THEORY AND IDENTIFICATION OF MARGINAL LAND AND FACTORS DETERMINING LAND USE CHANGE

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Abstract

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Biomass is being researched as a possible alternative to fossil sources of energy, in order to avoid externalities from fossil fuel use that affect the environment and the economy. Some biomass-based energy production systems may produce unwanted externalities in their own right, such as increasing the production pressure on the agricultural land base, resulting in a rise in prices of food commodities. Using marginal land for biomass production has been suggested as a solution. However, the definition of what constitutes marginal land is poorly understood. This paper provides a theoretical foundation for identification of marginal lands, and analyzes recent literature to assess how current usage of the term marginal correspond to the theoretical framework. Then, the paper devises empirical models that test possible methods of identification of the extensive margin of agricultural land in 19 counties in the state of Michigan. The models find that dynamic variables such as price changes have a statistically significant effect on land use change into and out of cropland. Land quality and regional effects are also statistically significant.

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Chapter 1: The Biofuel Debate

The use of biomass as a potential energy source has both champions and detractors. Proponents of biomass point to it as a potential source of fuel energy that provides economic and environmental benefits. The processing technology for turning biomass into biofuel is advancing, making biofuels both less expensive and less energy intensive to produce. Growing biomass absorbs as much carbon as burning biomass releases, so it could be a carbon neutral energy source, and biomass crops are seen as less damaging to soil and more beneficial as habitat than traditional cash crops. On the other side, critics point out that biomass crops will use land needed for other goods, like food production. Biomass must still be intensively produced and over the entire production cycle might actually use more energy than it generates. Intensive production is almost always less beneficial to the environment than native or restored land cover. Biomass production could push lands currently under native cover into production, resulting in a carbon debt. The question remains, is it possible to harvest the benefits of a biofuel industry but avoid the negative externalities such an industry may create?

Several recent studies have referenced marginal lands as a potential solution to the negative externalities that may be caused by biomass production. Marginal land is generally assumed to be land not being used for current production needs, or of such low quality it is ill-suited to modern intensive cropping systems. In theory, this land could produce biomass without pushing out traditional crops. Marginal land is also described as too poor in quality or too recently involved in agriculture to be supporting much native biomass, meaning it can be put into biomass production without releasing a large store of carbon. Planting perennial crops on soils vulnerable to erosion, or carbon-poor, could help preserve or restore those soils.

However, marginal lands are also more likely to be not used in agriculture for the specific reason that they are not suited to crop production of any kind. Such land may be too poor to grow any kind of crop, or soils too fragile to permit any kind of harvesting activity. In addition, soils may be engaged in other uses that cannot be provided if the land is dedicated to monoculture, such as providing native habitat.

The definition of marginal land as it affects policy is not new. In 1932, G.M. Peterson and J.K. Galbraith noted, "A program which might plan to remove certain of these lands [on the margin of cultivation] from cultivation and seek to prevent cultivation from being further extended in other areas must include recognition of the forces which governed the bringing into use of such land in the first place." Strikingly, in all the back and forth on the subject over the years, there has been very little research done to determine exactly what defines land as marginal, the quantity of this marginal land that is available, and the opportunity cost of these marginal lands.

Why marginal land?

Biomass is only a helpful alternative energy source if the industry can be made to produce more energy than it uses. Though the USDA has found that corn ethanol had a positive net energy ratio of 1.34 (Shapouri and Duffield, 2002), other research has produced conflicting results. A study in 2005 found that corn ethanol was actually energy negative, requiring 29% more fossil fuels to produce than it yielded (Pimentel et al, 2005). Switchgrass and woody biomass were even less promising.   However, a now well-known study from the University of Minnesota (Tilman et al., 2006) found that habitat-providing poly-cultures produced with few inputs on highly degraded land actually produced more net energy than intensively produced corn on fertile land. Therefore, extensive (low-input) production on poor quality soils may be a more energy-productive method of producing biomass.

Land is a limited resource, and different kinds of land are needed to produce different goods that people rely on, including food, fiber, and critical environmental services. There is already competition among these and other uses for land. Converting a portion of world energy supply to a land-based product would add to the competition, and could raise the price of necessary goods, including food. The general demand for land is already pushing the frontiers of available arable land. Douglas Morton and colleagues offer an empirical example of how higher prices for soybeans force deforestation in Brazil (Morton et al 2006). Recent spikes in food commodity prices worldwide have troubled some who feel food production should take priority over biomass production (Fritsche et al. 2006). Several studies have recently commented on the competition between food and fuel production should a biofuel industry become more widespread (Rajagopal et al. 2007; Fargione et al. 2008).

