forest Inventory and Analysis (FIA) program. FIA data provide forest growth by county, however, estimates are provided in volume per year rather than by weight. Since the FIA also provides data on dry biomass stock in tons, and volume stock in cubic feet, this ratio is used to estimate growth in dry tons. Resulting totals are reduced by the percentage of area for which no switchgrass yields are obtained. Results are shown in Table 2-11.

As shown in the table, there is little advantage to switchgrass production in terms of biomass tonnage when no nitrogen fertilizer is used; indeed forest outperforms switchgrass in dry tonnage by about 18 percent under these conditions. But this assumes dry biomass, while in practice there are important differences in moisture content. Switchgrass is harvested and dried like hay, typically with about a 15 percent moisture content (McLaughlin, Samson et al. 1996). For forest biomass harvested as woodchips, there is currently no easy or inexpensive drying method, and thus woodchips are typically burned green, at about 40 percent moisture content (Maker 2004). While dry forest biomass can have slightly higher energy content than dry switchgrass, switchgrass at 15 percent moisture content has more energy potential than woody biomass at 40 percent moisture content. So with no nitrogen fertilizer, forest may produce more energy on a dry matter basis, but under typical moisture conditions, switchgrass likely produces more energy. And with additions of nitrogen fertilizer, switchgrass biomass yields greatly exceed those of native forest. Indeed compared to forest, switchgrass is largely a vehicle for utilizing growth-enhancing nitrogen.

For biomass energy production, the question of forest versus field land use reduces to questions of total energy potential, production cost differences, and ecosystem service impacts. Clearly, it is imperative to better understand these differences and impacts. Under some circumstances, natural biomass production, e.g. in native forests or prairies, undoubtedly has higher total value than biomass crop production. This has significant implications for land-use optimization, in Massachusetts and elsewhere.

Conclusions

From results presented above, it is clear that switchgrass could increase availability of biomass in Massachusetts. While based on technical feasibility alone, the switchgrass quantity could be nearly double that currently available from forests, there are many obstacles that make such an expansion of biomass supply unlikely. Obstacles include production costs much higher than current costs for forest biomass, existing agriculture that is likely more profitable than switchgrass, landowner interest and motivation, restrictions on land use, and financial as well as environmental costs of land-use change.

Even in the most optimistic scenarios, the total biomass quantity supplied (woody and crop) will still be a fraction of current Massachusetts energy use, suggesting that energy conversion efficiencies will be important. In addition to efficiency issues, the total quantity supplied is likely inadequate to support cellulosic ethanol production. The Manomet report, for example, suggests that a cellulosic ethanol plant might require 1,096,909 dry Mg of biomass annually (Walker, Cardellichio et al. 2010).

Switchgrass will not likely enter the market unless biomass prices are significantly higher than now. Production cost on the most favorable land (of which there is very little) starts at about $91/dry Mg, and climbs to about $213/Mg for a quantity of 1,250,000 Mg/yr. Other studies have assumed that such prices are not economically feasible (e.g. Walker, Cardellichio et al. 2010) compared to recent biomass prices and to prices of fossil-fuel alternatives. This study, however, assumes that the relevant price comparison is to other renewables rather than to fossil fuels, and that biomass energy prices may have considerable long-run room for upward movement, in the context of developing a renewable energy portfolio.

These costs assume a nitrogen fertilizer input of 135kg/ha nitrogen fertilizer application. With a lower nitrogen application rate of 67kg/ha, maximum available quantity is lower, and with lower yields, costs are somewhat higher. With no nitrogen fertilizer use, modeled switchgrass quantities available are much lower and costs much higher than with nitrogen use. Empirical switchgrass trials have not yet confirmed model predictions of substantial nitrogen response. Should switchgrass dependency on nitrogen inputs be confirmed, this would suggest that more research on alternative biomass crops or crop mixes might be productive, particularly research on leguminous, nitrogen-fixing crops.

There is a substantial energy return on energy invested to produce nitrogen fertilizer, though this declines with higher nitrogen applications. Today nitrogen fertilizer is typically produced from natural gas, though it is possible to produce nitrogen fertilizer directly from electricity, which can be renewable.

Switchgrass yields with no nitrogen are similar to native forest yields on a dry-ton basis, but based on typical moisture content in practice, switchgrass energy yield per unit area is somewhat higher than for forest. Switchgrass with 135kg/ha nitrogen fertilizer is estimated to provide about 3.6 more dry biomass tonnage per hectare than native forest, but this equates to 5.4 times more energy yield, based on typical moisture contents in practice. Obtaining this increased yield by converting second-growth forests back to agricultural use would come at a significant financial cost and costs in environmental effects related to nitrogen application, as well as costs to the range of other ecosystem services provided by forests.

Though biomass crops are clearly not a renewable-energy panacea in Massachusetts, they may have limited but important applications. Likely among the most important is as a means to preserve farmland for which there is no current demand, for example where dairy farms have exited the industry. Given the cost of returning forestland to farming, keeping land in farming with biomass crops could prove valuable for future energy, food, or fiber production, and would help to provide landscape and habitat diversity in the Commonwealth.

Given its production process, switchgrass is more easily dried to low moisture content than forest biomass, and could be valuable in applications where low moisture content is important, for example in fuel pellet production. Biomass crops could also provide a way to utilize excess nutrients from sewage sludge or livestock operations, and to prevent these from becoming pollutants.

More research is needed on the likely gap between the technically feasible biomass crop supply and the likely market supply. Interactions with other markets, especially hay, are of primary interest. Chapters 3 and 4 look at landowner attitudes toward biomass crops, which also have an important bearing on market supply. Also, this study has examined only the potential for switchgrass as a cellulosic biomass energy crop in Massachusetts, and more research is needed on how other biomass crops (cool-season grasses, woody biomass crops, etc.) compare to switchgrass.

Ultimately, biomass crop production is just one of many possible land uses, and one of many possible energy sources. The value of biomass crops depends on both land-use alternatives and on energy demand and supply alternatives. More research is needed on the value of ecosystem services that may be gained or lost as land use changes to meet emerging energy needs. In particular, more research is needed on the total economic value of natural biomass production systems (e.g. forest, prairie) as compared to agricultural biomass systems.

Tables and Figures, Chapter 2

Table 2-1. Comparative switchgrass budgets

Study first author (year)	Duffy (2008)	Mooney (2008)	Haque (2008)	Perrin (2008)
study year(s)	2008	2008	2008	2001-2005
study state(s)	IA	TN	OK	NE, SD, ND
Important assumptions:				
discount rate	8%	8%	7%	10%
pounds nitrogen applied per acre	100	60	60	67
mean yield, tons/acre	4.0	6.4	5.4	2.2
Initial establishment, with reseed	$286	$222	$118	$71
Annual costs per acre:				
annualized establishment	$40	$51	$23	$13
land rent	$80	$100	$45	$60
annual maintenance	$79	$31	$25	$28
harvest	$129	$154	$97	$33
Total annual cost per acre	$329	$336	$191	$133
Total cost per short ton	$82.23	$53.03	$35.60	$59.98
Total cost per Mg	$90.45	$58.33	$39.16	$65.98

Table 2-2. Switchgrass budget per hectare, initial establishment

Initial establishment (amortized), $/ha		
	Duffy-IA	Modified for MA
Land rent	$197.68	$321.23
Machine operations		
disk	23.35	40.77*
harrow	15.44	37.06*
seeding & dry fertilizer	19.03	29.40*
spray herbicide	12.73	25.95*
Supplies		
seed	111.19	111.19
P (34 kg/ha @ $.81/kg)	27.43	27.43
K (45 kg/ha @ $.51/kg)	22.73	22.73
lime	155.67	155.67
herbicide	19.13	19.13
	$604.37	$790.56
Annualized cost @ 8%	$84.66	$110.74
Initial reseeding (expected value amortized), $/ha		
	Duffy-IA	MA
Land	$197.68	$321.23
Machine operations		
seeding & dry fertilizer	19.03	29.40*
spray herbicide	12.73	25.95*
Supplies		
seed	111.19	111.19
P (34 kg/ha @ $.81/kg)	27.43	27.43
K (45 kg/ha @ $.51/kg)	22.73	22.73
herbicide	19.13	19.13
	$409.91	$557.05
Probability of reseed	25%	25%
Expected value reseed	$102.48	$139.26
Annualized cost @ 8%	$15.27	$20.75
Total annualized costs	$99.93	$131.49

*PA rate (USDA and Pennsylvania Department of Agriculture, 2009)

note: this scenario uses Duffy fertilizer levels and yield

Table 2-3. Switchgrass budget per hectare, annual production

Production cost, $/ha/yr and $/Mg		
	Duffy-IA	modified for MA
Land	$197.68	$321.23
Machinery operations		
spread liquid N	11.86	27.18*
spread dry fertilizer	7.91	22.73*
spray herbicide	12.73	25.95*
Supplies		
N (112 kg/ha @ $.68/kg)	76.60	76.60
P (9 kg/ha @ $.81/kg)	7.09	7.09
K (102 kg/ha @ $.51/kg)	51.84	51.84
herbicide	19.13	19.13
Harvest-fixed		
mow/condition	$26.56	$35.09*
rake	13.10	21.50*
	$424.49	$601.24
Harvest-variable (@ 9.88 Mg/ha yield)		
bale	$222.65	$193.43*
stage	57.22	64.87*
	$279.87	$258.30
Interest on operating expense	$8.42	$10.37
Annualized expenses (from Table 2-2)	99.93	131.49
Total cost per hectare per year	$812.71	$1001.40
Mg/ha yield	8.99	8.99
Total cost per Mg	$90.45	$111.45

*PA rate (USDA and Pennsylvania Department of Agriculture, 2009)

note: this scenario uses Duffy fertilizer levels and yield

Table 2-4. Simulated ALMANAC yields and actual Massachusetts test yields

Nitrogen kg/ha	Simulated ALMANAC yield, Mg/ha	2009 actual mean yield, Mg/ha	Simulated difference from actual
0	7.56	8.11	-6.8%
67	9.35	9.44	-1.0%
135	9.80	9.83	-0.3%

Table 2-5. Parameter value assumptions for field proportion adjustment

Item	Symbol	Value	Unit
Tractor speed	z	13.5	km/hr
Effective width	w_e	3.6	m
Turning time	T	10.0	sec
Other downtime	d	0.1	hr/ha
Mean length		187.4	m

Table 2-6. Study land area by county, soils with crop potential, and land use

	Berkshire County	Hampshire-Hampden County	Worcester County	4-county area	
Total land area (ha)	245,116	305,444	409,014	959,574	
Soils with crop potential (ha)	51,530	150,714	128,481	330,725	
Crop potential, % land area	21%	49%	31%	34%	
Crop-potential land area after screening (ha):	Berkshire County	Hampshire-Hampden County	Worcester County	4-county area	land-use percent of total:
cropland	5,606	8,255	8,059	21,920	16%
grassland	4,062	4,500	5,838	14,400	10%
forestland	18,517	46,430	36,772	101,719	74%
Total (ha)	28,185	59,185	50,669	138,039	100%
Percent of soil area with crop potential remaining after screening	55%	39%	39%	42%	

Table 2-7. ALMANAC yield statistics across soils, Mg/ha

	Mean	Std dev	Min	Max
0 kg N	2.05	0.59	0.90	5.17
67 kg N	6.19	0.71	2.73	9.46
135 kg N	9.54	1.08	3.47	11.17

Table 2-8. ALMANAC yield statistics over 30-year simulations, Mg/ha

	Mean	Std dev	Min	Max
0 kg N	2.05	na	na	na
67 kg N	6.19	1.39	3.34	8.98
135 kg N	9.54	1.79	5.09	12.53

Table 2-9. Biomass net energy yield from nitrogen fertilizer use

Nitrogen applied, kg/ha	0.0	67.0	135.0
Nitrogen embodied energy, GJ/ha (based on 78.2 MJ/kg of nitrogen)	0.0	5.2	10.6
Switchgrass yield, dry Mg/ha	2.1	6.2	9.5
Switchgrass gross energy, GJ/ha (based on 18.4 GJ/Mg dry switchgrass)	38.6	114.1	174.8
Switchgrass energy, net of nitrogen embodied energy, GJ/ha	38.6	108.9	164.2
Increase in net energy with increased nitrogen application	na	182%	51%

Table 2-10. Studies of biomass crop ecosystem services

Potential environmental issue	Suggested Massachusetts biomass crop assessment	Ranney and Mann 1994	Graham, Downing et al. 1996	Pretty, Brett et al. 2000
Greenhouse gases	X			X
Hydrology	X	X	X	
Soil formation	X			
Soil erosion	X	X	X	X
Fertilizers	X	X	X	X
Herbicides	X	X		X
Pesticides		X		X
Wildlife habitat		X		X
Biodiversity		X		X

Table 2-11. Estimated forest biomass yields and switchgrass yields

	Berkshire County	Hampden-Hampshire Counties	Worcester County	4-county area
Forest biomass growth estimated from FIA data, dry Mg	452,954	534,672	597,374	1,585,000
Percent of forestland with switchgrass yield estimate	67%	78%	79%	
Forest biomass growth @ switchgrass land percentage, dry Mg	304,897	418,188	473,278	1,196,363
Switchgrass yield, 0 kg/ha N, dry Mg	208,070	327,616	475,760	1,011,446
Switchgrass yield, 67 kg/ha N, dry Mg	681,075	975,086	1,274,930	2,931,091
Switchgrass yield, 135 kg/ha N, dry Mg	910,449	1,489,653	1,949,988	4,350,090

Figure 2-1. The western Massachusetts study area

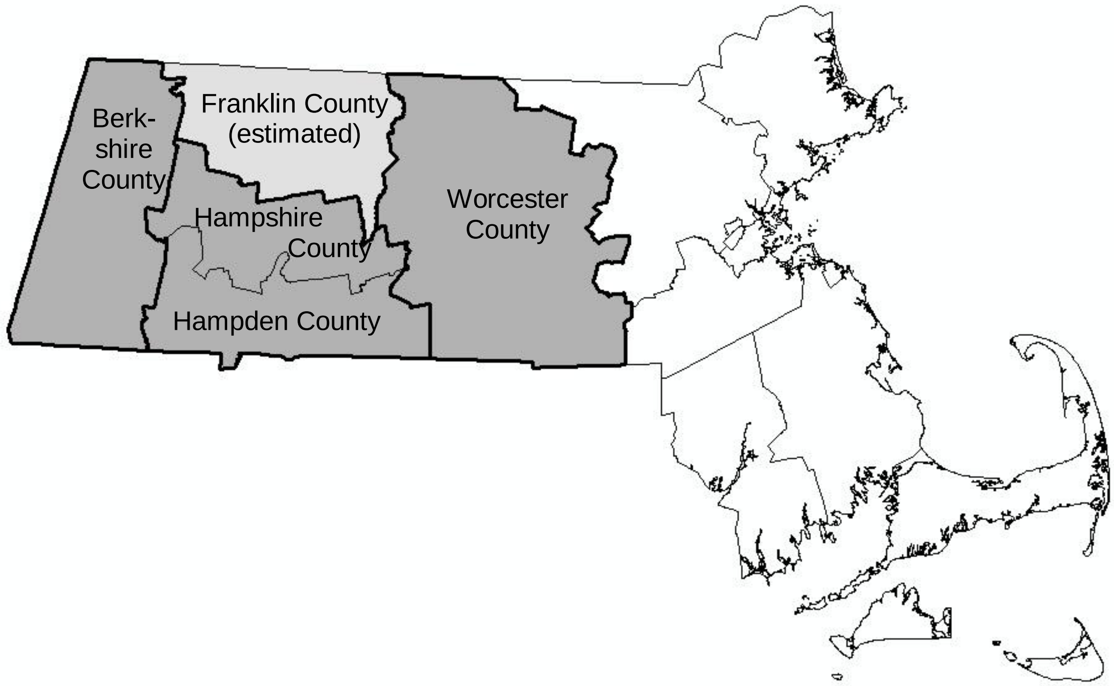


Figure 2-2. Soils with yield estimate for some crop

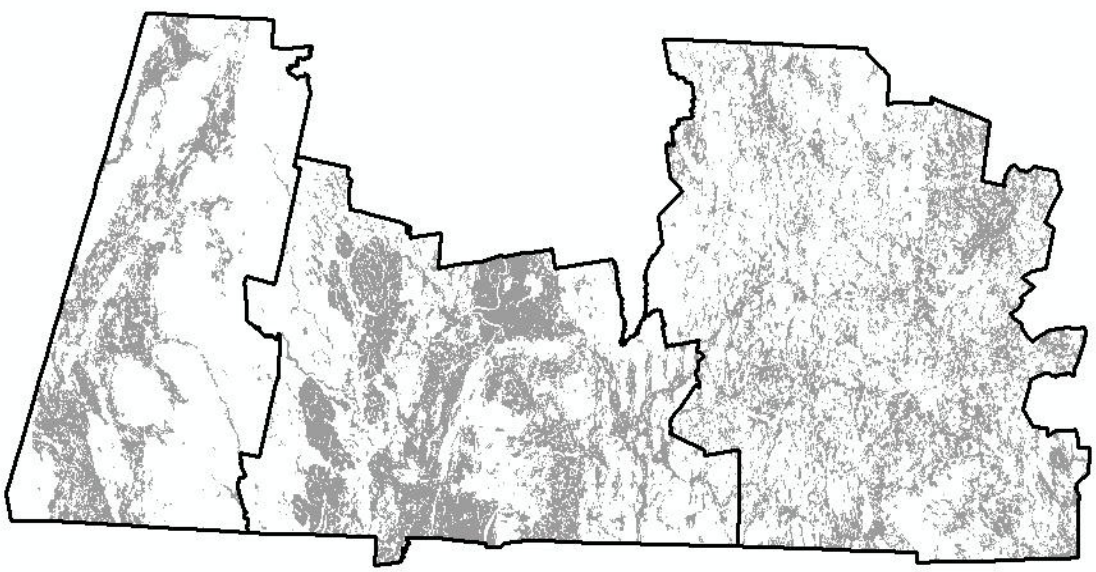


Figure 2-3, ALMANAC nitrogen stress model

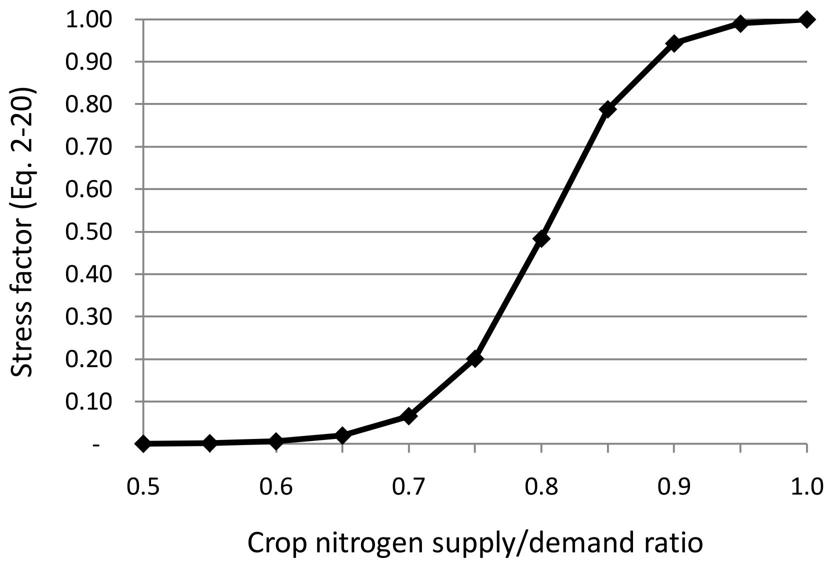


Figure 2-4. Schematic minimum travel distance to fields

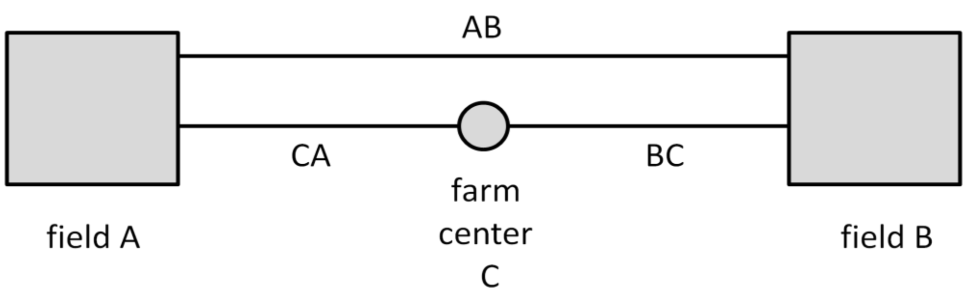


Figure 2-5. ArcGIS Model Builder operations

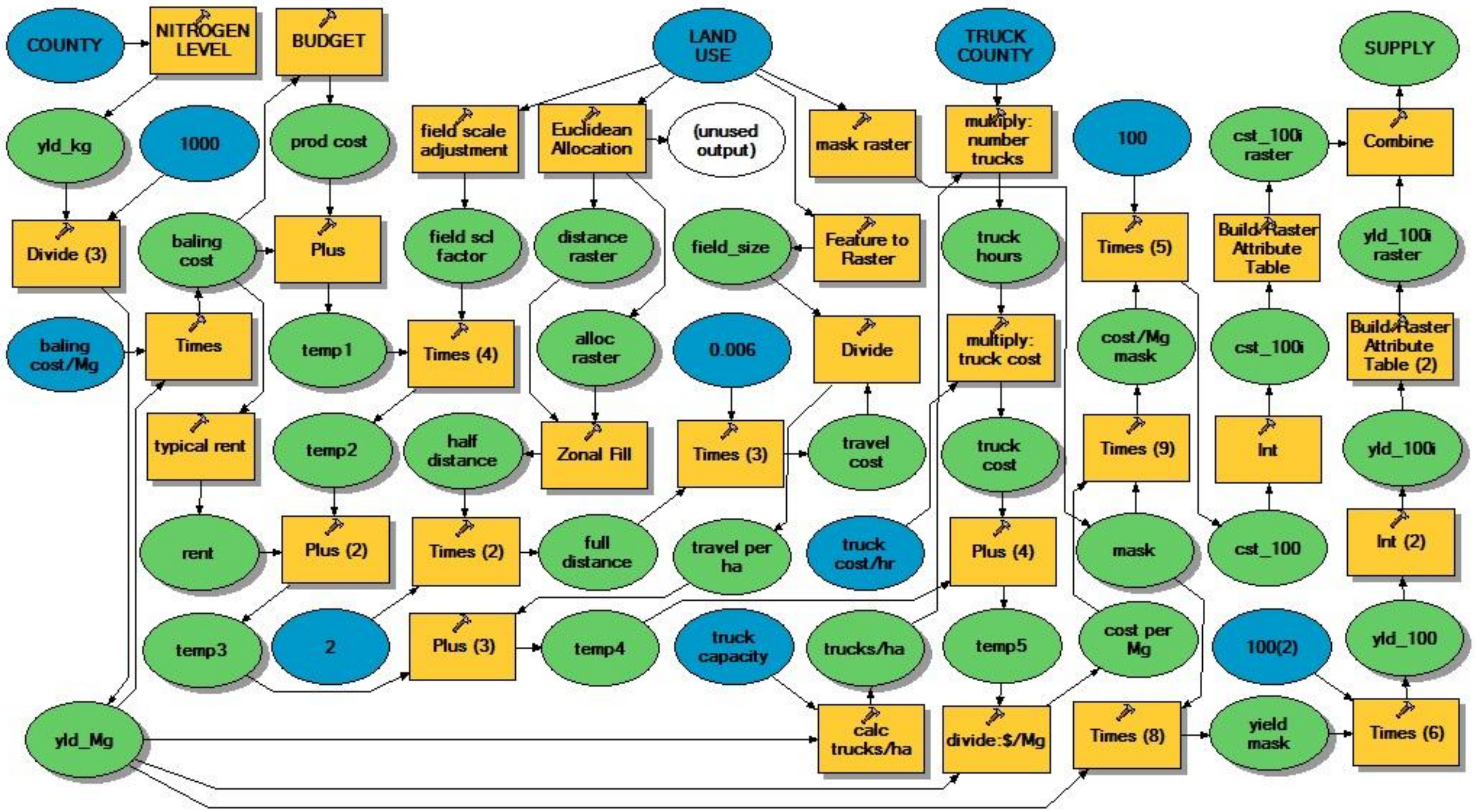


Figure 2-6. ALMANAC yield estimates by soil and nitrogen level

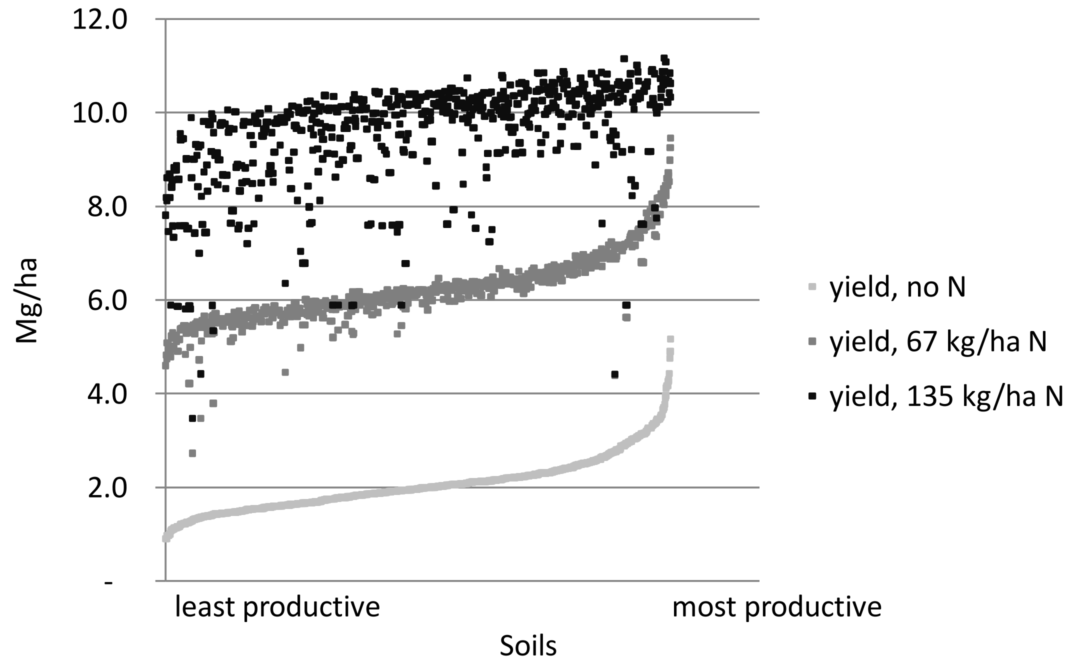


Figure 2-7. Mean yields for same soils at different elevations, no N

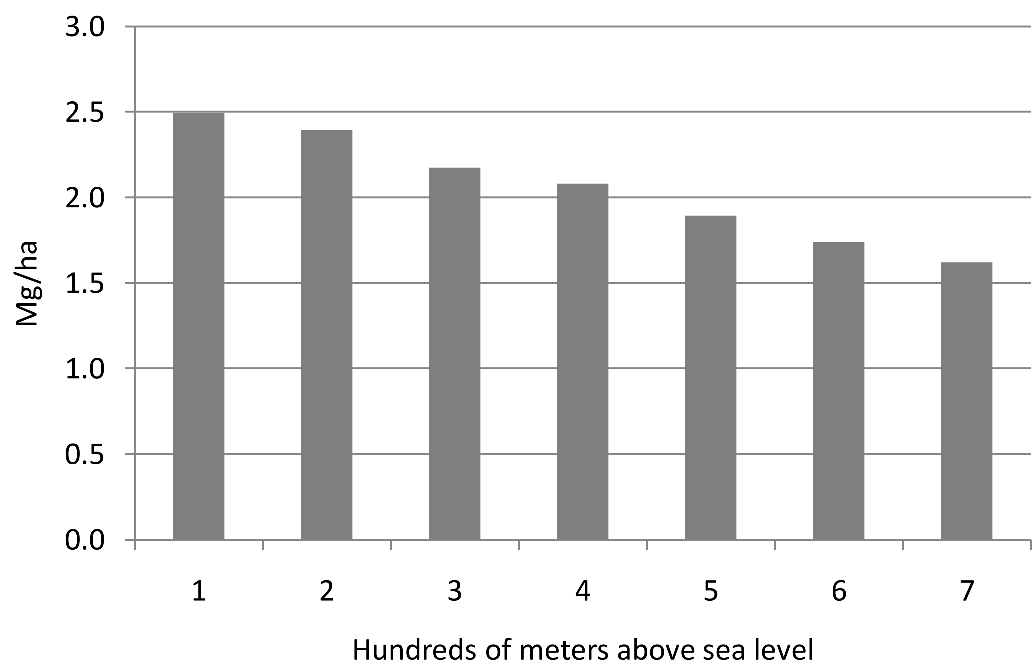


Figure 2-8. Supply functions by land use and aggregate, no N

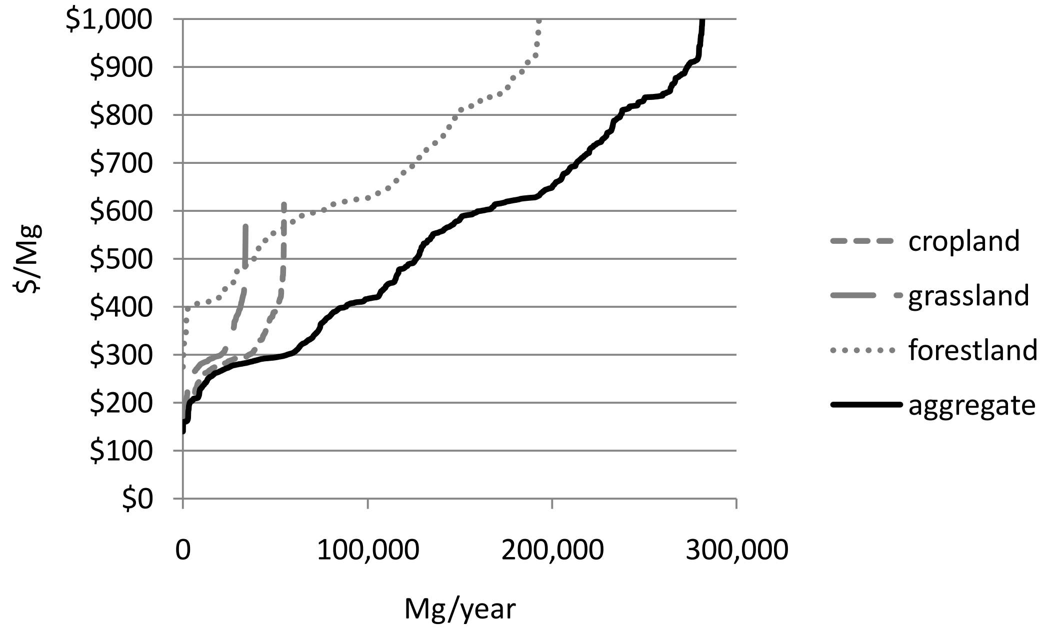


Figure 2-9. Supply functions by land use and aggregate, 67 kg/ha N

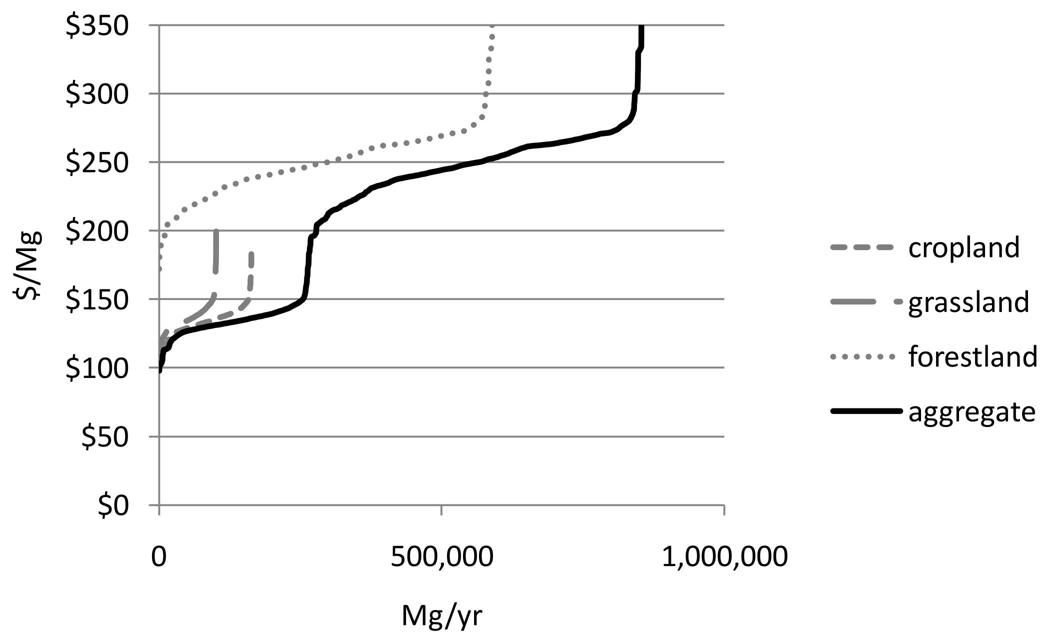


Figure 2-10. Supply functions by land use and aggregate, 135 kg/ha N

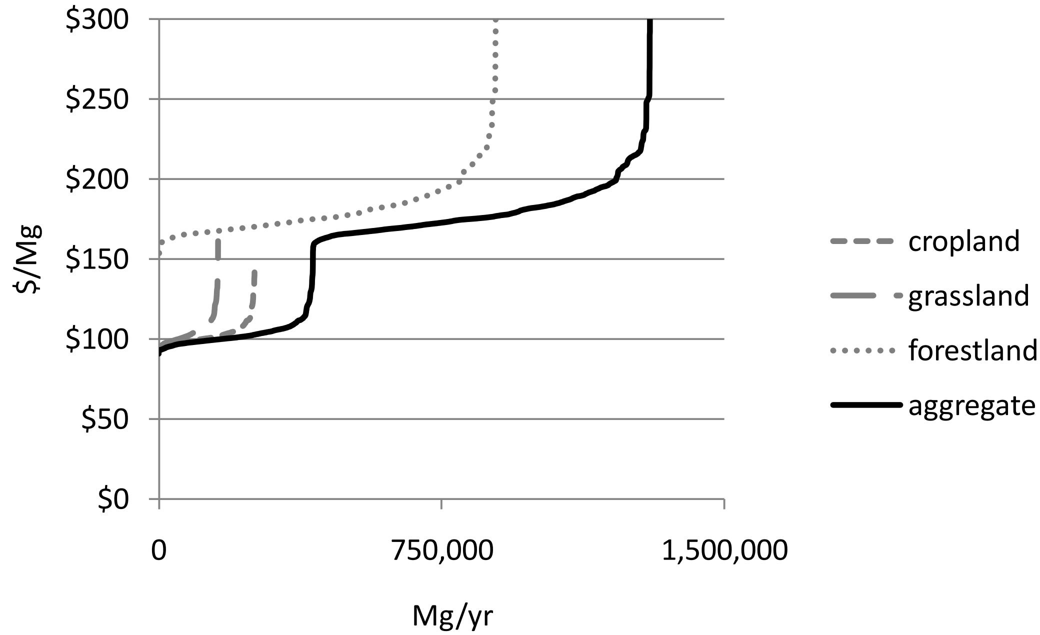


Figure 2-11. Aggregate supply functions by nitrogen fertilizer use, kg/ha

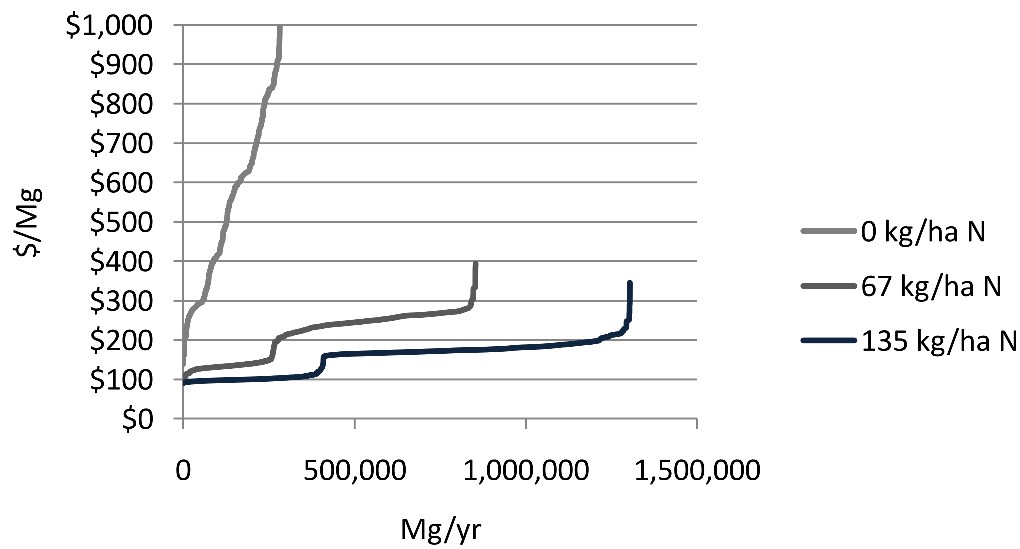
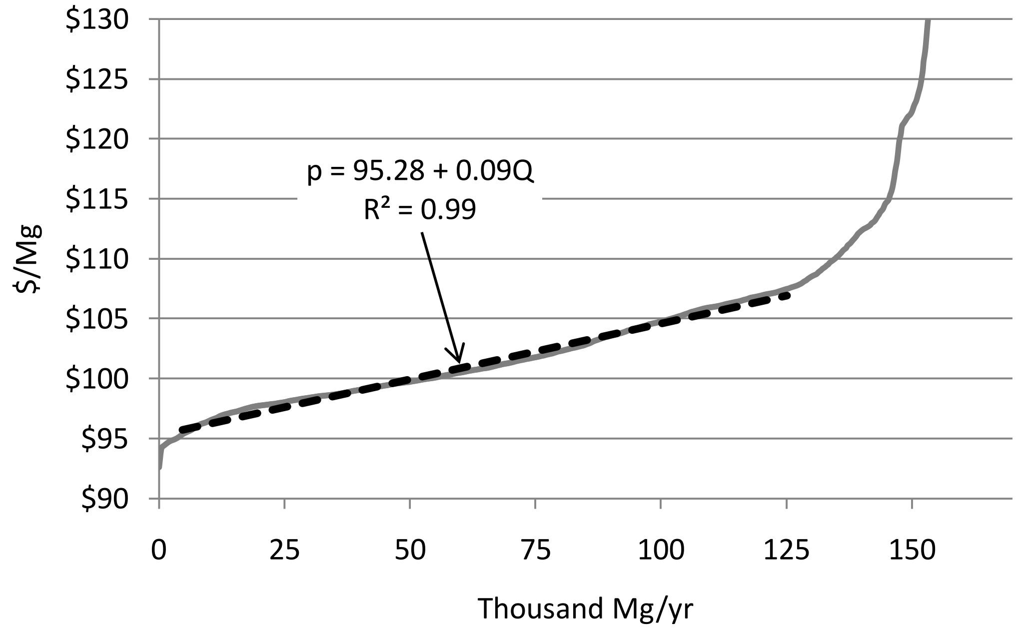


Figure 2-12. Grassland supply function, 135 kg/ha N



CHAPTER 3

BIOMASS CROP PRODUCTION AND LANDOWNER UTILITY

Introduction

As noted in the dissertation introduction, biomass can be thought of as a biological, low-efficiency solar collector. Though the attraction of biomass energy is that it can be relatively inexpensive compared to other renewable energy sources, its characteristic low solar-energy conversion efficiency means that a great deal of land is required to supply biomass energy in appreciable quantities. Chapter 2 demonstrates that such a land quantity in fact exists in western Massachusetts.

This chapter turns to the question of how likely that land is to be used for biomass crop production. The western Massachusetts land resource is owned by many individuals, and given the decline of farming in the region, we can assume that many hold property for reasons other than crop production. This study examines the circumstances under which such individuals might opt to make land available for the production of biomass energy crops. As suggested above, a primary interest is farmland no longer in use, given the opportunity to develop a new renewable energy resource without impacting food production or food prices. It can be assumed that much of this non-farmed land resource is owned by non-farmers, who are the main subjects of this chapter.