Thus, competition with traditional food and cash crops is a potential negative externality from biomass production, to be mitigated if possible. In a 2008 report, the Renewable Fuels Agency of the United Kingdom noted that biomass might avoid putting undue pressure on existing industry if "policies [are] focused upon ensuring that agricultural expansion to produce biofuel feedstock is directed towards suitable idle or marginal land or utilizes appropriate wastes, residues or other non-crop feedstock" (Gallagher, Berry, and Archer 2008). Another report produced for the World Wildlife Federation in 2006 found that though there were potential problems with biomass crops, they might be avoided if developed countries use their strong policy-making systems to prohibit bioenergy farming on land not currently farmed (Fritsche, 2006). Generally, in order to promote a new land-based product without infringing on the land used for other products, one would have to find land that is capable of production but not currently being used.

Biomass-based fuels are also expected to provide an environmental benefit by offsetting carbon and other GHG emissions. A biomass industry must reduce carbon emissions by displacing fossil fuels, and it must not emit carbon in other ways such that net carbon emissions from a biofuel lifecycle are positive. Biomass production that displaces native cover obviously incurs a carbon debt by disturbing the long-standing plants and soils. Biomass production on cropland indirectly results in carbon debt by pushing food agriculture into areas covered with native forest or grassland (Fargione et al. 2008). If biomass production spreads to cropland or forestlands, there could be severe negative impacts in terms of carbon emissions. Searchinger et al 2008 find that converting land – whether cropland, forest, or grassland – costs an average of 351 metric tons of carbon up front[1].

However, studies suggest that biomass has the potential to be carbon neutral or even carbon negative if grown on marginal lands. A 2007 study points out that the biomass is most likely to serve to capture carbon if the feedstock is produced on land "that was previously used for agriculture or pasture but that has been abandoned and not converted

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[1] The authors point out that using degraded or marginal lands for biomass production is still not likely as effective at reducing carbon emissions as simply reforesting or reseeding the land and managing it as native cover, though this implicit cost is not included in their calculations (Fargione et al. 2008).

to forest or urban areas" (Field et al., 2008). Fargione et al 2008 discusses the carbon emission reduction potential of different biomass crops in dedicated plantations. The results indicate that perennial biomass crops produced on abandoned or degraded lands "incurs little or no carbon debt and can offer immediate and sustained GHG advantages" as opposed to annual crops on land under native cover or on traditional cropland.

Where is marginal land, and how much is there?

A 2003 review of 17 studies of global biomass supply suggests that dedicated biomass plantations would be needed as a major feedstock supplier to any global biomass-based energy industry. The studies, mostly done in the 1990s, used different criteria to estimate yield levels and different methods for determining what land is available to biomass plantations in developing regions. The latter fell into three categories:

i) regional level calculations based on the assumption that certain shares of the present crop, grass, forest land could be converted

ii) estimates of surplus cropland in industrialized countries and degraded land in developing countries

iii) modeling based on geographically explicit land use/land cover databases

Results varied widely, ranging from 50 $EJyr^{-1}$ in 2050 to 240 $EJyr^{-1}$ in the year 2050 (Berndes et al. 2003). It is not surprising that such early efforts produced widely varying results. However, it is somewhat surprising that while nearly all suggested avoiding competition for land with existing industries by use of marginal, surplus, or degraded land, none of the studies addressed or proposed a method to address an actual quantification of available marginal land. This is of interest given that several of these studies have served as benchmarks cited in other research[2].

More recent studies continue to reference marginal or similarly described land, and to cite its production potential, without defining the land resource itself. A study by Hoogwijk et al (2003) attempts to determine the range of "biomass that can come available as (primary) energy supply without affecting the supply for food crops," looking at roughly 50 years into the future. This study assumes a global pool of approximately 430-580 Mha of degraded land (loosely defined in that study as deforested or otherwise degraded through human use, suitable for reforestation) could supply from 8-110EJy^{-1}.

The research cited above claims that biomass production on marginal lands is physically achievable, and will result in reduced carbon emissions without hampering food production. But the concept has still to be tested empirically. No quantification or physical analysis of marginal lands can be done until marginal is defined. Likewise, economic relationships relating to such parcels will depend on where parcels are located and what other opportunities are available to landowners. The amount of "marginal" land available and the yields achievable on that land are critical factors that will determine whether or not individual land owners actually decide to invest in biomass production.

- **How are "marginal lands" defined economically?**

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[2] For example, according to Google Scholar, Hoogwijk et al., 2003 has been cited 178 times, Lazarus et al., 1993 has been cited 73 times, Edmonds et al., 1996 has been cited 45 times, etc. (www.scholar.google.com, accessed online September 1, 2010).