First, the social challenge of minimizing biomass energy cost is described. Attention next turns to decision making by owners of potential biomass production lands, and similar models of forest landowner utility are described.

Potential biomass crop landowner decisions are then characterized in a theoretical utility maximization model, and results are demonstrated in a simulation that models potential changes in landowner utility. Finally, given the above, options for motivating landowner participation in biomass crop production are discussed.

Minimizing Biomass Cost

Assume some exogenous fixed demand for biomass, perhaps determined by renewable energy policy. The problem is then to minimize the cost of providing this quantity of biomass crop energy. Any particular area has a finite capacity to produce biomass crops, with marginal cost increasing as less productive land is put into use, as indicated by the technically feasible supply function f in Figure 3-1. Producing some quantity of crops Q_0 at the minimum total cost, however, would require participation by all landowners with marginal production costs less than or equal to p_1. In the event that some landowners fail to participate in biomass crop production, the actual supply curve would shift to the left, as shown by f'. This raises the marginal cost of producing Q_0 to p_2.

The shaded area *EC* above f and below f' is the energy cost increase attributable to non-participation decisions made by landowners (the difference between $Q_0(p_2-p_1)$ and *EC* represents additional rent to participating landowners, a transfer to producer surplus rather than an energy cost). Note that unlike the case of a typical market model, we assume here that because the land resource is finite, and the technically feasible supply function includes all usable land, new producers cannot enter the market. Energy cost increase *EC* will be larger where 1) more land is withheld from production and 2) the marginal cost curve is steeper. Both situations are likely in places like Massachusetts, where much land is owned by people who do not farm it (Chapter 4), and land quality is heterogeneous, with relatively little of the most fertile, least-cost production land, and with marginal costs increasing rapidly when less-productive land is used (Chapter 2). The energy cost increase from non-participation is likely high in such places[1].

Previous Landowner Utility Models

A question is what might motivate landowners with appropriate land to participate in biomass crop production. The biomass cropping decision by landowners parallels the problem faced by non-industrial private forest (NIPF) owners who must decide whether to harvest a forest, and how to weigh the harvest value of the timber against the recreation or amenity values provided by an unharvested forest. On this subject there is considerable theoretical literature.

Hartman (1976) was one of the first to propose that landowners might not be strictly profit maximizing in their forest management behavior. While the growth function of a forest suggests an optimal harvest age (for maximizing forest harvest and associated income), Hartman observed that recreation and other forest services may also increase with forest age, if people value older-

[1] Note that this energy cost may be balanced by values that landowners obtain by removing land from production. A significant question, discussed below, is the extent to which such amenity values might be obtained concurrently with biomass crop production.

growth forest more than younger. Including the effect of this forest amenity value delays the optimum forest harvest. And if amenity values are of a sufficient magnitude, it may never be optimal for a landowner to harvest.

In Binkley's (1981) seminal study, a household production function was used to model the joint production of timber and other amenity values from forests. Amenities (e.g. recreation) were thought to be decreasing in timber harvest, i.e. more harvesting means obtaining less amenity value. Landowners maximize utility with respect to income and amenities, subject to the timber and amenity production possibilities of the land, and to a constraint on total income (timber income and exogenous income). Binkley found that in theory, an increase in the price of timber does not unambiguously increase harvest: a potential income increase must offset amenity loss, and marginal utility of amenities is likely increasing in income (if amenities are normal goods). For the same reason, an increase in exogenous (non-timber) income may reduce timber harvest levels. These findings suggested that some landowners would not follow strict profit-maximizing criteria in making land use decisions.

Models similar to Binkley's (1981) have been used in a number of other forest studies. Boyd (1984) extended Binkley's production model by explicitly modeling technology, labor, and capital inputs. Like Binkley, Boyd found that increasing timber prices did not unambiguously increase harvest, at least in theory, and observed that harvest subsidies might in fact reduce forest production. But in Boyd's model, technology improvements and technological assistance did unambiguously increase harvest.

Max and Lehman (1988) used a model like Binkley (1981), but in a two-period framework. Hyberg and Holthausen (1989) extended this to a multi-period utility optimization model in which effect on reforestation investment could be examined. Results were similar to those in earlier models; timber price increases were shown to increase reforestation but to have an ambiguous effect on harvest. An increase in land holding cost resulted in both more harvest and less reforestation investment.

Pattanayak, Abt, and Holmes (2003) also used a theoretical model similar to Binkley (1981) with modifications allowing the model to be applied in an empirical study, which confirmed that forest amenities were important products for landowners. Models excluding the amenity component were found to have biased coefficients, and to incorrectly predict the probability of forest harvest (Pattanayak, Abt et al. 2003).

There is also empirical evidence of heterogeneous forest landowner preferences. Erickson (2002) examined differences in forest management decisions between farmers and non-farmers. While farmers placed a higher value on forest income than did non-farmers, there was also evidence of farmers having non-timber amenity values for forests. Similarly, within groups of farmers it has been shown empirically that heterogeneous preferences may exist for conservation-enhancing farming practices (Chouinard, Wandschneider et al. 2008). Clearly, a continuum of landowners exists between pure profit maximizers and pure amenity maximizers, and this continuum crosses the farmer-nonfarmer boundary.

While a landowner decision to use open land to produce biomass crops is similar to a harvest decisions made by forest owners, there are some differences. Most biomass crops are harvested annually or on a short (5-7 year) cycle rather than on a forestry cycle (e.g. 30 years). The potential income per harvest will be lower for crops than forest, but crops provide more frequent harvests. The amenity cost of harvesting crops is likely lower as well: a forest harvest is typically considered unattractive, at least temporarily, and may significantly alter a valued landscape (hence reduction in amenity values with harvest). Production and harvest of a biomass crop does change land character and create some noise and other possible disamenities, but the harvest is faster than in forests, and the resulting landscape change—to a mown field—is not as dramatic as in forest harvest. Indeed for smaller landowners the main amenity cost of raising a biomass crop may be foregoing a more manicured, mown appearance during the pre-harvest growing season.

Utility Maximization by Owners of Potential Biomass Cropland

A version of the household production function model proposed by Binkley (1981) can illustrate the biomass crop production decision. The model could represent either a landowner who enters into a contractual arrangement for biomass production on her land, or self-production of biomass by a farmer.

The landowner maximizes utility subject to a typical income constraint, but in this case income can be obtained from crop production as well as exogenously. If utility is increasing in expenditure on consumption goods, then maximizing utility requires expenditure of all income.

In this model utility maximization is also subject to a constraint on the production possibilities of the land. Land can produce income from a harvest, and can also produce amenity value for the owner. But we assume that producing one may come at the expense of the other, that using land for production makes it less valuable to landowners for other purposes. For example, using land to produce crops may alter its wildlife habitat.

Landowners may use potential biomass cropland at many different levels of intensity, and with differing end products. In New England, fields that remain unused revert quickly to forests, so non-use is not considered a long-run option for fields. At a minimum level of intensity, fields can be mowed at least annually to prevent forest regrowth. If cuttings are left behind, no nutrients are removed, and this level of use can be maintained indefinitely. Income is negative, since a cost is incurred for mowing, but amenity value may be obtained from such fields, perhaps from aesthetic value, or from option or bequest values obtained from preserving land from reforestation. Mowing to lawn height is a more intense use, requiring more frequent mowing (and more cost), but providing some landowners more amenity than from tall grasses. Hay production requires semiannual or annual mowing and some replacement of nutrients removed in forage, and income is typically positive where markets for hay exist.

Clearly, many different levels of use intensity are possible, providing many combinations of income (positive or negative) and amenities. As with the income constraint, maximizing utility requires a landowner to obtain a maximum total product of income and amenities from the land. In other words, for utility maximization the product of a given field must be on that field's production possibilities frontier for income and amenity products.

Following Binkley (1981), Boyd (1984), and Pattanayak (2003), the landowner utility maximization problem for biomass crop production is:

$$max\ U = U[a, c] \tag{3-1}$$

where: *U* is utility, a function of

a, amenity values, and

c, expenditure on consumption goods

subject to:

$$c = m + pq \tag{3-2}$$

where: *m* is exogenous income,

p is price received by the landowner for the harvest,

q is quantity of biomass crops produced

and also subject to:

$$TP = g[q, a] \tag{3-3}$$

where: *TP* is total product of the land,

including harvest and amenity values, and

g is the production possibilities frontier of the land

(for which there is implicitly a production function).

Using the Lagrangian method, the expression to be maximized is then:

$$L = U[a, c] + \lambda(m + pq - c) + \mu(TP - g[q, a]) \tag{3-4}$$

Assumptions about the utility function and production possibilities frontier include:

$U_a > 0$ $U_{aa} < 0$

$U_c > 0$ $U_{cc} < 0$

$g_q > 0$ $g_{qq} < 0$

$g_a > 0$ $g_{aa} < 0$

These are the usual assumptions of strict concavity; utility increases at a decreasing rate in both amenities and total income, and production possibilities increase at a decreasing rate in harvest. It is also assumed that production possibilities increase at decreasing rate in amenities, i.e. that additional amenity provision is more difficult at higher amenity levels. In addition, it is assumed that:

$U_{ac} > 0$

The marginal utility of amenities increases in consumption expenditure, i.e. amenities are assumed to be a normal good.

$g_{aq} < 0$

The marginal product of amenities decreases in harvest, i.e. increasing production intensity reduces amenity productivity.

Differentiating the Lagrangian (Equation 3-4), the five first-order conditions for a maximum are:

$$\frac{\partial L}{\partial c} = u_c - \lambda = 0 \qquad (3\text{-}5)$$

$$\lambda = U_c \qquad (3\text{-}6)$$

Equation 3-6 says that the shadow value of consumption expenditure, λ, equals the marginal utility of consumption expenditure.

$$\frac{\partial L}{\partial a} = U_a - \mu g_a = 0 \quad (3\text{-}7)$$

$$\mu = \frac{U_a}{g_a} \quad (3\text{-}8)$$

Equation 3-8 says that the shadow value of the total product, μ, equals the ratio of the marginal utility of amenities to the land's marginal product of amenities.

$$\frac{\partial L}{\partial q} = \lambda p - \mu g_q = 0 \quad (3\text{-}9)$$

$$\mu g_q = \lambda p \quad (3\text{-}10)$$

Substituting from Equations 3-6 and 3-8 into 3-10:

$$\frac{U_a}{g_a} g_q = pU_c \quad (3\text{-}11)$$

$$\frac{U_a}{g_a} = p\frac{U_c}{g_q} = \mu \quad (3\text{-}12)$$

From Equation 3-12, we see that at the optimum, the ratio of marginal utility of amenities to the land's marginal amenity product is equal to biomass price times the ratio of marginal utility of consumption expenditure to the land's marginal biomass product. Both of these terms equal μ, the shadow value of the total product of the land.

$$\frac{\partial L}{\partial \lambda} = m + pq - c = 0 \quad (3\text{-}13)$$

$$c = m + pq \quad (3\text{-}14)$$

$$\frac{\partial L}{\partial \mu} = TP - g[q, a] = 0 \quad (3\text{-}15)$$

$$TP = g[q, a] \quad (3\text{-}16)$$

Equations 3-14 and 3-16 simply state that the income and production possibilities constraints must bind for utility to be maximized.

Comparative static results of interest are shown below, where the Lagrangian bordered Hessian determinant is negative (|*BH*| < 0), by second-order conditions for a utility maximum on the constraint set (Chiang and Wainwright 2005, p. 363).

$$\frac{\partial q}{\partial m} = \frac{g_a(g_q U_{ac} - p g_a U_{cc})}{|BH|} < 0 \qquad (3\text{-}17)$$

Harvest is decreasing in exogenous income, since marginal utility of amenities increases with consumption expenditure (u_{ac} > 0), as noted above. This says that increasing landowner income from non-land sources decreases biomass crop production, all else equal. Biomass crop production will be more challenging in areas with low land-based income and high exogenous income, e.g. for areas where land is owned primarily for residential and recreational purposes.

$$\frac{\partial q}{\partial p} = \frac{g_a(q g_q U_{ac} - g_a(U_c + pqU_{cc}))}{|BH|} < or > 0 \qquad (3\text{-}18)$$

Harvest level with respect to price of biomass produced is ambiguous, since higher prices increase utility through increased income and consumption expenditure (U_c > 0), but additional income and consumption expenditure are also postulated to increase marginal utility of amenities (U_{ac} > 0). Thus, raising the biomass crop price may or may not result in additional harvest. This is the same theoretical result obtained by others for non-industrial private forest owners, though empirical forest landowner studies typically find harvest increasing in price (Chapter 4). A closer examination of the terms in Equation 3-18 suggests a possible explanation.

Given that:

$|BH| < 0$ and $g_a > 0$ (from above)

then:

$$\frac{\partial q}{\partial p} > 0 \ if \ (qg_qU_{ac} - g_a(U_c + pqU_{cc})) < 0 \tag{3-19}$$

$$\frac{\partial q}{\partial p} > 0 \ if \ (qg_qU_{ac} - g_aU_c - g_apqU_{cc}) < 0 \tag{3-20}$$

$$\frac{\partial q}{\partial p} > 0 \ if \ qg_qU_{ac} - g_apqU_{cc} < g_aU_c \tag{3-21}$$

$$\frac{\partial q}{\partial p} > 0 \ if \ U_c > \frac{g_q}{g_a}qU_{ac} - pqU_{cc} \tag{3-22}$$

Since $U_{cc} < 0$ (from above) and all other factors are positive, expressions on both sides of inequality 3-22 are positive. The question of whether harvest quantity is increasing with respect to price then becomes a question about the magnitudes of the partial derivatives. Since empirically, it is typically the case that harvest is in fact increasing in price, at least for non-industrial private forest owners, it must typically be the case that marginal utility of consumption is greater than the expression on the right hand side of inequality 3-22. Specifically, assume that the land's marginal product of harvest is at least as much as the marginal product of amenities ($g_q \geq g_a \rightarrow (g_q / g_a) \geq 1$). It could then be hypothesized that both of the second partial derivatives of utility (U_{ac} and U_{cc}) on the right-hand side of inequality 3-22 are relatively small in magnitude, i.e. that increases in consumption may not greatly affect marginal utility from either additional consumption or from land amenities. This would explain empirical results that have been obtained in many studies of landowner behavior.

It can be further postulated that landowner utility from income and land amenities is additively separable, i.e. that the level of landowner utility from income may not depend on utility from land amenities, or the reverse. This assumption has been made in some studies of forest landowner behavior (Max and Lehman 1988; Kuuluvainen, Karppinen et al. 1996), and implies that there is no interaction between landowner utility from income and utility derived from other land amenities, i.e. that U_{ac} equals zero. The Chapter 4 landowner survey finds no statistically strong relationship between income and amenity values, suggesting that the second cross derivative of utility (U_{ac}) is at least small, and that landowner utility from income and amenities may indeed be completely separable, in which case U_{ac} is zero.

The assumption of additively separable utility also allows for an explicit characterization of the weights landowners attach to income and amenity values from their land. In this case the Lagrangian becomes:

$$L = \alpha v[a] + (1-\alpha)w[c] + \lambda(m + pq - c) + \mu(TP - g[q, a]) \quad (3\text{-}23)$$

where:

α is a weighting factor for utility from amenity and income

v is utility as a function of

a, amenity values

w is utility as a function of

c, expenditure on consumption goods, and

the other variables and parameters are the same as above.

Assumptions include:

$v_a > 0$ $v_{aa} < 0$

$w_c > 0$ $w_{cc} < 0$

$g_q > 0$ $g_{qq} < 0$

$g_a > 0$ $g_{aa} < 0$

The new comparative static result of interest is:

$$\frac{\partial q}{\partial \alpha} = \frac{g_a(g_q v_a + p g_a w_c)}{|BH|} < 0 \tag{3-24}$$

This indicates that harvest is decreasing in alpha, the weight a landowner attaches to amenity values from the land. The more a landowner values amenities, the less that biomass crops are produced (assuming that utility is indeed additively separable).

Landowner utility can also be expressed as indirect utility, i.e. utility based on the exogenous-income, harvest-price, and land-product parameters, rather than utility obtained directly from consumption goods and land amenities themselves. This can be useful in empirical studies, as in the Chapter 4 landowner survey, since utility from consumption goods and land amenities cannot be directly observed.

The indirect utility function can be derived from the utility function using the implicit function theorem (Chiang and Wainwright 2005, p. 435). The indirect utility function gives the maximum levels of utility for different levels of price, income, and total product. As above, the landowner utility maximization problem for biomass crop production is:

$$max\ U = U[a, c] \quad (3\text{-}1)$$

with the associated Lagrangian equation:

$$L = U[a, c] + \lambda(m + pq - c) + \mu(TP - g[q, a]) \quad (3\text{-}4)$$

All variables are as defined above, and the set of first order conditions implicitly defines solutions for *c, a, q, λ,* and *μ* as functions of the exogenous parameters *m, p, and TP*:

$$c^* = c(m, p, TP) \quad (3\text{-}25)$$

$$a^* = a(m, p, TP) \quad (3\text{-}26)$$

$$q^* = q(m, p, TP) \quad (3\text{-}27)$$

$$\lambda^* = \lambda(m, p, TP) \quad (3\text{-}28)$$

$$\mu^* = \mu(m, p, TP) \quad (3\text{-}29)$$

The indirect utility function is obtained by substituting the solutions for c^* and a^* back into the utility function:

$$U^* = U[a^*(m, p, TP), c^*(m, p, TP)] \equiv V(m, p, TP) \quad (3\text{-}30)$$

where *V* is the landowner's indirect utility function. It can also be shown that a utility function will have an indirect utility function as its symmetric dual, even under very weak assumptions about the form of the utility function (Martinez-Legaz 1991). An indirect utility function thus provides the same information about utility as a direct function. This indirect utility function is the basis for the empirical study in Chapter 4.

Utility Simulation Study

The problem of motivating landowners to engage in biomass crop production can be seen more clearly in a simulation of utility changes, based on changes in biomass income and amenity values, for landowners who attach different weights to the amenity values of their land. The utility model used for the simulation is:

$$U = \alpha ln(a) + (1 - \alpha) ln(m + bH) \quad (3\text{-}31)$$

where:

U is utility, a function of

a, annual amenity values from the land, and

total income, received from

m, exogenous income ($/yr),

b, amount bid for biomass crop payment ($/ha/yr), times

H, the number of hectares growing biomass crops, and where

α is a weighting factor for utility from amenity and income.

Utility is again posited to be additively separable, and in this case, increasing with the natural log of amenity and income, i.e. increasing at a decreasing rate. A logarithmic utility function has been suggested by Arrow (1965, p.37) as being consistent with theoretical expectations, and satisfies the properties assumed above. This function has also been used in simulation of non-industrial private forest owner behavior (Max and Lehman 1988).

For the simulation results shown in Table 3-1, land area for biomass crop production is assumed to be 8.6 hectares, the mean grassland ownership reported in the Chapter 4 landowner survey (which included 78 percent non-farmers and 22 percent farmers, as defined in Chapter 4). Exogenous income is set at $57.2 thousand, a population-weighted average of 2008 county median household income in the five western Massachusetts counties (U.S. Census Bureau 2008), though results from Chapter 4 suggest median income is higher than this among western Massachusetts landowners. An arbitrary initial amenity value is set equal to income, at 57.2 thousand per 8.6 hectare plot, since changes in natural log values are sensitive to initial values. Initial landowner income per hectare is set at $0.321 thousand per hectare, based on the median payment landowners were willing to accept to plant biomass crops in the Chapter 4 study.

Table 3-1 shows percentage changes in utility from different combinations of crop income and amenity changes. Landowner utility weights for amenities (α) are shown in sections a, b, and c for alpha values of 0.1, 0.3, and 0.5 respectively. The "no harvest" column in each section shows changes in total landowner utility as amenity value increases, for landowners who choose not to produce crops. The next column shows utility change at different amenity change levels for landowners who do plant and receive the base income of $321 per hectare, as compared to not planting. The next column shows utility change for planting at $321/ha + 100% as compared to not planting, etc.

With an amenity weight (α) of 0.1, an increase in amenity values has about the same impact on utility as an increase in crop income. For example, doubling amenity value with no crop income produces 2.7% more utility, while doubling crop income with amenity held constant produces 3.0% more utility. But when landowners place more than a minimal weight on amenity values, amenity increases have more impact on utility. When landowners have equal utility weights for amenities and income (section c., α = 0.5), doubling amenity value increases utility eight times more than planting and doubling crop income, all else constant.

The reason for these simulation results is clear. The small landowners modeled here (based on a typical western Massachusetts situation) receive the great majority of their income from sources other than their land. Increasing biomass crop income changes their total income only slightly, while changes in amenity values may significantly alter utility received. While increasing crop income does raise utility, with these assumptions the effect is much smaller than when amenities are increased.

Note that crop income is likely a more significant determinant of utility for farmers, who receive a greater proportion of their income from the land, and who may have lower utility weights for land amenities than do non-farmers. For example, using the same model but with the Massachusetts average 27.1 hectares per farm (USDA 2009), the same exogenous income, and an amenity weight (α) of 0.05, doubling crop income with amenity held constant produces 6.5 times as much utility increase as doubling amenity value with crop income held constant. There is also greater utility increase from crop income when exogenous income is lower, which may be the case for farmers.

Motivating Landowner Participation in Biomass Crop Production

Returning to the social problem of minimizing cost of the desired quantity of biomass crop energy, it is clear from the discussion above that there will likely be challenges in motivating landowner participation. This may be especially true where there are small parcels of land with relatively low income potential but high amenity values for owners, in places where owners have considerable exogenous income, and where there may be negative externalities from crop production. This is likely the situation of biomass crops in Massachusetts.

Yet from the discussion above, it is also clear that at least two avenues toward total biomass cost minimization could be explored, related to 1) the shape of the land's production possibilities function and to 2) the landowner's utility function.

The land production possibilities function represents efficient combinations of biomass crop income and amenity values from a given piece of land. It would, however, be an oversimplification to consider only one possible function. Clearly, there are many ways to raise a crop for income, and many ways that amenity value might be provided by cropland.

At one extreme, a linear production possibilities function indicates a perfect tradeoff between amenity and income production (Figure 3-2, g_1). For each additional unit of income obtained, a unit of amenity is lost. A landowner can combine income and amenities in any proportion, but always loses one to gain the other.

More typically, we think of a production possibilities function as being concave (Figure 3-2, g_2). On the upper part of the curve, gaining an additional unit of income requires giving up less than a unit of amenity. This suggests either that land hectares are heterogeneous in their production capability for the two goods, or that the same hectares can jointly produce amenity and income. Also, with a high amenity level, securing low levels of income does not entail losing much amenity.

At the other extreme, an orthogonal production possibilities function (Figure 3-2, g_3) suggests that income and amenity production are completely independent. Any level of income up to the maximum can be obtained without giving up any amenity, and the maximum levels of both amenity and income are available together. Clearly, g_3 provides the highest landowner utility, at u_3.

While an orthogonal production possibilities function may not be technically possible, one can still ask how production possibilities might become more rather than less angular. The key is to seek ways to provide both amenities and crop production, with as little tradeoff between them as possible. There are a number of possibilities for increasing amenity production from land use, i.e. for increasing g_a. This pertains especially to currently idle farmland with biomass production potential:

- Choose biomass crops according to landowner aesthetic preferences. Grassy biomass crops like switchgrass have a more traditional agricultural appearance than woody crops like willow, and may be preferred by some landowners for this reason (and the Chapter 4 landowner survey finds that grassy crops are in fact preferred). Crop height may also be important, and can range from one to several meters depending on crop chosen. In some cases lower-growing species may be preferred for the views they afford, while in other cases taller species may provide valued screening and privacy.

- Design plantings to increase landowner use, for example by creating mown walking paths within biomass crop fields. This allows owners to access their land, observe seasonal changes, exercise outdoors, etc. The Tower Hill Botanical Garden in Boylston, Massachusetts, has mown networks of walking paths within its fields (though the fields are not harvested for biomass energy). Paths are designed for access to views and other trails, with occasional benches provided in prime locations. While mowing paths through fields is not a conventional farm practice, as this is an expense and the path area is lost to crop production, little agricultural land is lost in the provision an amenity that may be significant to at least some landowners (as the Chapter 4 results suggest).
- Use biomass crops to provide other amenities, e.g. wildlife habitat. Field ecosystems provide different habitat than woodlands, increasing species diversity in areas that are mostly forested. Biomass crops like switchgrass are well suited to bird habitat, since they are cut only once per year, in late fall, after nesting season (unlike hay, which is typically cut the first time in May, during nesting season). Chapter 4 suggests that wildlife habitat is a significant amenity for many Massachusetts landowners. At its Arcadia

wildlife sanctuary in Easthampton, MassAudubon has approximately 16 hectares of switchgrass planted specifically for bird habitat. While the switchgrass is not currently harvested for fuel, nothing would preclude this (Walker 2009).

- Minimize use of chemical herbicides, fertilizers, etc. on lands where this creates landowner disamenities or interferes with wildlife objectives. Though this likely entails some yield reduction and corresponding income decrease, it may also increase amenity value sufficiently to bring land into biomass crop cultivation that would otherwise not be used. Chapter 4 suggests that agricultural chemical use is a major landowner concern (especially for non-farmers), though organic alternatives may be more acceptable.

While this list is not intended to be exhaustive, it should be clear that standard crop production can be modified in ways that may create more landowner amenity value. Similarly, one can examine the nature of the landowner utility function, and ask whether there are ways to develop utility from crop production, i.e. to increase U_a. Again, there are at least several possibilities:

- Provide education on the social benefits of transitioning to renewable energy. As noted above, part of the motivation for biomass cropping is replacing fossil-carbon fuel, and social cost minimization requires participation by landowners with appropriate land. While many landowners likely value environmental benefits, the linkage between their land-use decisions and environmental outcomes may not be completely clear. This could be characterized as an information failure. Providing more information about social benefits of biomass crop production could increase landowner utility from participation.

- Seek ways to enhance social status of landowners who engage in biomass crop production. Providing recognition, awards, etc., may increase landowner utility and reduce biomass energy cost, at little or no cost to society.
- Appeal to landowners' desire for energy security. In many cases biomass energy will replace imported fossil energy, increasing national energy security and perhaps reducing costs of ensuring fossil fuel supply from unstable parts of the world. In some cases landowners may also get utility from personal energy security, i.e. from producing their own energy supply (though Chapter 4 suggests this is important to only a small number of landowners). Grass pellet production, for example, is technically feasible at a farm scale, so that a farmer might produce energy to heat her own home and facilities. Or, a community may derive utility from raising biomass crops to heat its own school. If energy self-production increases landowner utility, more biomass may be produced.
- Emphasize preservation, option, and bequest values of land. In New England, much land that has gone out of agricultural production has reverted to forest, potentially compromising its future agricultural productivity (Chapter 2). Landowners may receive utility from the knowledge that farmland is being preserved for use by future generations,

whether or not they actually value current production. As indicated in Chapter 2, this may be a primary niche for biomass crops in Massachusetts.

Conclusions

Biomass energy crops represent a potential (if partial) solution to the problem of securing a carbon-neutral energy source. By their nature, biomass crops require large amounts of land. For an area like Massachusetts that has rising marginal biomass production costs (as shown in Chapter 2), obtaining a given quantity of biomass at the lowest cost requires participation by landowners with appropriate land. Yet models of landowner decision making suggest that many landowners may not be inclined to use their land for biomass crop production, at least not if doing so results in significant loss of amenities from the land.

As economists, we typically prescribe prices as the tool of choice for influencing behavior. But for biomass crop production in some circumstances, theoretical results suggest that price increases may not be the most effective way to motivate landowner participation. Instead, attention should be given to modifying production practices in ways that increase (or at least do not decrease) owner amenities obtained from the land, and to improving information and social structures that increase landowner utility from participation in cropping.

As the earth transitions from a planet with few people and many resources to one with many people and fewer resources, new challenges in resource procurement are certain to arise. The case of biomass crops, which appears to require non-standard supply approaches, may become more typical.

Tables and Figures, Chapter 3

Table 3-1. Simulated percent utility change at different amenity weights

a. Utility change at amenity weight α = 0.1

percent change amenity	no harvest	percent change crop income per hectare		
		0%	100%	200%
0%	0.0%	1.0%	2.0%	3.0%
100%	1.7%	2.8%	3.8%	4.7%
200%	2.7%	3.8%	4.8%	5.7%

b. Utility change at amenity weight α = 0.3

percent change amenity	no harvest	percent change crop income per hectare		
		0.0%	100.0%	200.0%
0%	0.0%	0.8%	1.6%	2.3%
100%	5.1%	6.0%	6.7%	7.5%
200%	8.1%	9.0%	9.7%	10.5%

c. Utility change at amenity weight α = 0.5

percent change amenity	no harvest	percent change crop income per hectare		
		0.0%	100.0%	200.0%
0%	0.0%	0.6%	1.1%	1.7%
100%	8.6%	9.1%	9.7%	10.2%
200%	13.6%	14.2%	14.7%	15.2%

Figure 3-1. Energy cost to society of landowner non-participation

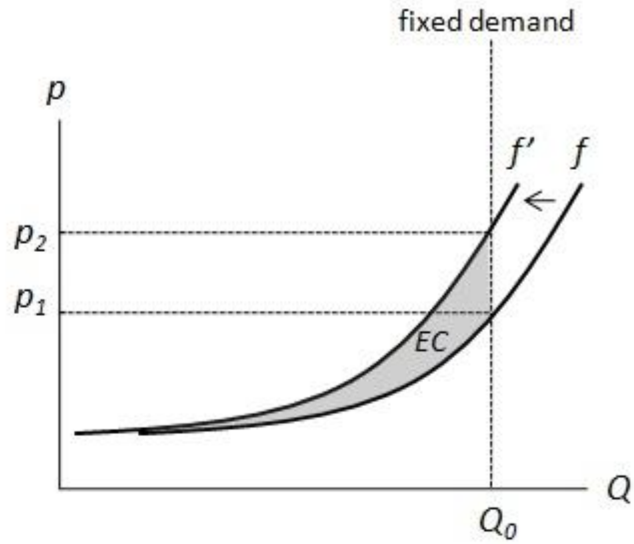
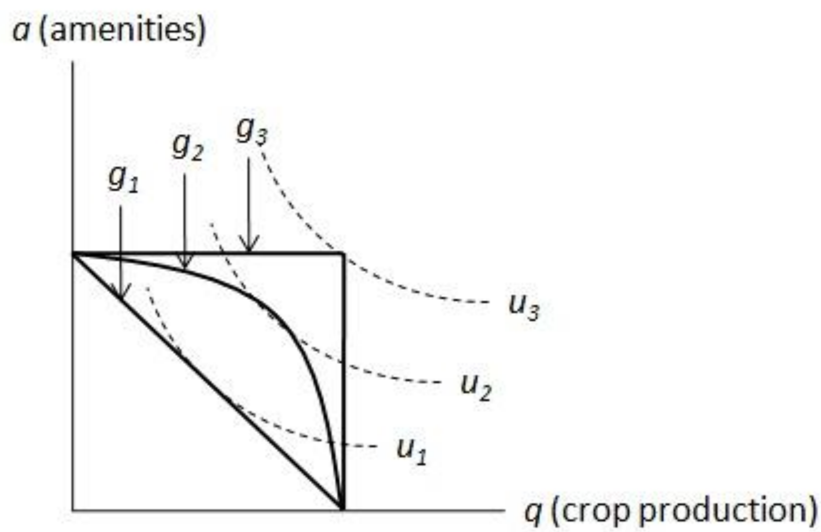


Figure 3-2. Production possibility frontiers and attainable utility levels



CHAPTER 4

A BIOMASS CROP LANDOWNER SURVEY

Introduction

As emphasized throughout this dissertation, biomass as an energy resource is land intensive. Chapter 2 looks at the western Massachusetts land area in detail, considering the quantities of land available, its likely productivity, and costs of its utilization. The analysis considers three general classes of current land use: cropland, grassland, and forestland that was likely either cropland or grassland in the past. Of these land-use classes, Chapter 2 demonstrates that forestland has economic limitations for biomass crops, as well as having obvious but unquantified ecosystem service costs to convert it back to agricultural production. Cropland may have economic issues as well, in that current New England field crops are likely of higher value than biomass crops. Existing grassland is the most obvious land resource for producing biomass energy from crops, though high values of hay and forage produced on these lands also present alternatives to biomass energy crop production. This chapter looks at the question of land-use value from the perspective of landowners, providing insights about the feasibility of using Massachusetts croplands and grasslands. Estimating payments or rents landowners would require to make their lands available for producing biomass energy crops is a primary objective of this study.

Chapter 3 considers landowner biomass cropping decisions from a theoretical perspective, and demonstrates that landowners may be reluctant to adopt biomass crops in areas like western Massachusetts, where many landowners have high exogenous incomes, and can be assumed to have high amenity values for land. This chapter looks at those same questions empirically, suggesting landowner characteristics associated with higher probability of biomass crop adoption, as well as suggesting approaches to biomass cropping that may have the greatest appeal to landowners.

Because there is no existing market for biomass crops in western Massachusetts, this study uses a contingent valuation (CV) approach, treating biomass crop income as a hypothetical good, and querying landowners about their willingness to accept different levels of compensation in return for planting biomass crops. While there is a large theoretical literature about the possible non-equivalence of willingness-to-pay (WTP) and willingness-to-accept (WTA) approaches (e.g. Hanemann 1991), for this study the WTA approach parallels the actual decision made by a landowner considering agricultural use, and thus suffers from no theoretical constraints.

Questionnaires were distributed to 957 owners of potential biomass cropland in western Massachusetts, with a usable return rate of 28 percent. Land with agricultural potential that is not now being farmed is of particular interest, and non-farmers comprise a large part of the survey sample. Seven different versions of the questionnaire with different bid levels were presented to different respondents.

Based on the proportion of respondents willing to accept each bid level, both non-parametric and parametric methods are used to estimate median and mean WTA, as described below. In addition, this study reports univariate analysis for land and landowner statistics of interest, bivariate measures of association between land and owner characteristics and WTA, cluster analysis that describes characteristics of groups most and least likely to adopt biomass crops, and a binary logistic model that predicts bid acceptance based on bid level and vectors of land and owner attributes. Together, these complete a picture of current biomass crop potential in western Massachusetts.

Previous Research

A review of the literature finds few other landowner surveys related to biomass crops, and finds only surveys of farmers. One study of Tennessee farmers mailed 15,002 questionnaires (with a 24 percent response rate) asking farmers an open-ended question about how many acres they would plant to switchgrass under self-defined "profitable" conditions (Jensen, Clark et al. 2007). Analysts then used a Tobit model to predict acres planted based on demographic, attitudinal, and farm characteristics. The majority of farmers was found to be unfamiliar with the idea of growing switchgrass for energy. Younger farmers, those with more education, and those with higher off-farm income were more likely to be interested. Farms with higher current net income per acre were less interested. An open-ended question asking the minimum required profit per acre for switchgrass production provided no usable data, due to the wide range of responses received, and apparently differing interpretations of profit (Clark 2009).

Another study in central Florida looked at landowner attitudes about biomass production, in a region where raising biomass field crops would be a significant departure from citrus and ranch styles of agriculture dominant in the region (Rahmani, Hodges et al. 1996). Questionnaires were sent to 940 landowners (with a 33 percent response rate), and several large corporate landowners were interviewed individually. Data from the 128 responding landowners who had non-citrus acreage were retained for analysis (since citrus conversion to biomass crops was assumed to be unlikely). Less than 15 percent of respondents claimed any knowledge of biomass crops, which the study found to be a significant barrier to adoption. Although a few landowners were willing to grow biomass crops for as little as $25/ha profit, willingness to plant increased non-linearly with increasing bid amount (mean and median WTA were not reported).

A qualitative survey using a convenience sample of 52 farmers and farm industry representatives in Iowa found potential biomass crop profitability to be an important, but not the exclusive factor in deciding to plant switchgrass (Hipple and Duffy 2002). Other factors such as probability of success, compatibility with current crops, consistency with farmer values and beliefs, and aesthetic and wildlife impacts were also found to be important. Respondents had difficulty ranking the importance of these factors, as they usually considered combinations of attributes rather than individual attributes in their decision making. Reported factors discouraging switchgrass planting were many and varied, including lack of secure markets, capital requirements, lack of knowledge or uncertainty about new crops, increased complexity of farming multiple crops, and distrust of government programs. The study reported that many farmers were taking a "wait and see" approach to biomass crops.

While there is very little (if any) previous research on biomass crop planting decisions by non-farmer landowners, as in the Chapter 3 study, there are many empirical studies of Non-Industrial Private Forest (NIPF) landowner harvesting decisions, which are likely similar to biomass crop planting questions. An early empirical study by Dennis (1989) in New Hampshire used harvested timber volume as a dependent variable in a Tobit model, with both forest and landowner characteristics as right-hand side variables. While harvest volume was found to be sensitive to forest attributes like species composition and stock volume, timber price was not found to be a significant explanatory variable even at the 20 percent probability level. Yet several owner characteristics were identified as significant. For example, both owner income and education were negatively correlated with harvest volume. This study showed empirically that owner characteristics influenced forest harvest decisions, and supported Binkley's (1981) hypothesis that harvest would be decreasing in exogenous income (see Chapter 3).

Similarly, a study by Newman and Wear (1993) using U.S. Forest Service data from the southeastern United States rejected a null hypothesis that industrial and non-industrial owners had identical profit functions. While both groups were found to manage forests in a manner consistent with profit maximization, non-industrial owners exhibited higher values for standing timber.

The differences in supply behavior by the two groups were found to be complex, and not completely explained by simple price differentials.

Since then, econometric analysis has been used extensively to model forest landowner decisions; an article summarizing this research notes that "several books and hundreds of papers have been written on the subject" (Amacher, Conway et al. 2003, p. 139). In general, studies continue to find landowners maximizing utility over more dimensions than just timber income, though timber income is often found to be significant. One consistent finding is that land area owned is positively correlated with harvest probability. Other land or owner factors identified as significant have varied in type and magnitude across different studies.

Research continues along these lines. For example, Conway (2003) used data from a Virginia landowner survey in estimating the importance of factors typically assumed to be important in harvest decisions, as well as some novel factors. Timber price was found to be a positive and significant predictor of harvest, as expected. Yet the coefficient for owner debt-to-income ratio was also found to be significant, and larger in magnitude than timber price. Owner intent to bequeath timberland was found to be negatively associated with timber harvest, as was absentee ownership. Clearly, landowner behavior is complex with respect to land-use decisions, and not easy to adequately model.

Theoretical and Empirical Models

The theoretical basis for assessing respondents' valuations of hypothetical goods is the change in utility from provision of a hypothetical good. As in Chapter 3, define indirect utility (*V*) as a function of exogenous income (*m*), price of biomass crop product (*p*), and the total product of the land (*TP*):

$$V = V(m, p, TP) \tag{4-1}$$

The total product of the land can be further disaggregated into the quantity of biomass crops produced (*q*) and land amenities (*a*) derived from use of the hypothetical good (*X*), land that could be used in biomass crop production:

$$V = V(m, pq, a(X)) \tag{4-2}$$

Let X_0 represent land use without planting biomass crops, X_1 represent land use with biomass crops planted, and *b* be the hypothetical payment made for planting biomass crops, equal to *pq*. Then the minimum willingness to accept (WTA) a bid for planting biomass crops would occur when:

$$V\{m + b, a(X_1)\} = V\{m, a(X_0)\} \tag{4-3}$$

Minimum WTA occurs when utility from planting biomass crops plus additional income *b* is the same as without biomass crops. Thus *b* can be considered a measure of compensating variation for the welfare change (Bateman, Carson et al. 2002), which in this case is the amenity difference from the land use change.