- **What factors contribute to land use change, and how can these factor influence the extensive margin of land use?**
- **Can existing land use analysis tools be used to determine the location and extent of land at the extensive margin of agriculture?**

There are several ways to define the term “marginal.” In a general sense, the academic community often uses marginal to refer to land of poor quality for agriculture or susceptible to erosion or other degradation (Peterson and Galbraith 1932; Dangerfield and Harwell 1990; Lal 2005). Though it is still a relative term, this kind of biophysical classification of marginality can be assigned to a given unit of land on a permanent basis. If all else is equal, or land unlimited, then farmers would choose land purely based on the capacity of the soil, and all land with good soil would be available to farmers.

However, in the debate regarding biomass production, “marginal” refers to the economic opportunity available to the land owner and the land use choices that might be made by land owners. When considering management implications for land as an economic resource, marginal should be defined within the context of economics. Economists define marginal land as land at the extensive margin of production (Barlowe 1986; Peterson and Galbraith 1932). That is, land where revenue from optimal production is just equal to costs of production.

In an economic production context, “marginal” is a relative term. Land that is marginal for one use might be highly productive for another. Given the interest in the concept of using marginal lands for biomass production, this paper endeavors to outline a consistent framework for identifying the productive value of land. We then review recent literature to determine if the current usage of the term “marginal” and similar terms conforms to an economic definition, especially where economic outcomes are anticipated. We then apply our framework to an analysis of land use in Michigan from 1996 to 2006.

Chapter 2: Conceptual Framework

Landowners and government land managers are interested in knowing how biomass production might impact land use patterns currently observed. Researchers, when discussing related topics, often reference a "surplus" or "marginal" set of lands that could be dedicated to biomass, often implying specific externalities, good and bad, that might occur from this type of land use. There has long been discussion in economic circles related to conceptualizing how to categorize land for effective management, and how to identify marginal lands (Peterson and Galbraith 1932; Gardner 1977; Barlowe 1986). However, there has been little research directly on this hypothetical land resource, in terms of defining and quantifying it, and land categorization structures developed by economists have not been applied to the biomass debate.

To determine which land is "marginal," and where, and what that means in terms of availability for biomass production, we need to understand what marginal means. Marginal is a term describing the relative suitability of a unit of land for any specific type of productive use. Thus, to understand marginal, we must understand how land is determined suitable for a given use.

Land is utilized in order to maximize utility. For the purposes of this study, utility can be defined as any net benefit to an individual or to society resulting from consumption of a particular good or service. A land unit can be practically described as marginal if it is likely to be transitioned to a different use given a marginal shift in any factors that affects the land unit's ability to provide utility, whether through profits used to buy consumption experiences, or direct consumption from products or services provided by the land, known as amenities.

Production in this case refers broadly to any way the land is involved in generating goods or services that can be consumed to provide utility. Because we want to address land use decisions, we limit this discussion to utility that accrues directly to the owner, regardless of harm or benefit that might be incurred by others.

Land quality:

In 1821, economist David Ricardo laid the foundation for the theory of why different units of land have different values. The difference in these values is what is known in economic terms as land rent. According to Ricardo, the heterogeneous nature of different parcels of land gives rise to land rents, as production practices are applied to land of different quality. He noted that as land becomes scarce, and less productive land is cultivated to meet the demand of the population, rents become extractable from land. As Ricardo phrased it, ‘When…land of the second degree is taken into cultivation, rent immediately commences on that of the first quality, and the amount of that rent will depend on the difference in the quality of these two portions of land" (Ricardo, 1919). Thus, land quality can be represented by a vector q $(q_1, q_2 \ldots q_n)$, where q_1 represents the highest quality land, and q_n the lowest quality brought into production. Rent r from parcel i can be calculated as price p_y of output times quantity of output $y(q_i)$ minus $y(q_n)$. Rent, is should be noted, is relative to the base unit of land, unit n.

Equation 1: $r_i = p_y * (y(q_i) - y(q_n))$

Ricardo is careful to explain that improvements on the land, including buildings, irrigation systems, or other improvements, constitute an investment of capital, and returns to those improvements are returns to capital, and are not attributable to the land. The land rent is a product of what Ricardo calls the "indestructible powers of the soil" (Ricardo, 1919), and what will here be referred to as "quality" of the land, meaning soil quality, and also encompassing other physical factors such as climate and slope. While modern economists might not agree that any characteristics of the soil are truly indestructible, it is generally accepted that the biophysical attributes of a unit of land are relatively stable and contribute to its value.