Landowner utility, however, is not observable. For the empirical study, vectors of observable land characteristics (*k*), landowner (*o*) characteristics, and landowner attitudes (*s*) are included as indicators of unobservable utility, and an error term *(ε)* captures all remaining unobservable components of utility. A landowner will accept a bid and plant biomass crops if:

$$V\{m+b,k,o,s,a(X_1)\}+\varepsilon_1 > V\{m,k,o,s,a(X_0)\}+\ \varepsilon_o \quad (4\text{-}4)$$

or rearranging with respect to the utility differences, a landowner accepts when:

$$V\{m+b,k,o,s,a(X_1)\}-V\{m,k,o,s,a(X_0)\}\ >\ \varepsilon_o-\varepsilon_1 \quad (4\text{-}5)$$

Though the foregoing represents the theoretical basis of the study, and an analysis can proceed along these lines by explicitly modeling indirect utility differences, this requires some assumptions about the form of the indirect utility function and results in complex formulations for demand parameters. Cameron (1988) observed that the process can be simplified by omitting the underlying utility model, and directly modeling respondents' willingness to pay or accept. The corresponding utility formulation would then be more complex, but in most cases (as in this one) it is not necessary to model utility directly. This study follows Cameron, using the so-called "bid function" (Bateman, Carson et al. 2002) or random WTA approach to directly model willingness to accept a hypothetical rental proposal. As above, let WTA be a function of underlying utility:

$$WTA = h(m,b,k,o,s) \quad (4\text{-}6)$$

where *h* is the random WTA function.

For a dichotomous choice survey where respondents face a binary choice of whether or not to accept a proposal, a binary logistic model is commonly used, with error terms assumed to have a logistic distribution. The binary logistic model for probability of acceptance is:

$$Pr(yes)=\frac{1}{1+e^{-\Omega}} \quad (4\text{-}7)$$

where the form of Ω to be estimated is:

$$\Omega = \beta_0 + \beta_1 m + \beta_2 b + \beta_3 k + \beta_4 o + \beta_5 s + \varepsilon \qquad (4\text{-}8)$$

and:

m is income,

b is the bid amount (the hypothetical payment),

k is a vector of land characteristics,

o is a vector of landowner characteristics

s is a vector of landowner attitudes, and

ε is an error term.

Results of this model are used to assess how differences in WTA the hypothetical payment for planting biomass crops vary across the population of interest.

Methods

A landowner survey is used to generate data for the WTA model above and to generate other statistics of interest for the study.

Survey population

The population of interest is western Massachusetts landowners who have appropriate land for biomass crop production. A total of 957 landowners are included in the study. This group represents the segment of the landowner population that can feasibly be contacted for participation, as described below. While the landowners in the group are not randomly drawn from a larger population of interest, their inclusion is a result of a number of unavoidable random factors, and does not reflect any apparent bias in representing the population as a whole. This section describes the process for including landowners in the study.

First, land that can feasibly be used for biomass crop production in western Massachusetts is identified. The process is similar to that used in the supply function estimate (Chapter 2), but with several important differences. For this landowner-study portion of the project, the only land-related criteria for inclusion are having a potential agricultural soil, having an open, non-forest land use, and having a contiguous plot size larger than one hectare.

As in Chapter 2, a SSURGO (Soil Survey Geographic) soil map from the National Resource Conservation Service (NRCS) is the most critical component of the selection process. Soils having a yield rating for any crop are included. The SSURGO yield ratings are indicators of agricultural productivity for different crops, and soils with these ratings likely represent current or former agricultural soils. Many soil types do not carry any crop yield rating, and are excluded as likely being unsuitable for biomass crop production. Franklin County is again excluded from the study, since a digital SSURGO map is incomplete and unavailable at the time of the study. It is assumed that Franklin County landowner characteristics and attitudes are similar to those of landowners in Berkshire, Hampden, Hampshire, and Worcester Counties.

Land-use criteria are then applied using data from MassGIS. Candidate land uses included are cropland, pasture, "open" land (a general category), brushland/successional land, and utility corridors (which are frequently mentioned as potential biomass crop production areas).

One component of the Chapter 2 study also looks at the production potential of former farmlands now reverted to forest. The landowner study, however, is aimed at assessing biomass cropping attitudes only about non-forested lands, and thus forest land is not included as a candidate land use. Based on early discussions about the survey, it appears that very few landowners are receptive to the idea of deforestation for the purpose of biomass crop production. Such deforestation would also have complex impacts on climate change and other environmental variables, a complexity that cannot easily be captured or reflected in a survey.

In Chapter 2, where much of the land included is forested or otherwise not currently in agricultural use, several environmental screens are applied to exclude sensitive areas like priority habitat. Since no non-agricultural areas are included in the landowner study, no such screens are applied.

Potential production areas below a minimum size threshold of one contiguous hectare are removed, and the remaining areas are considered candidate plots. In many cases these plots of candidate land are parts of much larger ownership parcels. For example, there might be a three-hectare plot of land meeting all production criteria on an ownership parcel of 20 hectares.

Ownership parcels for the candidate plots are then identified using GIS tax assessor maps. Such digital maps are used in some towns and are compiled by MassGIS. The four-county western Massachusetts study area has 135 towns (not including Franklin County, as noted above). Of these, 64 towns or 47 percent have provided digital tax assessor maps to MassGIS. Since the tax assessor maps are the critical link to identifying ownership of candidate land, only candidate plots in the 64 towns with digital tax assessor maps are included in the study.

The GIS study identifies a total 5,162 candidate plots. As described below and shown in Table 4-1, candidate plots are eventually linked to 957 landowners who are included in the study. First, candidate plots missing values in the "map_ID" field are removed, because the map_ID value identifies a tax parcel, and is used to identify a parcel's owner. Parcels with map_ID values are matched to landowner name and mailing address data obtained from the Warren Group of Boston, a firm that provides real-estate data. Such landowner data are publicly available from town tax-payer lists, which are compiled by the Warren Group.

Next, non-private-individual landowners are removed from the list. A total of 271 government properties (23 percent of removals at this stage), 468 commercial properties (40 percent), and 90 properties owned by non-profit schools and other institutions (7 percent) are removed at this stage. In addition, 351 parcels owned in trust (30 percent) are removed. For example a parcel owned by the "John Doe Trust" would be removed, since it is not clear who the trustees would be, or who would make decisions about land use on such parcels. These removals greatly reduce the number of parcels included in the study, with 1180 parcels or 44 percent of the parcels for which ownership data are available removed at this stage. While it is clear that a mail questionnaire would not be the appropriate instrument for assessing biomass crop production potential on commercial, institutional, government, and trust-owned property, a topic for future research is how land-use decisions are made on such properties, given the extent of non-private-individual land ownership in western Massachusetts.

Next, duplicate landowners are removed, as many owners hold multiple parcels. Both identical and near-identical owners are consolidated, for example, records for "John Doe" and "John E. Doe" at the same mailing address would be reduced to one eligible study participant. Finally, addresses already used in concurrent landowner surveys at the University of Massachusetts and those used in a pilot study are removed. This results in 957 participants for the landowner study (Table 4-1). As noted above, the 957 are a subset of the landowner population in western Massachusetts, but they represent the entire population that can feasibly be included in the study.

Survey instrument development

Given that a primary objective of the research was determining mean and median WTA values for planting biomass crops, a dichotomous choice contingent valuation (CV) technique was chosen for the survey. Since only landowner mailing addresses (not phone numbers) were available from tax records, a mail questionnaire was required, and hence the single-bound dichotomous choice format was appropriate. While choice modeling methods (e.g. choice experiments, contingent ranking) have been successfully used to untangle the relative importance of different attributes of a hypothetical good, biomass crop attributes were assumed to be difficult to describe in a mail questionnaire and to have landowners understand, since there is no existing biomass crop industry in the region. In this case, the simpler dichotomous choice CV format represented a more direct way to assess WTA amounts. For this format, five to eight bid levels are recommended (Champ, Boyle et al. 2003), meaning five to eight questionnaire versions with different bid amounts.

The survey instrument used is shown in the Appendix. Initial questions related to attitudes about biomass energy in general, included in part because of recent controversy about wood-fired biomass electric plants in the region. After a short (three paragraph) description of biomass crops, landowners were asked about their general interest in biomass crops, and about the importance of specific aspects of biomass crops (e.g. income potential, impact on wildlife). This was followed by the CV question and follow-up questions, which varied depending on whether respondents accepted or declined the proposition. Landowners were then asked about attitudes on environmental issues, and reasons to own land in Massachusetts. The questionnaire ended with demographic questions and an open-ended comment section.

Some of the questions about land ownership and landowner attitudes were taken verbatim from earlier landowner surveys conducted by the University of Massachusetts; these sections had thus been thoroughly pre-tested.

A focus group of five volunteer (not randomly selected) landowners was used to help develop the survey instrument. At the focus group meeting, participants were first asked to discuss open-ended questions about biomass energy and biomass energy crops. Next, participants wrote their (open-ended) minimum WTA figure for planting biomass crops on a piece of paper and handed this in. Finally, participants reviewed an early draft of the survey instrument, and made written comments. At the end of the evening, a short presentation was made on biomass energy crops, since people participated based on their interest in the subject (but the presentation was made at end of the meeting to avoid influencing results).

Bid amounts for the survey were established from the open-ended responses of the focus groups. Bid levels of $124, $371, $618, $741, $865, $1112, and $1359 per hectare were selected ($50, $150, $250, $300, $350, $450, and $550 per acre).

After the focus group, four additional landowners reviewed the modified survey instrument in an open-dialog format, where participants read questions aloud and articulated their reactions and interpretations while reading. The survey instrument was again modified based on these results. Finally, a total of ten individuals who were knowledgeable about biomass crops and/or landowner surveys reviewed the survey instrument and gave comments before the pilot survey phase.

An initial pilot survey with 98 randomly selected landowners (meeting the criteria described above) used virtually the same instrument and procedures as the main survey. Minor changes were made for the main survey, based on experience in the pilot study.

Survey procedures

This study uses Dillman (2009) as a primary reference for survey methodology, with minor modifications as described below. The survey process consists of a number of contacts with the target population, attempting to achieve the maximum possible response rate and to minimize non-response bias. Dillman suggests four contact points in the survey process:

1. Everyone in the target sample is sent an initial letter describing the project and the upcoming questionnaire, and requesting participation.
2. About one week later, the questionnaire booklet is sent, again with a cover letter stressing the importance of participation. This mailing also includes a business-reply envelope to return completed questionnaires.
3. After another week, everybody receives a postcard, thanking them for completing the questionnaire, in the event they have done this, or reminding them to do so if they have not.
4. After two additional weeks, a complete replacement packet (questionnaire, cover letter, business reply envelope) is sent to everyone who has not yet responded.

In this study, the basic Dillman process is followed, but with the following modifications:

1. In the initial introduction letter, a URL and survey code are provided to allow participants to complete the questionnaire on-line. This is thought to have several advantages, including improving response from those who prefer to respond electronically or prefer not to see paper used in the

survey process, reducing paper usage and postage cost, and reducing data entry time. The on-line and paper versions of the survey instrument are essentially identical. One exception is that the on-line version uses skip logic to present different follow-up questions to those who accept or decline the hypothetical bid. This difference is easily corrected, however, by purging the paper-questionnaire data of "accept" follow-up responses from people who declined, and vice versa.

2. Based on results of the pilot study, the return on sending an entire replacement packet to the approximately 75 percent of the target population who have not replied after two weeks is questionable; for the main survey, a second reminder postcard is substituted, including a telephone number where replacement questionnaires can be requested.

For all correspondence, University of Massachusetts letterhead and envelopes are used, and all pieces are mailed with stamps rather than being metered. Both practices are thought to elicit higher response rates (Dillman, Smyth et al. 2009).

Results and Analysis

Of 957 landowners for whom addresses are obtained, three percent were found to have incorrect addresses, and the total successfully contacted was 926. Of these, there were 318 responses, or 34 percent of those successfully contacted. Not all respondents answered every question, and questionnaires without the hypothetical WTA answer were rejected as insufficient. Questionnaires completed on-line without a valid access code were also rejected, to prevent multiple responses from the same households. A total of 261 usable responses remained in the data set, or 28 percent of those contacted. Questionnaires completed on-line accounted for 23 percent of the usable responses.

Demographics

For respondents providing demographic data, 71 percent are male (n = 253), and 97 percent describe themselves as "white" (n = 247). Median age is in the 55-74 category, with 63 percent of landowners in this age group (n = 255). Educational levels are high: 42 percent report education beyond a 4-year college, 41 percent have completed a two- or four-year college degree, 17 percent stopped their education after high school, and only 0.4 percent have not completed high school (n = 255).

Median household income is in the $75,000-$149,000 per year range (n = 221), higher than the $57,398 population-weighted average of 2008 county median household income for the four-county area (U.S. Census Bureau 2008). Twenty-four percent of respondents have household income exceeding $150,000. Land-based income (farming, logging, etc.) accounts for less than one percent of household income in 68 percent of respondents, and for less than ten percent of income in 86 percent of the landowners (n = 249). Only six percent receive more than half their household income from their land.

"Farmers" are defined in this study as respondents who self-identify as farming for income and report more than one percent of household income from land-based activities. This is roughly equivalent to the definition used in the USDA Census of Agriculture, which defines a farm as "an operation that produces, or would normally produce and sell, $1,000 or more of agricultural products per year" (USDA 2009, p. A-1). The sample includes 57 farmers, or 22 percent of the sample. No farmers in the sample report that they would never grow biomass crops, i.e. all farmers surveyed will at least consider the possibility.

In addition to the 22 percent of landowners defined here as farmers, 11 percent report farming for income (but receive less than one percent of household from farming), and 39 percent report farming but not for income, e.g. farming for home consumption (n = 255). Only 28 percent of landowners in the sample report not farming at all.

An ever-present risk in survey research is non-response bias, where attitudes of those not completing questionnaires differ systematically from those responding. Given the survey methodology for this project, it is not possible to assess this bias potential with follow-up surveys of non-respondents. Instead, demographic data from the survey are compared to regional data from the U.S. Census Bureau. This establishes that the survey sample is at least demographically similar to the population of interest.

Data from the American Community Survey (U.S. Census Bureau 2008) are used for this comparison, with data from Public Use Microdata Areas (PUMAs) covering the five western Massachusetts counties (including Franklin, though this county was not included in the landowner survey). Records are retrieved for individuals over 18 years of age from households who own homes with lots at least four hectares (ten acres) in size. Income is reported for each household unit. Households are considered "farmer" households if farm income is at least $1000 per year, the definition used in the USDA Census of Agriculture (2009). Age and education data are used for the person in each household with the highest individual income (i.e. assuming this person was most likely to have completed the landowner survey). Individual and household weights provided by the American Community Survey are used to estimate population proportions. Results are shown in Table 4-2.

As shown in the table, the landowner survey sample is similar to the western Massachusetts landowner population a whole, though the survey sample is somewhat older, better educated, and has higher income than the general landowner population in this region. Such individuals may be more likely to participate in optional surveys. But crosstabulation of demographic characteristics with hypothetical biomass crop planting decisions shows no strong statistical correlation between willingness to accept and age ($\chi^2 = 2.00$, $p = 0.57$), education ($\chi^2 = 3.91$, $p = 0.27$), or income ($\chi^2 = 3.88$, $p = 0.42$). This provides confidence that the survey sample is reasonably representative of the landowner population as a whole.

The proportion of farmers in the landowner survey sample is also higher than in the general landowner population. These owners of potential biomass cropland may be a population with a slightly different character than the land-owning population in general.

Qualitative information

The last survey question asks landowners for any additional comments they might have about biomass energy crops. In general, the comments and questions received are reflective of the range of issues surrounding biomass energy, as discussed in this dissertation and in other current literature. These qualitative data provide a more nuanced view of biomass potential than the quantitative data: many landowners would consider biomass crop production under certain circumstances, or if specific concerns were resolved. This may suggest greater long-run landowner participation potential than indicated by the quantitative data analysis below.

Many comments also reflect a need for more information (or reflect misinformation) about biomass energy. Education will be a key component of biomass energy crop development. Below are substantive portions of comments received (some comments are omitted, and some edited for length):

"Sounds like a good idea. Many people are doing nothing with vacant land."

"…For us to participate we would have get enough money to replace the hay that we grow."

"If the USA or Massachusetts is in a desperate situation re. energy, the equation changes and I would be more ready to consider changing the hayfields (alfalfa) over to a biofuel."

"Any crop that would not depend on hand labor or good weather to harvest would be interesting. The weather changes are becoming a factor, and labor is more expensive or non-existent…"

"I am quite concerned about smoke from incineration, especially if the Russell plant goes through. So I am not excited about biomass at all."

"We currently have a WHIP contract for 15 acres we are maintaining as a grassland bird habitat. Under that contract, those acres cannot be planted with crops. A section of one field was planted with sunflowers to provide a biomass source of fuel. The birds loved it and we loved it. For us, sunflowers would be preferable to switchgrass."

"Might provide an option to get some income. I cannot get anyone to farm the tillable acreage even to cover taxes. Also, due to some acreage being on top of a municipal recharge water area, there are restrictions on fertilizers and pesticides. However, there are no restrictions on the taxes!!"

"We think they are a great source of energy. We need new ways to reduce oil and fuel consumption. Our farm, unfortunately, does not have a lot of acreage available..."

"I would be hesitant to surrender my open land to biomass crops because I fear compromising the grass diet of the white-tail doe. My forefathers worked long hours to clear the land. I would be concerned about the root structure of poplar trees taking over, and how to return the land to tillable conditions."

"Like the concept and consider it a good fuel source. Use of biomass energy would need to still permit cleaner air, not contribute to asthma, etc."

"Biomass is the way to go. What about the recent restrictions on harvesting timber on state lands?! What a reversal of biomass ideas!..."

"I support this, but need much more detailed information."

"Would need to know if compatible with 61A since program is critical for us to be able to maintain ownership due to financial considerations. Would need more info about switchgrass and compatibility with other hay and pasture grasses. Poplar is food security for beaver and we do not want to encourage or attract the beaver population, since they are already threatening existing timber and hay pasture..."

"From what I know the cost to produce the energy is higher than the energy it takes to create the energy."

"…Burning wood is not good for air quality. The windmills (several here in the Berkshires) are very expensive…"

"Is switchgrass an invasive species? Is switchgrass poisonous for animal consumption? Once planted and a decision is made to change crop—how do you get rid of it?"

"I know very little about biomass energy. If I had a lot more information about these grassy crops, I think my answers would be different in this survey."

"I don't believe biomass is the answer to our energy problems."

"I know little of biomass. I have heard it takes more energy to produce ethanol than it produces. This, if true, is disturbing, especially if it is only keeping the corn growers—especially corporate growers—in business. I support local farms—small farms."

"For the past 40 years we have operated a choose-and-cut Christmas tree operation on the five acres we have of cleared land. We currently let our neighbors graze their three horses on approximately 2.5 to three acres of our land. We are very interested in biomass energy but feel our land probably isn't large enough to put into production. Also at our ages (65 to 70 years old) we probably wouldn't be interested in this venture."

"I am currently looking for a way to decrease the annual cost of ownership and maintenance on my property in Royalston. Due to the current economic situation, I've considered selling, but the idea of the fields becoming a housing development is extremely distasteful."

"Anything to help not using so much oil, gas, and dangerous chemicals used in products."

"Because open field acreage in Massachusetts has declined sharply due to development, etc., the remaining fields are precious resources for many wildlife species. Thus we prefer grass to trees, and would carefully study the effect on wildlife of any biomass product proposal…"

"I am very concerned about the pollution created by burning biomass for energy. I believe that the biomass plants proposed for Deerfield, Russell, and Springfield will definitely negatively impact the air quality in western Massachusetts."

"Our interest in this is highly dependent on the value of the crop toward controlling climate change, how bio-fuel is managed, who gets the profit, etc. If and when it is deemed the best and most important use of our land, we will consider it."

"To take land of out of vegetable and hay production for biomass would not be a good idea."

"Our Connecticut valley cropland is too valuable to raise biomass crops. Raise vegetables and help the world."

"The thought of using my open land for biomass crops is very interesting. It is hard to know whether the cost of growing the crop would be recouped at $300 per acre."

"I am interested to know as much as is available as it applies to alternative income generators for the farm."

"I believe that burning biomass is bad for the environment. I also question whether the energy derived from biomass crops is worthwhile given the energy needed to till, plant, harvest, and transport."

"I believe the production of electricity from biomass has great potential. However, the key to its success is the intelligent selection of sites for the power plants…"

"Biomass production will need large fields; I don't know if my small acreage will make much of a difference."

"I don't think about oil, gas supplies…Center of education is where we should be putting more energy."

"I would like to see biomass crops, but on land not suitable for people's food…I bought my land to grow food, to show my children farming, for family recreation and to get away, and finally to pass on to them. The pictures on the cover, although exciting from an energy perspective, don't seem family friendly like a field of squash might be to kids that love to eat them!"

"I'd love to see tobacco farmers turn their land into biomass fuel production. "

"My initial choice would be a grassy biomass crop but I am also interested in woody pulp depending on many factors. For this particular site, wood pulp may be more appropriate. Total land available probably is too small for consideration or good use."

"Burning wood or grass is not good for green environment—takes the country back to the stone ages. New technology is water power, wind power, sun power or nuclear power. Due to the large population, biomass is too minimal…"

"Sorry we aren't much help—but we are happy with our land as it is."

"Biomass is a term that needs more explanation for most of us. More information should be circulated as to its use, coverage of planted areas, harvesting arrangements, and to whom it would be sold or turned over to."

"Biomass should be small to moderate in scope, as opposed to massive complexes run by large corporations for the profits of the already wealthy energy giants. I would like to see smaller (possibility of cooperative) groups of farmers include manufacturing, distributing and maybe even retail. In this way farmers and landowners could control their independence, livelihood and profitability."

"This program sounds like we are all going backwards instead of forward. Let's drill for natural gas and oil here in the good ole USA."

"With shrinking industry in the USA, we need jobs. If biomass energy crops provide jobs and profits, we should pursue biomass."

"I am not a big fan of monoculture management."

"We rent a small portion of our land to a farmer. I would not for any amount of money want to hinder his work. We do not receive any substantial rent, but the land is tilled yearly and no invasive trees grow up as a result of seasonal plowing. I like it that way. I would rent to biomass farmers if for some reason my present renter were to retire."

"Lots of vague doubtful feelings. Would love to reduce ratio of forest to open. Tyringham valley almost all woodland now, with loss of farming, etc…"

"I have strong concerns about biomass energy. In my opinion, the state was too quick to decide that chipping up New England's forests and burning them was the answer to dwindling oil supplies… Also, the resulting pollution and particulates released into the atmosphere are a serious negative...At this rate, New England will look like it did in 1830 when charcoal production and firewood for Boston etc. clear cut 90% of forestland. The biomass industry was started off on the wrong foot."

"Having locally grown, renewable energy sources is very important. We have a solar hot water system and heat partially with firewood. Reducing our society's need for foreign fossil fuel is very important to our family."

"Biomass energy plants don't seem to solve any problems. Switchgrass and thermal may be viable at some point."

"Biomass crops are adding much more cost to animal feed and they are taking away from small backyard and small farms that feed grains to farm animals…"

"Love sunflower fields and understand these can be planted for biomass crops."

"Very interesting concept, need to be assured that it is financially prudent. New 'infrastructure' is daunting."

"My concerns: 1) Is biomass an efficient source of energy? (i.e. how much energy does it take to convert it into energy vs. its output?) 2) Is it a clean source of energy? 3) Will its production displace food production and cause food prices to increase worldwide? 4) Will it displace the locally grown/organic farm production, so that we go back to importing our food over vast distances? (not that we've stopped doing that, but the locally grown movement is taking hold)…"

"The profits need to cover the expense of the land and make a profit for the work being done."

"What is the cost of harvesting? What special equipment is necessary? Is it easy to find someone to harvest the crop for me? What would the cost be?"

"A very scary prospect for the Berkshires!!! NO."

"We give part of our open meadow (about 50 acres) to local herdsmen for summer pasture. We benefit by our participation. In addition we pay to have the pasture mowed each year just to leave the field open."

"Good idea."

Quantitative information: univariate results

Respondents generally rate their knowledge of biomass energy as low, with 72 percent saying that have "very little" or "little" knowledge of biomass energy, and the median response being "very little" (n = 255). On the other hand, 55 percent have "positive" or "very positive" attitudes about biomass energy, with 39 percent "neutral", and only six percent holding "negative" or "very negative" feelings (n = 254). Landowners generally feel positive but uninformed about biomass energy.

After reading a brief description of biomass crops, 50 percent of respondents report being "not" or only "slightly" interested in biomass crops, while 28 percent report being "quite" or "very" interested, with the balance being "fairly interested"(n = 258).

Given a hypothetical payment to plant biomass crops, 54 percent of responding landowners elect to accept the hypothetical proposition, and 46 percent decline (n = 261). Median willingness to accept (the payment accepted by 50 percent of respondents) occurs in the range between the $124 and $371 per hectare bids. More precisely, using estimation methods described below, median WTA is $321 per hectare per year. Mean WTA is much higher, as described below.

For those declining, the main reasons given for declining and proportions citing those reasons are as follows (n = 121):

- "Other uses of my fields are more important to me"—59 percent.
- "I would need more details about planting, managing, and/or harvesting the crop"—40 percent.
- "The suggested profit was too small"—37 percent.
- "I would never consider growing a grassy or woody biomass crop"—14 percent.
- other reasons (narrative answers)—32 percent.

Regarding a choice between a woody biomass crop (e.g. poplar) and grassy crop (e.g. switchgrass), among those who would consider planting a biomass crop (n=231), 61 percent prefer a grassy crop, while only five percent prefer woody, with 34 percent neutral or undecided. The apparent popularity of grassy crops over woody may be an important factor in biomass crop acceptance; note, however, that the questionnaire included only one photo each of grassy and woody crops, and results may be sensitive to the specific photos chosen.

Respondents rated seven considerations on planting biomass crops on a five-part Likert scale, from "not important" to "very important" (Table 4-3). Again among those who would consider planting a crop, "impact on wildlife habitat" has the highest proportion citing this as a "quite" or "very" important consideration (58 percent, n = 239). While biomass crops might in fact have positive wildlife impacts (e.g. with less bird disturbance at nesting time than from producing hay, which is typically cut in May), or negative impacts if critical habitats are altered, no such information was provided to respondents. More research as well as education is needed on wildlife impacts of biomass crops, as this is clearly a large landowner concern.

"Possible chemical fertilizer or herbicide use in production" is the next most cited as a "quite" or "very" important consideration (55 percent, n = 237), and has the highest proportion selecting the factor as "very important" (36 percent). Here it is assumed that people who consider chemical use important have concerns, i.e. might be predisposed to restrict chemical use on their lands. This has big implications for biomass crop economic viability, as discussed in Chapter 2. Among non-farmers, 62 percent feel chemical use is "quite" or "very" important, while only 30 percent of farmers share this view, a significant difference ($\chi^2 = 16.6$, $p < 0.001$).

Respondents report owning a total of 7,864 hectares of land in western Massachusetts, with a mean ownership area of 32 hectares. Though farmers (as defined above) comprise only 23 percent of the sample reporting land ownership (n = 247), collectively they own 46 percent of the reported land, with a mean ownership of 64 hectares, compared to 22 hectares for non-farmers.

Responding landowners have approximately 1,993 hectares of grassland, as calculated from landowner-reported total land and reported percentage of grassland. Cropland is similarly calculated at 1,745 hectares. While farmers own 65 percent of the reported cropland, non-farmers own 55 percent of grassland.

Survey respondents who accepted the hypothetical payment for growing a biomass crop own 57 percent of the combined cropland and grassland, a total of 2,150 hectares. Those who accepted the planting proposition are willing to plant 849 hectares, or 39 percent of their total grassland and cropland holdings.

Current land products are shown in Table 4-4. Hay is the dominant product for both farmers and non-farmers, with 70 percent of all responding landowners reporting hay production. More research is needed on possible biomass crop interactions with the existing hay and forage market.

Means and variances

A primary purpose of the landowner survey is to determine median and mean willingness to accept (WTA) values for planting biomass crops. These can be interpreted as rents landowners would require to make their land available for biomass crop production. This land-rent estimate is also used in the Chapter 2 supply function calculation. Both the non-parametric Turnbull (1976) estimator and a parametric estimator are used to arrive at mean WTA, yielding somewhat different results.

Willingness to accept a hypothetical payment has some probability density function (PDF). The associated cumulative distribution function (CDF) is in theory a monotonically increasing function: increasing payment should result in an equal or greater probability of acceptance. Each point on the CDF represents the probability of a particular WTA value or less. The survivor function is 1-CDF, a monotonically decreasing function where each point represents the probability of a particular WTA value or more. The area under the survivor function represents mean WTA (Bateman, Carson et al. 2002).

Empirically, a non-parametric estimate of the survivor function can be made by observing the proportion of landowners that refuses the hypothetical payment at each bid level *j*:

$$\widehat{p_J} = \frac{N_j}{n_j} \qquad (4\text{-}9)$$

where estimated probability of refusing bid *j* is the number rejecting bid *j* (N_j) divided by the sample receiving bid *j* (n_j). Note that for a willingness-to-pay (WTP) estimate, the survivor function is estimated by the proportion accepting each bid, which, similar to refusing a WTA offer, is a decreasing function of the bid.

While theoretically the survivor function should be monotonically decreasing (proportion refusing does not increase when bid level increases), because of random variation in responses from a sample, this is not always the case empirically. If the proportion refusing should increase at any bid level, this is corrected by pooling responses from that bid and the next lowest bid level, assuming that landowners who accept a particular bid would also have accepted a higher bid (Bateman, Carson et al. 2002).

Denoting the number of bid levels as *J* and the number of pooled bid levels lost as *pb*, the resulting monotonically decreasing survivor function is then defined by a maximum of *J - pb* points. The next question is how to connect these *J - pb* points into a survivor function. With regard to a WTP estimate, Bateman et al. (2002) recommend establishing a lower bound on WTP by connecting points with a step function. As described above, probability of acceptance is estimated at bid b_j based on the proportion accepting the bid. This probability is assumed to correspond to all payments greater than b_{j-1} and less than or equal to b_j, resulting in observed points being on the outside corners of the step function (Figure 4-1, dashed line). While this lower bound estimate of WTP is conservative and appropriate for a willingness-to-pay study, a lower bound on willingness to accept would not be a conservative estimate.

While an upper-bound would be a conservative estimate of WTA, this presents empirical problems. If a step function is used with observed points on inside corners, the area under the upper tail of the function is undefined, i.e. there is no obvious estimate for the horizontal intercept (bid required to obtain zero probability of refusal). This study instead connects the observed points with a linear spline function (Figure 4-1, solid line), representing the best estimate of WTA. Line segments connect each pair of points. Horizontal and vertical intercepts are estimated from the slope of the line between points at b_1 and $b_{J\text{-}pb}$, the lowest and highest bid points. The area under this function is then calculated to arrive at the non-parametric mean WTA estimate.

The Bateman et al (2002) variance estimator is:

$$var(WTA) = \sum_{j=0}^{J} \left(b_j - \overline{WTA}\right)^2 \left[\widehat{p_J} - \widehat{p_{J-1}}\right] \qquad (4\text{-}10)$$

where the observed probability differences between bid levels can serve as weights, since probabilities sum to one. The value for b_0 is zero, and b_J is the horizontal intercept of the survivor function, calculated as described above. Estimated variances are used to calculate confidence intervals for each of the mean estimates below.

In calculating mean WTA, respondents who would not plant biomass crops at any bid level are first excluded from the data (respondents who refused the bid offered and indicated "I would never consider growing a grassy or woody biomass crop"). Responses are also excluded from landowners who accepted the planting proposition but in a follow-up question indicated they would plant zero acres; the open-ended question on acreage planted is thus used as a check on certainty.

Median WTA occurs where the value of the survivor function is 0.5, i.e. where there is a 50 percent probability of landowner bid acceptance. As noted above, this occurs in the $124-$371 per hectare bid range, specifically at $321 per hectare using the linear-spline survivor function described above (32 percent of respondents accepted at the $124 bid level, and 55 percent accepted at the $371 bid level).

As shown in Table 4-5, for the landowners of interest in the sample (n = 244), the overall mean WTA is $918 per hectare per year, with a 95 percent confidence interval of $854 to $981 per hectare. In calculating the mean, the vertical intercept, or probability of accepting with a bid of zero, was estimated to be 28 percent. This is plausible, since some landowners now face mowing costs for maintaining their fields, and would thus improve their financial positions by growing biomass crops even with no payments made, i.e. zero profits. The estimate of 28 percent acceptance at zero bid is also consistent with earlier focus-group findings, though only seven percent of respondents who accepted and answered a follow-up question on their minimum payment (n = 73) gave values of $12 or less per hectare ($5 or less per acre). The estimated horizontal intercept, or bid for which the probability of rejection is zero, is $2827 per hectare. For respondents who rejected the bid and answered the follow-up question on their minimum payment (n = 37), the mean response is $1922 per hectare, with a modal response of $2471 per hectare. Thirty-five percent of these respondents gave values of $2471 or more per hectare. Thus, the horizontal intercept of $2827 is plausible.

Mean WTA varies significantly by subgroups (Table 4-5). The mean WTA for farmers is $2362 per hectare, compared to $765 per hectare for non-farmers, a significant difference ($t = 9.0$, $p < 0.001$). Farmers may have or perceive more valuable land-use alternatives than do non-farmers. Similarly, landowners with larger holdings (greater than the reported median of 15 hectares) have an estimated mean WTA of $1407 per hectare, compared to $830 per hectare for those with less than median acreage ($t = 7.41$, $p < 0.001$). This may again relate to the greater number of alternatives available to owners of large acreages.

In the cases of both farmers and owners of large acreages, however, the mean estimate is driven higher by large upper tails. Only 37 percent of farmers and 56 percent of owners of large acreages accepted the planting proposition at the highest bid level ($1359 per hectare). The horizontal intercepts (bids where probability of rejection equals zero) are estimated at $5925 and $4757 per hectare for farmers and owners of large acreages, respectively, and both of these are likely inflated by the assumed linearly decreasing probability of rejection. While more research specifically with farmers, using higher bid levels, would yield more accurate WTA estimates for these groups, it is also the case that biomass crop prices in foreseeable future are unlikely to support land rental rates above $1359 per hectare. The mean cropland rental rate for the lower 48 states is $222 per hectare (USDA 2009). Thus, landowners requiring this level of return to their land are effectively excluded from biomass crop supply.

A non-parametric approach as used above is often preferred for estimating mean WTA, as this avoids making assumptions about the distribution of WTA. In cases such as this one, however, some data are essentially missing, given that no bid offers higher than $1359 per hectare were made, while some landowners clearly had WTA levels exceeding this. In such cases a parametric estimator, with an assumed distribution, may also be useful.

A binary logistic model is used in this study to model the influence of different covariates on landowner WTA, as described below. This type of model can also be used to generate a parametric estimator of the mean. In a binary logistic model of WTA with only the bid as an independent variable, a mean estimate can be obtained by simply dividing the negative of the estimated constant, $-b_0$ by the estimated bid coefficient, b_1 (Buckland, MacMillan et al. 1999). This results in an estimated WTA of $2022 per hectare per year. But because the presence of other covariates (as in this study) biases such estimates, Buckland et al. (1999) suggest an alternative mean estimation method.

The procedure employs binary logistic models in two stages. In the first stage, the full model with all covariates is estimated. This produces estimates for a constant and coefficients for the bid variable and all other covariates (those shown in Table 4-6). These estimates are then used to calculate the acceptance odds for each of the *n* respondents in the sample. Respondents are pooled into *J* groups corresponding to the *J* bid levels in the study, and mean acceptance odds are calculated for each group. These are used to generate predicted acceptance for each group, where mean odds less than one result in prediction of rejection, and odds greater than or equal to one result in a prediction of acceptance. The resulting binary acceptance variable is then used in a second-stage binary logistic model, using *J* observations from the *J* bid-level groups, and bid level as the sole independent variable. Finally, from this model an unbiased mean estimate is obtained by dividing the negative of the constant, $-b_0$, by the bid coefficient, b_1 (Buckland, MacMillan et al. 1999).

Using this procedure, a parametric mean estimate of $658 per hectare per year is calculated. This is higher than the $321 per hectare median estimate, but lower than the $918 per hectare mean estimate obtained from the non-parametric method. Given the circumstances of this study, with a large proportion of respondents rejecting the highest bid level, the parametric mean WTA estimate of $658 per hectare per year is likely the better figure.

Bivariate measures of association

As an initial exploratory technique, a cross-tabulation table is generated for each independent variable against the binary choice of accepting or declining the hypothetical offer to plant biomass crops. This technique captures association between accepting the offers and landowner opinions as reflected by ordinal Likert-scale responses to many of the survey questions. The Pearson chi-squared statistic is used to test the null hypothesis that two variables are independent (i.e. unassociated), with large chi-squared values suggesting likely associations.

The most notable result is that few of the independent variables describing land, owner, and attitudinal characteristics are statistically associated with willingness to accept the hypothetical offer, though there are several exceptions. Not surprisingly, a positive feeling about biomass energy is strongly correlated with the WTA decision ($\chi^2 = 30.5$, $p < 0.001$), as is the response to an initial question about general interest in biomass crops ($\chi^2 = 79.1$, $p < 0.001$).

Higher ratings of the importance of crop income are associated with higher acceptance rates ($\chi^2 = 14.0$, $p = 0.007$), though those who feel strongly that agricultural income is an important reason to own land are less likely to accept ($\chi^2 = 16.6$, $p = 0.002$). Similarly, rejecting the hypothetical planting proposition is associated with having higher land-based income ($\chi^2 = 13.9$, $p < 0.003$). Biomass crops may appeal to landowners for whom land income is an important, though not a primary reason to own land.

Those who rated the ease of walking through fields with higher importance were significantly less likely to plant biomass crops ($\chi^2 = 10.5$, $p = 0.033$), maybe reflecting an amenity value of land, as discussed in Chapter 3. Also, people who expressed stronger agreement with the statement "My land should provide for the needs of future plant and animal populations" were more likely to plant ($\chi^2 = 9.9$, $p = 0.042$), which could suggest that people value the habitat diversity provided by biomass crops (as compared to forest), or perhaps just suggests that some environmental values are associated with willingness to plant biomass crops.

But overall, the great majority of the demographic and attitudinal attributes, when considered individually, do not show statistically significant association with landowners' willingness to accept the proposition to plant biomass crops. It would appear difficult to generalize about how individual landowner characteristics relate to their inclinations toward biomass cropping, though the multivariate models below do provide some clues in this regard.

Cluster analysis

Another exploratory technique is cluster analysis, which identifies groups of respondents that are "close" to each other when measured across multiple demographic or decision-space dimensions. This technique is frequently used in market analysis, for example, to help in characterizing market segments. In this study three clusters are identified using three dimensions:

a) farmer status, as described above: self identifies as farming for income, reports more than one percent of household income from land-based activity.

b) land return: agrees or strongly agrees with the statement: "Land must provide a return to cover the expenses associated with ownership."

c) strong environmentalist: strongly agrees with all of the statements: "I would be pleased if a rare or threatened species was found on my land"; "My land should provide for the needs of future plant and animal populations"; "I have a responsibility to leave my land in at least as good condition as I found it"; and "Climate change is an important problem for society to address."

Across these three variable dimensions, two-step cluster analysis using Schwarz's Bayesian Criterion identifies three clusters:

Cluster #1 includes 23 percent of the valid sample (n = 219). This cluster is entirely farmers, the median level of agreement that "Land must provide a return to cover the expenses associated with ownership" is 5.0 (strong agreement), and only two percent of this cluster fit the strong environmentalist criteria. This cluster has the lowest proportion of respondents accepting the hypothetical bid, at 39 percent. Median education and median income categories for this cluster are both 3.0 (completed 2- or 4-year college degree and $35,000-$74,999, respectively).

Cluster #2 is the largest, with 46 percent of the sample. The group has no farmers, the median agreement with the land-return statement is 4.0

(agreement), and none in this cluster is defined as a strong environmentalist. This cluster has 64 percent accepting bid offers, the highest proportion of the three clusters. Median education category is 3.0 (completed 2- or 4-year college degree), like cluster #1, but the median income category is higher, at 4.0 ($75,000-$150,000).

Cluster #3 includes 31 percent of the valid sample, has seven percent farmers, median land-return agreement is the lowest at 3.0 (neutral), and the cluster has the highest proportion of strong environmentalists, at 31 percent. In this cluster 56 percent of respondents accept their bids, more than cluster #1 but less than cluster #2. Median education and income categories are the highest, at 4.0 for both income and education (completed more than 2- or 4-year college and $75,000-$150,000, respectively).