Land rents become an important factor in land use choice when one makes the assumption that landowners are primarily motivated by the desire to capture the highest rents possible. Ricardo notes that when given the choice, farmers will use the best quality land first, and leave lesser quality land undisturbed, because an equal investment into a high quality unit of land will provide a greater return than into a lesser quality unit of land. Once the best lands are in production but do not meet demand, landowners must decide whether to invest more in land currently in production (increased investment can take many forms, from additional fertilizer to a new tractor) or put new land previously idle into production.

In Ricardo's simple model, this difference in land quality is what drives differences in how land is used. The profit-maximizing owner will invest in land up to the point where the cost of the unit increase in investment yields an equal increase in return (assuming diminishing returns). This is known as the intensive margin of production (Barlowe, 1986). But different land quality gives the land owner additional options. The land owner will invest in the best quality land first, but will trade off increasing investment in that unit (and getting diminishing returns) with extending production to new, lesser quality land, so as to maximize the total returns to investment. If bringing new land into production results in a greater return on investment than continued intensive increase on land already planted, the landowner will shift from intensive to extensive investments. The extensive increase in production will continue until the land owner reaches the extensive margin of production. The extensive margin is the point at which the value of production, net of all expenses and holding all other factors of production constant, reaches zero as land quality declines. Using Ricardo's simple model of land and capital as the only inputs, the value of production is equal to the rent from land quality. At the extensive margin, rents are at or approaching zero.

$$\text{Equation 2:} \quad r_i(q_i) \leq 0$$

The model can be expanded to include other inputs, but to discover the extensive margin, all other factors must be held constant. In other words, holding all other inputs, prices and other factors of production constant, the best the land owner can do at the extensive margin is break even (Barlowe, 1986). It is important to note that the extensive margin pertains to a given use j, defined by the method of production rather than the end product. The extensive margin does not pertain to all of the production options open to the landowner for a given unit of land. Thus, it is very unlikely a unit of land could be identified as marginal for all uses. Even though the output may remain the same, the landowner will likely adjust the inputs used other than land depending on their costs and the land unit's ability to make efficient use of the inputs. Therefore, as land quality declines, production methods shift to accommodate the decline in land quality, and several marginal thresholds may be crossed before the land is of such poor quality that the landowner of a parcel at a certain level of quality decides to produce a different product.

Location:

We have described a continuum of land quality. Rent declines as land quality declines, as does the net benefit from production. Rent is defined as the benefit to an owner from the land quality difference alone, but production can result in profit benefits that are greater or less than the rent from land heterogeneity. The actual level of profit, π, and the point where $\pi_i(q_i)=0$, depends on factors other than just land quality, and so other factors contribute to land use choice. Von Thunen, writing after Ricardo in the 1800s, was one of the earliest economists to introduce factors external to the land unit itself to the theory of land use, by elaborating how the theory of location value.

Von Thunen's analysis begins with a world that consists of a simple plain with a homogenous land resource. In this world, no one location has any advantage on any other, all land has equal value, and any product can rationally be produced in any location. Now, add a city in the center of the plain. The city is a concentrated market and a more desirable place to trade. Produce from land that is farther away from the village incurs a higher transportation cost to get to the village, and thus produce from more distant land is less profitable. This in turn transfers to the value of the more distant land itself, making it lower than the value of lands closer in. In addition, heavier products incur a higher transportation cost than lighter products. Suddenly, production becomes spatially stratified, according to the relationship between the costs of production

– specifically, transportation requirements – and the value of the output (Von Thünen 1966). In Von Thunen's model, the profit per unit is simply the price minus the transportation cost, $\pi_i = y(q_i)*(p_y - p_t)$. This model can easily be expanded to fit any situation where production incurs a cost per unit. In agriculture in general, after land and manager time, many costs are incurred on a per unit basis. For biomass production in particular, per-unit harvest costs (c_h) increase dramatically as yield increases (James et al., 2010).

Von Thunen adds to the picture by noting that these production costs result in a range of production options available to any land owner (land use is $j = [j_1, j_2 \ldots j_m]$) that may be more or less profitable depending on the location of the land unit. According to Von Thunen, more intensively-produced goods like vegetables and dairy facilities should be produced closer to the city center, while lower value goods should be produced farther out. Distance from the city center was determined by the optimization of value of crop and the transportation costs incurred. Production must be optimized not only according to characteristics of the land unit, but also according to external relationships of the parcel to other factors of production, including location relative to markets.

Von Thunen's critical addition to a model of optimal land use goes beyond introducing transportation cost as a factor of land use choice. He introduces the concept of factors not inherent in the unit of land as contributing to the value of that land. Locations relative to input sources and markets for outputs is one important factor. Other economists have built on Von Thunen by identifying other kinds of variables that impact land use choice, including range of land use options, input and output price, technology, managerial characteristics, and policy (Barlowe 1986; Peterson and Galbraith 1932) .

This is not a comprehensive list of the elements that drive land use choice, but it illustrates the breadth of factors beyond land quality. Each of these variable categories is explained in greater detail below.

Price:

Ricardo states that "when land of an inferior quality is taken into cultivation, the exchangeable value of raw produce will rise, because more labor is required to produce it." Modern day economists base the value of a good in the total supply available and the total demand for that good. The farmer is a price taker, and the price of a good is exogenous to his production. As the price for the product rises, farmers will place "land of inferior quality" into production, because the increased revenue will compensate the farmer for the extra costs necessary for production on inferior lands. (In effect, the increase in price causes the extensive margin to shift to lower quality land.) In doing so, the owner will pull land out of whatever use it was in before.

Policy:

Policies set at local, state, and national levels shape market relationships, and thus the profitability of different production options. Policies that establish subsidies, restrict chemical inputs, and reward retiring fragile lands have already had a major impact on agriculture in the United States. Biomass policies are set on a course to have equal if not greater importance. The Biomass Crop Assistance Program subsidies included in the Food, Conservation and Energy Act of 2008 (Public Law No: 110-246) have set a precedent for strong government support to the biomass industry, while also indicating government preferences for production methods that do not increase greenhouse gas emissions relative to fossil fuels use. Biomass production is being indirectly subsidized by supports to the end product, ethanol, and directly subsidized by payments for establishment and harvest. At the same time, the EPA has stipulated that biomass supply chains that do not result in increased greenhouse gas emissions will receive greater government support. This is one example of how policy can influence land use choice.

How a policy is incorporated into a model depends entirely on how the policy is structured. Policies can eliminate production systems from the set of options *(j)* open to landowners, by prohibiting certain activities on certain types of land, for example. Subsidies can increase the attractiveness of production systems that would be otherwise rejected by landowners. Adding policy variables to a model can be difficult because not all policies are determined exogenously. Especially at a local level, policies are often designed to respond to a trend in land use, or prompt a change in land use (Irwin and Geoghegan, 2001). Zoning laws, environmental restrictions, price supports, tax credits, as well as road construction and maintenance, utility service areas and other government interventions can be critical to land use choice, however, researchers should be wary of introducing endogeneity through local policy variables.

Manager characteristics and technology:

The extensive margin may not be the same for all land managers. The utility derived from direct consumption of amenity benefits will vary from person to person, affecting total utility derived from the land and the value a land owner obtains from a given production system. In addition, the profitability of a given production system may be partially dependent on the land owner's own skill or experience in managing the system.

Thus, the optimality of different production systems can vary in a predictable way depending on certain characteristics of a land owner or manager. In their review of economic models of land use change, Irwin and Geogeghan note the variables “family size, off-farm income, education level, wealth and ability to bear risk” as potential measures of different trends among land managers that might impact land use choice (Irwin and Geoghegan 2001). In some cases, moral or cultural considerations, such as preferred lifestyle or a strong sense of environmental stewardship could also impact which land use an individual person considers optimal. To the extent that these preferences are reflected in a regional culture – are similarly held by a majority of people, and are not random to an individual, they can influence land use patterns at a broader area.

Similarly, not all technologies and techniques are known or available in all locations. In comparing two different geographical regions, it may be necessary to control for differences in production methods. This is particularly relevant to agriculture. Farming practices that conserve soil and habitat may be more widely known and adopted in one location versus another. The intensity of farming in one location may make machinery affordable that for farmers in a different location is cost-prohibitive. Though over the long term land owners can invest and adopt new technologies, in the short term, the production options they consider are limited to those they can implement with the set of machines, production techniques, and other inputs that are already available.

Utility from amenities:

The extensive margin of land is generally defined in economics as the point at which profits from two uses become equal as land quality changes. However, landowners may not capture all of the rent from their land in the form of profit. Amenity benefit streams also have a significant impact on land use choice. Depending on the relationships between marketable goods and amenities produced on a unit of land, the amenity benefits may increase, offset, or not affect the opportunity cost of switching land use. For example, if presence of wildlife is a non-market benefit desired by the land owner, such may help offset the opportunity cost of switching from corn production to perennial biomass production, assuming perennial biomass increases the non-market benefit. If, on the other hand, the land is not subject to any intensive production, a switch to biomass production might decrease the non-market benefit, increasing the opportunity cost of the switch.

A Model of Land Use Choice

Hardie and Parks, in their construction of an econometric area base model to predict land use, expand on the model of land value to demonstrate how land use transitions (Hardie and Parks, 1997) across different land units. Hardie and Parks use the basic profit function $\pi^*(q) = px(p,q,s)$, where q represents land quality, p is price vector, x represents a vector of inputs and outputs, and s represents land manager characteristics. The equation measures variable profits. Total profit is determined by subtracting fixed costs.