To summarize, cluster analysis suggests that non-environmentalist farmers who value financial returns from land are the least likely segment to plant biomass crops. On the other hand, non-environmentalist *non*-farmers who also value land-based income are the most likely to plant. Non-farming environmentalists with less concern about land-based income, and the highest income and education levels, are an intermediate case with regard to probability of planting biomass crops.

Binary logistic model

To gain further insight into factors leading respondents to accept or decline the hypothetical planting proposition, a binary logistic model is used. The logistic model is commonly used in survey research, since it requires no *a priori* assumptions about distributions of response variables, and since it is suitable for both categorical and continuous data. In this analysis, the dependent variable is the survey respondent's binary choice of accepting or declining the hypothetical proposition to plant biomass crops. A coefficient in a logistic model represents the partial effect of a unit change in an independent variable on the natural log of the odds of the binary dependent variable. A more convenient interpretation is obtained by exponentiating an estimated coefficient, which reveals how changing a predictor by one unit changes the odds ratio for accepting the hypothetical proposition, all else equal. Coefficient estimates, along with their signs and statistical significance, can thus help to explain the magnitude, direction, and likely significance of factors relating to biomass crop acceptance.

Independent variables are selected for the analysis based on theoretical determinants of landowner willingness to accept the hypothetical planting proposition, where willingness to accept is based on landowner utility derived from planting or not planting a biomass crop. Theoretical expectations about landowner utility are discussed at greater length in Chapter 3 of the dissertation. In the binary logistic model, landowner decisions to accept are modeled as:

$$Pr(accept) = h(m, b, k, o, s) \qquad (4\text{-}11)$$

where *m* represents exogenous income, *b* represents the bid level, and *k*, *o*, and *s* represent vectors of land characteristics, landowner demographic characteristics, and landowner attitudes, respectively. Independent variables from the landowner survey and the expected signs of their coefficients are as described below.

Bid:

One of seven bid levels received by the respondents: \$124, \$371, \$618, \$741, \$865, \$1112, and \$1359 per hectare per year (\$50, \$150, \$250, \$300, \$350, \$450 or \$550 per acre per year). For the binary logistic model, the bid amount is treated as a continuous variable. As shown in the Chapter 3 comparative static analysis, the effect of a higher bid is theoretically ambiguous. Higher payment increases the opportunity cost of enjoying land amenities associated with non-production, and perhaps encourages landowners to seek such amenities elsewhere (a substitution effect). At the same time, higher payment raises landowner income, increasing the marginal value of amenities (an income effect). Which effect dominates is then an empirical question.

Land characteristics:

Hectares of grassland owned, calculated as described above. Hectares of grassland is expected to increase probability of acceptance, as grassland is likely the most suitable area for biomass crops (as discussed in Chapter 2), and owning more hectares increases income potential. This is consistent with the literature on non-industrial forest management, which consistently finds larger ownerships more likely to be harvested (Amacher, Conway et al. 2003).

Hectares of cropland owned, also calculated. Both of the land variables are continuous. The effect of increasing cropland is likely negative; while such land could be used to grow biomass crops, it may be more profitable in other agricultural uses. Biomass crops are generally thought to be a relatively low-value agricultural commodity, and a recent study confirms that corn is more profitable than cellulosic crops at foreseeable cellulosic crop prices (James 2010).

Landowner demographic characteristics:

High income, a binary variable, indicating landowners reporting annual household income in the highest category (income > $150,000). As discussed in Chapter 3, higher exogenous income is expected to decrease marginal utility from biomass crop income, and is therefore expected to have a negative effect on acceptance probability.

Education, also a binary variable, indicating landowners reporting education in the upper two of four education categories, or education beyond high school. Education may have a positive effect on probability of acceptance, since biomass crops are a relatively recent phenomenon, and better-educated citizens may be more abreast of such recent developments. Education is frequently (though not always) found to be a significant and positive predictor of non-industrial forest harvest.

Farmer, defined as described above, and identified with a binary variable. Farming has an uncertain effect on acceptance probability. On one hand farmers are expected to be better equipped to implement agricultural initiatives than other landowners. On the other hand, they may be more risk averse, since a portion of their existing income is derived from current land use, and they may be more price sensitive, as they are expected to compare potential biomass crop profit with expected profit from alternative crops.

Landowner attitudes, including values for land amenities:

Feeling about biomass energy, the second question in the questionnaire. Before any discussion of biomass crops, respondents were asked "In general, how do you feel about biomass as an energy source?" This refers to biomass energy in general, not only to biomass crops, and respondents were presented with five response options, from "very negative" to "very positive", with a "neutral" option in the middle. The variable in the logistic model is binary, indicating respondents who chose either of the two positive responses. Willingness to accept a planting proposition is expected to increase with positive feelings about biomass energy, all else equal.

Strong environmentalist, a binary variable as discussed above. This indicates respondents who chose the strongest level of agreement with all four statements about environmental values. The effect of this variable is uncertain; while strong environmentalists presumably want the best outcome for the environment, they may not be certain that biomass crops provide this outcome. In particular, though biomass crops are a renewable energy source, cropping of any kind can have negative environmental effects as compared to leaving vegetation unmanaged.

Strong opinion about crop appearance, a binary variable. One land attribute that may be an important amenity for rural Massachusetts landowners is the appearance of their land. As discussed in Chapter 3, the possible significance of land-derived amenities in general is an important question in this research. The binary variable for crop appearance represents landowners who both rated the crop appearance as "quite important" or "very important", and also indicated that enjoying the scenery was "quite important" or "very important" as a reason to own land. It is assumed that the effect of strong opinions about crop appearance will be negative, i.e. that landowners may consider biomass crops less attractive than current land use (since current land use is likely more traditional), though this is not certain. As noted above, the survey booklet provides two photos of biomass crops, one each of a grassy crop and a woody crop, and results from the appearance questions may be sensitive to the selection of photos for the questionnaire.

Recreation important. This represents another possible amenity obtained from owning land. The binary variable indicates respondents who rated personal recreation as a "quite important" or "very important" reason to own land in Massachusetts. If landowners already obtain recreation amenity value from their land, changing land use by growing biomass crops may negatively affect this amenity value.

Wildlife habitat important. As indicated above, many landowners rated impact on wildlife habitat as an important consideration in planting biomass crops, and wildlife habitat may provide another important amenity value for landowners. This binary variable indicates landowners who both said impact on wildlife habitat was "quite important" or "very important" as consideration in planting biomass crops, and as a reason to own land. While the actual impacts of biomass crops on wildlife are likely ambiguous, as discussed above, it is assumed that landowners who currently derive utility from wildlife amenities may be less inclined to change current habitat, and therefore be less inclined to plant biomass crops.

Two methods are used to determine that variables do not exhibit excessive collinearity: 1) correlation coefficients are calculated, and found to be less than 0.5 in all cases, and 2) the same variables are entered in a linear regression model where variance inflation factors (VIFs) are calculated, with no values over 2.0 observed (a VIF ≥ 10 is typically thought to indicate excessive collinearity).

Logistic model results:

Overall, results of the binary logistic model are highly significant. The omnibus test of model coefficients tests the null hypothesis that the coefficients do not predict the probability of accepting a bid better than a model with the intercept alone. This test yields a chi-square score of 48.8 ($p < 0.001$), indicating high overall model significance.

The classification table (Table 4-7) indicates that the model correctly classifies respondent decisions to accept or decline with an overall accuracy of 70.3 percent, including 37.1 percent false positives (predict accept but observe decline) and 23.3 percent false negatives (predict decline but observe accept). The Nagelkerke R^2 measure (a pseudo R^2 used in logistic models) is 0.300. While this is not unusually low for a model with cross-sectional data, it does indicate the difficultly of modeling complex landowner decisions with a small number of predictor variables, and is consistent with the low number of significant correlations found in the bivariate analysis discussed above.

Additional confidence in the overall significance of the model is provided by the Hosmer-Lemeshow goodness-of-fit test, a test specifically designed to assess fit of a logistic model. This tests the null hypothesis of a linear relationship between the independent variables and the log odds of the dependent variable. The statistic is distributed as a chi-square, with low chi-square values (and high p-values) indicating the null hypothesis cannot be rejected, and that the model is likely appropriate. For this model, the Hosmer-Lemeshow chi-square statistic is 2.729 ($p = 0.950$), indicating the model is likely a good fit.

Estimates and significance for the individual predictor variable coefficients are shown in Table 4-6. The bid coefficient estimate is positive and statistically significant ($p = 0.014$). Higher biomass crop income per hectare increases probability of landowner acceptance, all else equal. As discussed in Chapter 3, increasing the bid has theoretically ambiguous results. But in this study (as in most other empirical studies) the substitution effect dominates the income effect, with landowners willing to forego land amenities associated with non-production when the opportunity cost of those amenities rises.

The coefficient for the variable representing a positive feeling about biomass energy has greater significance than the bid amount ($p = .001$), and the magnitude of the effect is large; a positive feeling about biomass energy has approximately the same impact on the log odds of planting a biomass crop as a $1004 per hectare increase in the bid level. This is consistent with the discussion in Chapter 3, which suggests that factors other than profit maximization are likely important in land-use decisions by owners.

The negative sign of the high-income coefficient is consistent with theory, which predicts that those with higher incomes would be less likely to accept the planting proposition (assuming lower marginal utility of additional income from biomass crops), though the estimated income coefficient is not statistically different from zero ($p = 0.540$). This may indicate that income does not play a large role in generating utility from biomass crops, as discussed in Chapter 3, and that income therefore not a good empirical predictor of willingness to accept.

The farmer coefficient is negative and highly significant ($p = 0.003$), indicating that farmers are less likely to accept the planting proposition. This suggests that western Massachusetts farmers have current per-hectare income opportunities better than those presented by biomass crops. In a separate model, the farmer variable is interacted with low, medium, and high bid-level variables. All of the farmer-bid-level coefficient estimates are negative, suggesting that farmers are less likely to accept even at the highest bid levels. The farmer-medium-bid and farmer-high-bid coefficients are statistically significant ($p = 0.043$ and $p = 0.013$ respectively).

The significance of the of farmer coefficient also raises a question about the specification of the model, i.e. whether farmer behavior is so different from non-farmers that farmer coefficients for all variables might in fact be different than for non-farmers. In a separate model, the farmer binary variable is interacted with all other variables in the model. Several of these interaction terms are found to be statistically significant, including the farmer-grassland ($p = 0.021$), farmer-education ($p = 0.031$), and farmer-habitat-importance ($p = 0.036$) variables. But in a structural test of the famer-interaction model against the base model, the log likelihood ratio for the interaction model does not decline sufficiently from the base model to indicate that the interaction model is a statistically significant improvement ($\chi^2 = 17.624$, $p = 0.062$). Farmer behavior appears to be somewhat different from other landowners, but not quite significantly different at the five percent probability level.

The crop-hectares coefficient sign is negative, indicating that more cropland reduces probability of planting biomass crops, perhaps for the same reason that being a farmer reduces the probability of planting, though the crop-hectares coefficient is not statistically significant ($p = 0.573$). As expected, the grass-hectares coefficient is positive and statistically significant ($p = 0.020$), indicating that those with more grassland are more likely to plant biomass crops. These results could also relate to ownership: as noted above, a majority of the cropland is owned by farmers, while a majority of the grassland is owned by non-farmers.

The coefficient for the variable indicating strong environmental feeling is positive (strong feelings imply higher probability of accepting) though not statistically significant ($p = 0.125$). This may reflect environmental ambiguities associated with biomass crop production, as noted above. By contrast, strong feelings about land appearance reduce acceptance probability, are highly significant ($p = 0.003$), and large in magnitude. Strong feelings for appearance have approximately the same impact on the log odds of planting as an $1503 per hectare reduction in the bid level. Again, this is consistent with theoretical expectations from Chapter 3: profit maximization is not a landowner's sole objective.

The coefficients for the other two amenity-related variables are not significant: neither importance of recreation opportunities on an owner's land nor importance of providing wildlife habitat is a significant predictor of willingness to accept the biomass crop planting proposition ($p = 0.197$ and $p = 0.430$, respectively). The habitat coefficient has the expected negative sign, while contrary to expectations, the recreation coefficient has a positive sign.

Given the theoretical interest in determining whether and to what extent amenity values from land depend on landowner income (see Chapter 3), amenity-income interaction terms are developed and tested in a separate model. Three interaction terms are created from the income variable with the variables for importance of appearance, recreation, and habitat provision respectively. Contrary to theoretical expectations, all variables have positive signs, indicating that landowners who both have high incomes and value land amenities are more rather than less likely to plant biomass crops than owners who only have high incomes. And none of these variables is found to be statistically different from zero. Based on this study, it appears that income has very little empirical relationship to utility received from amenity values of land.

Conclusions

The study described in this chapter finds many Massachusetts landowners interested in biomass crop possibilities, and willing to consider biomass crop production. In a contingent valuation exercise, 54 percent of respondents accept hypothetical bids for planting biomass crops on their land. At $658 per hectare per year, the parametric mean landowner payment estimate is higher than in other parts of the United States where biomass crops might be produced. But mean WTA is inflated by a segment of the population, especially farmers, who apparently have more lucrative agricultural options and are unlikely to use good cropland for biomass production. The median WTA level of $321 per hectare is a more feasible level of payment for biomass crop land (see Chapter 2), and there is 33 percent acceptance for bids of only $124 per hectare (n = 39). A quantity of production land can clearly be made available at relatively low cost per hectare.

It appears that the most promising areas for biomass crops are grasslands owned by non-farmers. While owners of smaller land parcels are willing to accept lower payments for planting biomass crops, total grassland hectares owned increases probability of acceptance; thus, smaller land parcels that are predominantly grassland may be particularly promising. Based on this survey sample, a majority of grassland in the region is owned by non-farmers. Possible biomass crop interactions with hay and forage markets are an important area for additional research.

Results of the empirical study are broadly consistent with the theoretical propositions put forth in Chapter 3. While the comparative static analysis in that chapter suggests that the effect of a per-hectare payment increase is ambiguous, this study finds strong empirical evidence that increasing payment increases probability of planting. Though the estimated income coefficient from the binary logistic model has the expected negative sign, it is not statistically significant, and from other results the posited relationship between income and marginal amenity values is not empirically evident. More broadly, the study clearly shows that potential crop income is not the only important consideration for most landowners, and that landowner utility maximization involves more than crop income. For example, respondent feelings about biomass energy are better predictors of planting acceptance than potential crop income, strong opinions about crop appearance greatly reduce odds of planting, and there is a correlation between preferring easy walking through fields and rejecting the biomass crop planting proposition.

All of this suggests that a nascent biomass crop industry must design cropping systems with multiple landowner objectives in mind. This survey finds that grassy crops will likely be more accepted than short-rotation woody crops The ability of biomass cropland to provide wildlife habitat appears to be a particularly strong landowner interest. The aesthetic component of croplands is also important to some landowners, as is usability of fields for walking (and presumably for other purposes).

A likely conflict stems from economic dependence of biomass crops on fertilizer applications, as shown in Chapter 2, and the concern of many landowners about chemical fertilizer use. This concern is particularly apparent among non-farmers, those who would otherwise be most inclined to accept biomass crops, and for lower payments. Feasibility of organic fertilizers and/or alternative crops or crop mixes that may be less nitrogen dependent than switchgrass (e.g. legumes) will likely be an important research question.

In general, more research is needed on the multi-functional properties and environmental effects of biomass crops, as these are clearly landowner concerns. For example, are there certain crops, mixtures, or management practices that are particularly beneficial or detrimental to wildlife? Can biomass crops in Massachusetts enhance rather than diminish the wildlife diversity that appears to be important to area landowners? Environmental ambiguities also need to be more clearly resolved for landowners who must weigh the global benefits of producing renewable energy, e.g. from reduced carbon emissions, against local impacts of their land use.

More research is also needed on the potential for using institutional and government-owned land for energy production, as there is a large quantity of such land, and the constituent owners are likely demographically and attitudinally different from private landowners. For example, in the course of survey development, the author was contacted by an employee of an area land trust. While the employee was personally interested in biomass crop potential in fields owned by the land trust, he was uncertain about whether biomass crop production would be perceived as consistent with the organization's mission.

In addition to research, education will likely be an important component of biomass crop development. A majority of landowners in the region feel that they know very little about biomass crops, and 40% of those rejecting a hypothetical planting bid cited a need for more information as a reason for rejection. Landowner knowledge and attitudes about biomass crops clearly play a large role in their willingness to plant, and such attitudes are likely more important than potential payments in garnering landowner approval. While this study reveals potential for biomass crops in Massachusetts, landowner assent is not a given, and will depend on developing a positive record and a supportive public.

Tables and Figures, Chapter 4

Table 4-1. Identification of sample for landowner survey

	Number of parcels	Reduction
Parcels meeting criteria, from GIS study	5162	
Parcels with map_ID field	4623	10%
Parcels with owner addresses found	2685	42%
Parcels owned by private individuals	1505	44%
Unique owners of parcels	1140	24%
Owners not used in pilot study	1048	8%
Owners not used in other UMass studies	957	9%

Table 4-2. Western Massachusetts landowner population demographic characteristics: American Community Survey and biomass crop landowner survey sample

		American Community Survey	Biomass crop landowner survey
Age categories			
1	18-34	6%	0%
2	35-54	42%	23%
3	55-74	40%	64%
4	75+	13%	13%
		100%	100%
Education categories			
1	less than high school	6%	0%
2	high school	46%	17%
3	2 or 4-year college	41%	41%
4	more than 2 or 4-year college	7%	42%
		100%	100%
Income categories			
1	less than $15,000	6%	3%
2	$15,000-34,999	12%	10%
3	$35,000-74,999	28%	30%
4	$75,000-149,999	45%	34%
5	more than $150,000	9%	24%
		100%	100%
Farmer status			
0	non-farmer	90%	78%
1	farmer	10%	22%
		100%	100%

American Community Survey: landowners with >4 ha land
Biomass crop landowner survey: landowners with >1 ha land suitable for biomass crops.