This function captures the profit impacts of some of the elements of production noted above, names land quality, prices for inputs and outputs, and manager traits. We modify the Hardie and Parks model by noting how additional factors including available technology, existing policy framework, and amenity values might be included to create a more complete measure of relative land use profitability.

Equation 3: $\pi^*_{ijt} = g(q_i, l_{it}, m_{ij}, \tau_j, p_{yt}, \lambda_{t,} \alpha_{ijt})$

Equation 3 is a reduced form model of this expanded equation, where j=1…n represents a range of production options, i represents the unit of land, and t represents the period of time. As stated previously, q represents land quality, and p variables are prices. The basic profit function is total revenue (price of output minus transportation costs (p_t) times total output) minus production costs including land price among other input costs. The relationship of other factors, including location (l), manager traits (m), technology available (s), and policy (λ) will vary by situation. We assume variables q, p, m, τ and l are exogenous. Maximum profit is determined by first optimizing each production system. Each expression is then applied to one parcel of land using the land quality determinant,

Equation 4: $\pi^{*j} = \max(\pi^{*1}, \pi^{*2} \ldots \pi^{*n} \mid q_i, l_{it}, m_{ij}, \tau_j, p_{yr}, \lambda_t)$

However, a profit function elaborates only part of the utility a land owner may derive from a given land use. Utility is a measure of total benefit. In general utility can be derived from consumption of goods purchased with profits, so profits convert directly into utility, or utility can be enjoyed directly, from a good, service or trait that is not purchased. In the case of land, such goods are enjoyed directly by the landowners, and cannot be purchased or in any way converted to a dollar value. Consumption and amenity benefits (α) are balanced in order to optimize utility.

Equation 5: $U^*_i = f(C(\pi_{ijr}), \alpha_{ijr}),\ \text{s.t. } C \leq \pi$

results in one optimal land use for each unique combination of land quality, technology available and manager traits, within a context of policy and prices, and considering the amenity benefits of the land unit. Note that the profit function is not π^*, which maximizes profit. The land use option that optimizes utility may not correspond to the land use option that maximized profit when considered in isolation of amenity benefits.

Though it is important to note the role of amenity benefits, the actual value of those benefits, as it has no monetary equivalent, is difficult to measure. The relative importance of amenity benefits is thus unknown. This paper will proceed under the assumption that landowners on average are primarily interested in maximizing profit, acknowledging that the assumption is largely untested.

Table 1. Variables included in conceptual model of land use choice

π	Profit	The net gain from production of product j, used here as a proxy for utility
q	Land quality	A cardinal index of land quality values
l	Location	The relative location of markets and other points of interest
m	Manager traits	Characteristics of the land manager such as education, experience, wealth, family size, other income, etc., that may determine his ability to adopt (knowledge, ability to take on risk, etc.) some land use options.
τ	Available technology	Technology available in the area (for use when comparing across regions)
x	Input level	Quantity of input per unit of production or per unit of land
y	Yield	Production per land unit
p	Price	Price includes separate prices for inputs (p_x) including land price, and output (p_y).
λ	policy	Policies at a national, state or local level that impact the land use choice. Policies can be in the form of taxes, subsidies, prohibitions, etc.

α	Amenity values	Any benefit that is generated by the land, and enjoyed by the owners, but not able to be directly converted to a financial value (may be incorporated into land value as an amenity)
i	Land unit	In this study, land unit is a 30m pixel (.25 acre)
j	Land use	The full set of land use options open to the land owner
t	Time period	Period in which observations are taken. In this study, data from two timesteps are used, 2001 observations and 2006 observations.