Table 4-3. Importance level of factors in considering whether to plant a biomass crop, percentage of respondents

	Not important	Slightly important	Fairly important	Quite important	Very important
Possible income from the crop	13.0%	21.3%	22.6%	17.2%	25.9%
Appearance of the crop	16.3%	18.8%	25.9%	19.7%	19.2%
Impact on wildlife habitat	5.0%	11.3%	25.5%	29.3%	28.9%
Ease of walking through fields with crops	23.9%	23.5%	25.2%	17.2%	10.1%
Possible chemical fertilizer or herbicide use in production	10.5%	12.7%	21.9%	18.6%	36.3%
Final use of the crop (heating, electricity generation, or transportation fuel; small-scale or large-scale)	35.9%	15.6%	20.3%	17.7%	10.5%
Whether you could use the crop to heat your own home or buildings	30.7%	24.4%	21.4%	13.4%	10.1%

Table 4-4. Current agricultural outputs produced on survey respondent lands, percent of respondents

Land currently produces:	Non-farmers	Farmers	All
Pasture or hay	67%	82%	70%
Corn or other field crops	18%	32%	21%
Vegetables	30%	44%	33%
Orchard products	10%	9%	10%
Berry products	12%	14%	13%
Maple syrup	3%	11%	4%
Timber	17%	42%	23%
Firewood	32%	58%	38%

Table 4-5. Nonparametric mean WTA estimate for biomass crop planting, dollars per hectare

	n	Mean	Std dev	95% CI min	95% CI max
All*	244	$918	$506	$854	$981
Farmers	55	$2,362	$1,282	$2,023	$2,700
Non-farmers	180	$765	$516	$689	$840
Owners of large parcels	117	$1,407	$573	$1,303	$1,511
Owners of small parcels	119	$830	$621	$719	$942
*excluding those who would never plant, and those who were not certain					

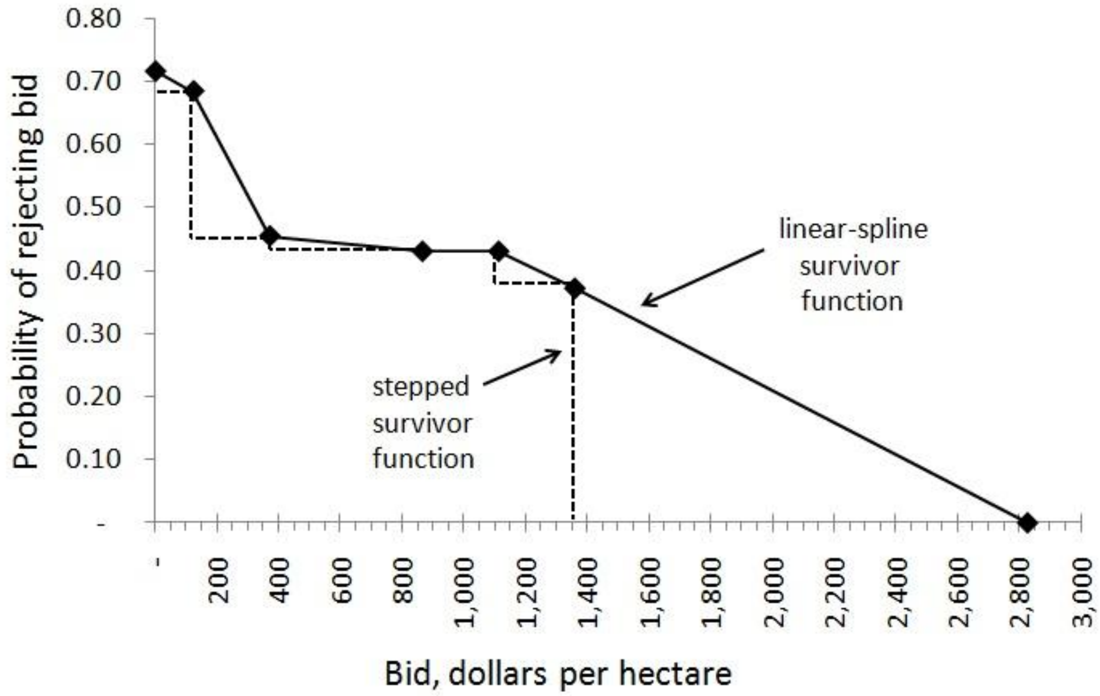
Table 4-6. Landowner survey binary logistic model variables and results for dependent variable: binary willingness-to-accept decision

	mean	b	se	Wald	p-value	exp(b)
Constant		-2.244	0.686	10.696	0.001	0.106
Bid, hundred dollars/ha (continuous)	7.51	0.111*	0.045	6.061	0.014	1.117
Grassland hectares (continuous)	8.60	0.060*	0.026	5.388	0.020	1.062
Cropland hectares (continuous)	7.49	-0.004	0.007	0.318	0.573	0.996
Highest income (binary)	0.24	-0.251	0.410	0.375	0.540	0.778
High education (binary)	0.83	1.069*	0.498	4.610	0.032	2.911
Farmer (binary)	0.23	-1.525**	0.508	9.024	0.003	0.218
Positive feeling biomass energy (binary)	0.55	1.155**	0.341	11.479	0.001	3.175
Strong environmentalist (binary)	0.09	1.050	0.684	2.355	0.125	2.857
Appearance important (binary)	0.14	-1.668**	0.571	8.542	0.003	0.189
Recreation important (binary)	0.54	0.483	0.375	1.661	0.197	1.621
Wildlife habitat important (binary)	0.45	-0.311	0.395	0.623	0.430	0.732
$\chi^2 = 48.8$, $p < 0.001$						
Nagelkerke pseudo $R^2 = 0.30$						
*significant at the 0.05 probability level						
**significant at the 0.01 probability level						

Table 4-7. Landowner survey binary logistic model: table of classifications for observed and predicted value

	Predict decline	Predict accept	Percent correct
Observe decline	56	33	62.9%
Observe accept	24	79	76.7%
		Overall correct	70.3%

Figure 4-1. Non-parametric estimation of mean WTA



Notes: horizontal and vertical intercepts estimated;
$618, $741, and $865 bids pooled

CHAPTER 5

CONCLUSIONS

As shown early in this dissertation, western Massachusetts has a large land base that is suitable for biomass crop production, approximately 14 percent of western Massachusetts land area given soil characteristics, current land use, and screening for environmentally sensitive areas. Fully utilizing this land base for biomass crops could yield an estimated biomass harvest of 1.3 million dry metric tons per year, based on a model simulating switchgrass growth with high applications of nitrogen fertilizer. This quantity of biomass energy represents about 1.5 percent of 2008 Massachusetts energy consumption, assuming a switchgrass energy value of 18.4 GJ/Mg and energy conversion efficiencies comparable to current efficiencies.

Yet the balance of this dissertation shows that for a number of reasons, this technically feasible level of biomass crop production is very unlikely. Production potential is first considered separately for different land uses.

Of the potential agricultural soils identified in western Massachusetts, a large portion (74 percent) is now forested. Though these areas likely represent former farmland, and could in principle be used again for agriculture, the production cost estimates of Chapter 2 show that there would be large financial barriers to using this land. In addition, converting forestland to farmland would likely entail costs in foregone forest ecosystem services, and in the short run, the cost of an initial release of carbon currently sequestered in forestland. While these non-financial costs are readily apparent, they have not been quantified in this study.

Current cropland represents 16 percent of the potential biomass crop land base identified in Chapter 2. But as suggested by the landowner survey in Chapter 4, most of this land is likely growing higher-value agricultural products, and using this land for biomass production would require a large increase in biomass energy prices. Farmers queried in the Chapter 4 survey require payment levels for agricultural land rent that are very high in comparison to biomass land rents in other parts of the United States, presumably as a result of high earning potential per unit area for other Massachusetts crops. In addition, using cropland for biomass production could have adverse welfare impacts in the form of higher food prices or less local food production. Several comments received on the Chapter 4 landowner survey reflect this concern.

Of the land-use types evaluated in this study, current grassland appears to have the greatest potential for biomass crop production, though grassland represents only 10 percent of the viable land base identified in western Massachusetts. At a land rental rate of $321 per hectare, the median WTA from the Chapter 4 study, western Massachusetts grassland could produce switchgrass at prices starting at about $95/dry Mg and rising to about $107/Mg for a quantity of 125,000 Mg per year (Figure 2-12). This assumes that biomass crops would be competitive with hay (the dominant grassland product) at the $321/ha land-rental rate, though more research is needed on potential interactions with the hay and forage market.

These quantities and prices assume the highest level of nitrogen-fertilizer use modeled in Chapter 2. More data are needed to empirically confirm the modeled impact of nitrogen fertilizer use on switchgrass production. New fertilizer use on the scale implied by the model would result in additional ecosystem service costs, for example from release of nitrous oxide (N_2O, a greenhouse gas), and in nitrate (NO_3) pollution of groundwater and waterways. The Chapter 4 landowner survey also revealed that chemical fertilizer use is a concern for a large number of western Massachusetts landowners, and it can be assumed that some portion of the otherwise-available land base would be withheld from production if synthetic fertilizer were used. More research is needed on potential for organic fertilizers (which may be of less concern to landowners) and on biomass crops or crop mixes that might be less nitrogen-fertilizer dependent (for example, crops or mixes including nitrogen-fixing legumes).

Chapters 3 and 4 also demonstrate that some quantity of the available land base will likely not be used for any crop production, given that many landowners (especially non-farmers) have motivations for owning land that are not strongly related to the land's income-generating potential. As shown theoretically in Chapter 3, with some supporting empirical evidence from Chapter 4, amenity values for land (as opposed to production values) are likely high for landowners with high exogenous incomes, which are in fact found among much of the western Massachusetts landowner population. Thus, even the relatively modest biomass crop supply estimate of 125,000 Mg/year likely overstates actual production potential; a more realistic figure might be half this quantity, based on median WTA. In terms of energy potential, 62,500 Mg/year of switchgrass would represent only about 0.1 percent of 2008 Massachusetts energy consumption.

Chapter 3 suggests that an important area of research is adapting biomass crop production processes so as to optimize across both energy-production and amenity-production variables. Chapters 3 and 4 also indicate that landowner education will be an important part of developing a Massachusetts biomass crop industry.

While the potential contribution of biomass crops to a Massachusetts renewable energy portfolio appears small on a percentage basis, this is understated by comparing production potential to current energy consumption. All feasible renewable energy portfolios include a large conservation component, using new or existing technologies to provide similar energy services with lower energy expenditure. If more fossil-fuel externalities were internalized in energy prices, the resulting higher energy prices would result in less energy consumption. With higher energy prices, many feasible but unused conservation strategies (e.g. higher insulation levels) would be implemented. Current energy consumption is of course determined in part by current prices, and there is a degree of long-term demand elasticity which would become apparent at higher, cost-internalizing energy prices. Thus, the potential percentage contribution of biomass crops is likely higher than it appears when compared to current consumption.

Even if biomass crops are not the major component of a future renewable energy portfolio, biomass crops still have relevance. The situation of biomass energy crops is similar to many potential renewable energy sources. For example, the potential energy contributions of methane from landfill gas or from dairy herd manure are likely quite limited as well, given the small numbers of landfills and dairy herds in the state. Yet capturing the available energy from these sources both taps an otherwise unused energy source, and has additional benefits from preventing the atmospheric release of methane, a potent greenhouse gas.

Any renewable energy portfolio will likely include a variety of such small-scale sources, since the nature of renewable energy is that it is widely dispersed across the landscape, and some of these sources may be locally significant. For example, grass pellets for heating fuel can be made on a relatively small scale, and in Pennsylvania, mobile grass pelletizers are being developed to produce local fuel for heating local schools and other facilities with biomass-burning heating equipment (http://www.wayneindependent.com/news/x1295933651). In such a context, biomass crop production could have important economic, educational, and other social benefits.

Biomass crops could make several other important contributions in addition to energy production. First, as suggested in Chapters 2 and 3, biomass crops may represent a means to prevent unused farmland from reverting to forest. Chapter 2 shows that costs to return forest to farmland are extremely high. In the future, society may have need for additional agricultural land, be it for food, fiber, or energy production. Currently landowners face annual mowing costs to maintain fields and prevent forest regrowth, representing a landowner expense.

As shown in the Chapter 4 landowner survey, 33 percent of landowner accepted bids of only $124 per hectare for planting biomass crops. Any kind of production that covers its own costs will likely have value to such landowners, in addition to the social value of maintaining the land base for future agricultural production.

Maintaining existing non-forested land may also have additional benefits for wildlife and aesthetic diversity. Different land-use types support different kinds of flora and fauna. Cellulosic biomass crops may be able to support desirable species, for example of birds, as at the MassAudubon switchgrass planting in Easthampton. Human residents and tourists may also prefer some landscape diversity to continuous forest cover across western Massachusetts.

Chapter 2 shows that switchgrass, one potential cellulosic biomass crop, is responsive to nitrogen fertilizer application. While as noted above, this can be problematic in some circumstances, in other situations this may represent a valuable way to remove nutrients that would otherwise be pollutants. For example, biomass crop fields may be appropriate places to spread municipal sewage sludge, since biomass crops are not consumed as food. The same may be true for fields around animal feeding operations, where biomass crops may be used to absorb excess nutrients.

All of this suggests potentially important niches for cellulosic biomass crops in Massachusetts, but also a need for more research in several areas. If providing wildlife habitat is a major landowner objective, as shown in Chapter 4, then a better understanding is needed of habitat consequences of alternative biomass crops and management practices. Some crops and practices may have significantly different results than others. Switchgrass, for example, while one of the most studied cellulosic biomass crops, is not necessarily optimal for objectives that include both crop yield and habitat provision.

Similarly, fertilizer use needs to be better understood in terms of its total impacts. Application of synthetic nitrogen fertilizer clearly has costs in both pollution and in discouraging landowners who would otherwise be interested in biomass crop production. Alternative crops, crop mixes, and/or fertilizers may produce greater total value than typical switchgrass cultivation using substantial applications of anhydrous ammonia or other forms of nitrogen fertilizer.

As shown in Chapter 2, simulated switchgrass yields without nitrogen application are of the same magnitude as natural forest biomass growth. In some ways, biomass crops represent just a means to take advantage of the growth-enhancing effects of nitrogen fertilizer. Yet this raises the question of how the total benefits and costs of natural forest or prairie biomass production compare to costs and benefits of production in an agricultural setting. In some cases, total biomass production values including biomass energy, pollution avoidance, habitat provision, etc., may be higher under less intensively managed production, and there is need for more research in this area.

While biomass crops will not likely solve the problem of renewable energy supply in Massachusetts on their own, they may make a small but important contribution in this regard, and under the right circumstances, they also have the potential to provide other important social benefits.

APPENDIX

SURVEY QUESTIONNAIRE

Massachusetts Landowner Survey: Grassy and Woody Biomass Crops

switchgrass—a grassy biomass crop

poplar—a woody biomass crop

Massachusetts Landowner Survey: Grassy and Woody Biomass Energy Crops

This research is being conducted by the University of Massachusetts to assess Massachusetts landowners' interest in grassy and woody biomass energy crops. Your answers will be held in strict confidence. Participation is voluntary and you may stop at any time, but your help would be greatly appreciated. Results will be used to evaluate the potential for grassy and woody biomass energy crops as an energy source in Massachusetts. The survey should take about 15 minutes to complete, and can also be completed by visiting this website:

www.umass.edu/resec/biocrops

For questions about the research or survey, contact:

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Thank you for participating.

1. How much do you already know about biomass energy in Massachusetts?

○	○	○	○	○
very little	little	some	much	very much

2. In general, how do you feel about biomass as an energy source?

○	○	○	○	○
very negative	negative	neutral	positive	very positive

Biomass energy includes all energy from plant material. Biomass can be made into pellets for use in home heating, can be burned to generate electricity, and can be used to make ethanol fuel and similar products. Most biomass energy in Massachusetts now comes from forest wood chips.

This survey is about grassy and woody biomass crops that can be grown in fields. Grassy crops like switchgrass look like hay (but taller—see photo front cover), and are harvested once each year. Woody biomass crops like poplar are harvested about every seven years (taller than grassy crops, but not as tall as forest trees—see photo front cover).

Grassy and woody biomass crops are perennials, growing for many years after initial planting, and they can be grown on most land in Massachusetts. On an annual basis, biomass crops typically produce more biomass per acre than forests. Grassy and woody biomass crops do <u>not</u> include corn, soybeans, canola, or other food crops.

3. On any fields (or non-forested areas) that you own, how interested would you be in using the land to grow a grassy or woody biomass crop?

○	○	○	○	○
not interested	slightly interested	fairly interested	quite interested	very interested

○ I don't own any fields or non-forested land.

4. Would you be more interested in a grassy crop or a woody crop?

○	○	○	○
grassy	neutral	woody	don't know

In considering whether to plant a biomass crop, and what crop to plant, how important are the following:

5. Possible income from the crop:

○	○	○	○	○
not important	slightly important	fairly important	quite important	very important

6. Appearance of the crop:

○	○	○	○	○
not important	slightly important	fairly important	quite important	very important

7. Impact on wildlife habitat:

○	○	○	○	○
not important	slightly important	fairly important	quite important	very important

8. Ease of walking through fields with crops:

○	○	○	○	○
not important	slightly important	fairly important	quite important	very important

9. Possible chemical fertilizer or herbicide use in production:

○	○	○	○	○
not important	slightly important	fairly important	quite important	very important

10. Final use of the crop (heating, electricity generation, or transportation fuel; small-scale or large-scale use):

○	○	○	○	○
not important	slightly important	fairly important	quite important	very important

11. Whether you could use the crop to heat your own home or buildings:

○	○	○	○	○
not important	slightly important	fairly important	quite important	very important

Please consider carefully the following imaginary situation.

12. Consider a situation where you could plant (or have someone else plant) some or all of your fields with a grassy or woody biomass crop (your choice). Assume you had a guaranteed market for the crop.

If you could cover all expenses for planting, maintaining, and harvesting the crop (including your time), and could make the net profit per acre shown below, would you plant at least some of your fields?

Remember that your fields will not be available for other uses as long as they are planted in biomass crops.

For a profit of [bid] per acre per year, I would:

○ not plant ○ plant

13. **<u>If you decided to plant</u>:**

About how many acres of land would you plant to a grassy or woody biomass crop?

[ ] acres

I did decide to plant at the profit level shown, but actually would have planted for as little as [ ] dollars profit per acre per year.

14. **<u>If you decided not to plant</u>**, please describe why (check all that apply):

☐ The suggested profit was too small.
☐ I would need more details about planting, managing, and/or harvesting the crop.
☐ Other uses of my fields are more important to me.
☐ I would never consider growing a grassy or woody biomass crop.

Please describe any other reasons you decided not to plant:

I decided not plant at the profit level shown, but would plant for a profit of [ ] dollars per acre per year.

15. *Please indicate your level of agreement with the following statements:*

a. Land must provide a return to cover the expenses associated with ownership.

○ strongly disagree ○ disagree ○ neutral ○ agree ○ strongly agree

b. I would be pleased if a rare or threatened species was found on my land.

○ strongly disagree ○ disagree ○ neutral ○ agree ○ strongly agree

c. My land provides benefits for society.

○ strongly disagree ○ disagree ○ neutral ○ agree ○ strongly agree

d. My land should provide for the needs of future plant and animal populations.

○ strongly disagree ○ disagree ○ neutral ○ agree ○ strongly agree

e. I have a responsibility to leave my land in at least as good condition as I found it.

○ strongly disagree ○ disagree ○ neutral ○ agree ○ strongly agree

f. Climate change is an important problem for society.

○ strongly disagree ○ disagree ○ neutral ○ agree ○ strongly agree

16. How important to you is each of the following reasons to continue owning land in Massachusetts?

	not important	slightly important	fairly important	quite important	very important
a. Income from timber	○	○	○	○	○
b. Income from agriculture	○	○	○	○	○
c. Financial investment	○	○	○	○	○
d. Personal recreation	○	○	○	○	○
e. To obtain firewood	○	○	○	○	○
f. To make maple syrup	○	○	○	○	○
g. As a place to live	○	○	○	○	○
h. To enjoy the scenery	○	○	○	○	○
i. To pass on to children	○	○	○	○	○
j. To preserve family & tradition	○	○	○	○	○
k. To protect land from development	○	○	○	○	○
l. To provide wildlife habitat	○	○	○	○	○
m. To have privacy	○	○	○	○	○
n. To protect the environment	○	○	○	○	○
o. To leave land unmanaged, letting nature take its course	○	○	○	○	○

17. Do you live in Massachusetts year round?

○ no ○ yes

18. About how much land do you own in Massachusetts?

[ ] acres in [ ] parcels

19. In what year did you personally first acquire this land?

[ ]

20. Do you farm any of your land in Massachusetts?

○ no ○ yes, but not for income ○ yes, for income

21. What does your land currently produce? (check all that apply)

- ☐ pasture or hay
- ☐ corn or other field crops
- ☐ vegetables
- ☐ orchard products
- ☐ berry products
- ☐ maple syrup
- ☐ timber
- ☐ firewood

22. About what percentage of your land is:

grass pasture or hay land	tillable cropland	orchard or perennials	woodland
%	%	%	%

23. Is any of your land in a current-use tax program (Chapter 61, 61a, or 61b)?

○ yes ○ no ○ don't know

24. Is any of your land under a conservation restriction prohibiting future development?

○ yes ○ no ○ don't know

25. Your gender is: ○ male ○ female

26. Your age is:

○ 18-34 ○ 35-54 ○ 55-74 ○ 75+

27. You describe yourself as (check all that apply):

☐ Hispanic ☐ White ☐ Black or African Am. ☐ Am. India n ☐ Asian ☐ Pacific Islander ☐ other

28. Your highest level of education completed is:

○ less than high school ○ high school ○ 2 or 4-year college ○ more than 2 or 4-year college

29. Your household income is:

○ less than $15,000 ○ $15,000-34,999 ○ 35,000-74,999 ○ $75,000-150,000 ○ more than $150,000

30. About what percentage of your household income typically comes from your land (farming, timber sale, etc.)?

○ less than 1% ○ 1%-10% ○ 10%-50% ○ more than 50%

31. Please give us any other comments you may have about biomass energy crops:

Thank you for completing this survey. Please return it in the accompanying envelope. For questions or comments, or to receive a summary of survey results, please contact:

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