Land Use Transition

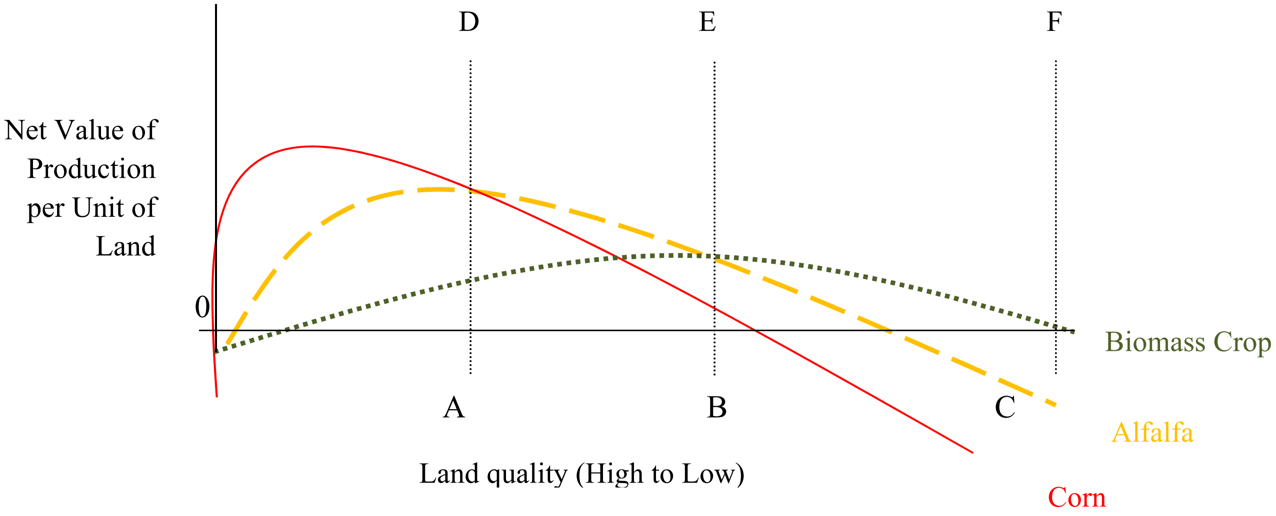
using Equation 4, it is possible to identify the extensive margins between distinct land uses. Any model of land use that takes into account both inherent and external economic factors, and allows for competition between different land uses, can be adapted to identify marginal lands. This concept is presented graphically in Figure 1. The extensive margin for each use is the point at which the curve for the next best use intersects the current use as quality decreases (quality decreases to the right).

The model contains a few key features that allow for the comparison among land uses. Parcels with like optimal productive uses should fall in contiguous blocks along a segment of a land quality vector, q. Relative value of different uses can be determined by mapping multiple uses across the vector of q. We assume that the continuum of q is monotonic, and continuous, and therefore differentiable at all points (Palmquist 1989; Lichtenberg 1989). As we have described it, q is a composite good representing soil qualities, location, and other fixed attributes of the land that have value for production. Ricardo represented this value as discrete, but more recent applications have considered a continuous value of q (Lichtenberg 1989) . The precise conceptualization of q depends on the data used to measure it. It can be discrete or continuous, as long as it is differentiable at all values for q.

We also assume the vector J is a nominal set of different land uses, including both for-profit production endeavors and uses that generate exclusively amenity benefits, such as vacation property.. In this conceptual model, J can encompass everything from commercial development to wilderness areas.

Figure 1, adapted from Barlowe 1986, shows hypothetical net revenue from three different production operations as dependent on the quality of the land unit used in production. The shape and slope of the lines in Figure 1 are dependent on the exogenous variables. At the highest land rent, or most value-generating end of the land quality scale, corn generates high profits (land quality section ‘A’). Net value of the output decreases rapidly as the quality of land drops. With the high land costs of section ‘A’, alfalfa is the second-best option relative to corn. But on lower quality land, section B, alfalfa is the most profitable activity. Line D represents the point of transition, where $\pi^{*j}(q_i)' = \pi^{*m}(q_i)'$. But the profitability of alfalfa is decreasing as land quality declines (the cost per unit produced is increasing as more non-land inputs are required to substitute for lack of soil quality), until eventually biomass, a lower intensity production system, is able to generate higher net returns than alfalfa and land use again transitions at line E (section C). The path of these incremental value functions assumes that the land quality impact on yield is a lesser issue for biomass than for alfalfa.

Figure 1. Production net revenue graphed over a continuum of land quality (Adapted from Barlowe 1986)



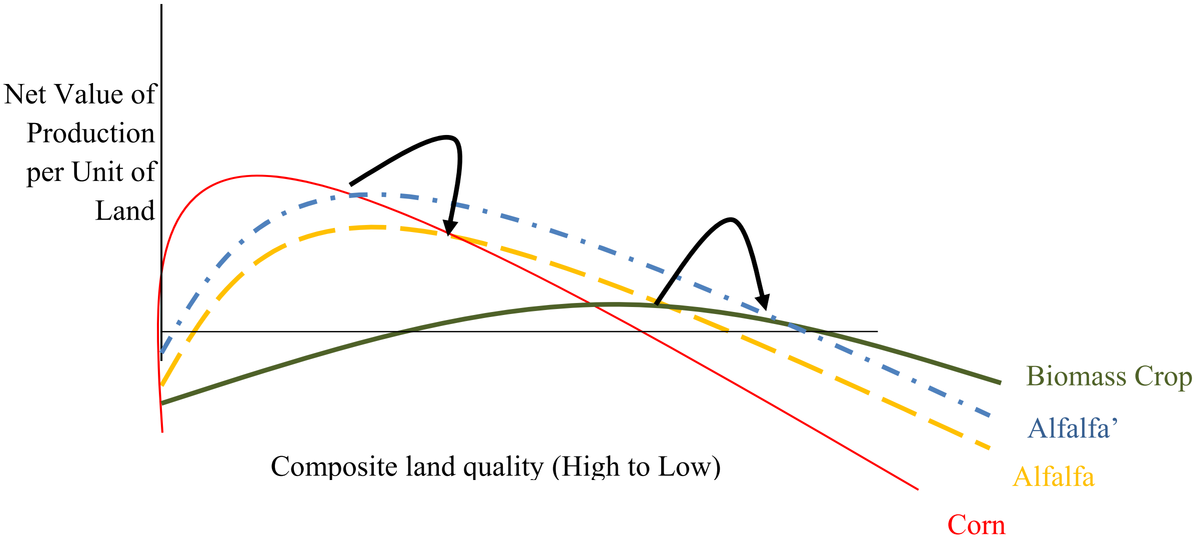
It is key to note that the shift in land use does not necessarily happen at the point where net revenue from production drops to 0, but rather at the point where, given the unit decrease in land quality, the next best opportunity equals the more intensive opportunity in net revenue. The point of marginality for land cannot be determined by analyzing land suitability for a single productive use. The range of uses must be taken into consideration.

Dynamic Nature of Extensive Margin

Assuming factors that determine profit remain unchanged, land use choice should also remain unchanged. Land use change, especially over the short term, is driven only by the dynamic variables in the land use choice model. Ricardo referred to the properties that make up q as “indestructible.” While land unit traits are not perfectly fixed, they change over a relatively long period of time. Variables m and t, likewise, can be considered as fixed in the short term. However, vectors for p, λ, and possibly α are dynamic, and they cause the extensive margin of land use, and the points of transition between land use to also be dynamic. Peterson and Galbraith, 1932, referred to this as the "essentially shifting character of the margin of cultivation". For example, the ratio between total input costs and total revenue per unit land determines slope of the incremental value function, and this ratio changes with price.

A price increase for output from use j, assuming utility for all other uses holds constant, can pull land of quality both above and below the quality of land currently engaged in use j. For example, if the price of alfalfa suddenly increases, it will assimilate resources from both corn and biomass. Land transitions into alfalfa from corn at a higher land quality, and transitions out of alfalfa into biomass at a lower quality than previously, following the price increase. Figure 2 demonstrates this shift. The arrows highlight the change in the points of transition.

Figure 2. Change in production net revenue due to change in output price



Valuing *q* Across Categories of Use

The composite nature of q makes the representation above difficult to translate to an empirical model if land uses outside agriculture are to be included. There are many uses for land, and all compete for a limited land base. Complicating the model is that factors of the composite q are not equally important across uses. Proximity to schools, for example, is highly valuable in residential neighborhoods, but of little use to farmers, while homeowners generally don't value the depth of topsoil under their houses. Table 2 shows common attributes of land across three different uses for land, and indicates whether the attribute is likely to have a positive, neutral or negative value for a land owner engaging in that use. To address this issue, it would probably be necessary to apply the model so that only uses that value similar properties of land are assessed in the same model.

Table 2. Land unit attribute value across different land uses

	Soil organic matter	Animal habitat	Proximity to schools
Residential	Neutral	Neutral/Negative	Positive
Recreational	Neutral	Positive	Neutral
Agricultural	Positive	Neutral	Neutral

Only dynamic exogenous variables have the ability to shift the extensive margin of a land use, moving that unit of land either above or below the point where other options are more profitable. As land use change on average occurs at the extensive margin, it is an indicator of what level of land quality marks the extensive margin of a given use in a given context. Therefore, in order to identify the land at the extensive margin for a given use, it would be useful to know how sensitive a land use choice is to shifts in the dynamic variables.

Chapter 3: Meta-analysis of Recent Literature on Bioenergy Feedstocks

This chapter provides a meta-analysis of recent studies that link biomass production with a specific type, or types, of land. Specifically, we consider whether the term "marginal land," or a similar term, is used in reference to land that meets the economic definition of marginal lands, and whether the studies are considering all factors that influence land use choice and land use change when considering which lands are marginal or which should be used for biomass.

In 1993, D.O. Hall and colleagues published a broad overview of the concept of an energy supply from biomass that has since been frequently cited (Hall et al. 1993). In a bulleted list of potential benefits from a biofuel industry, the article presents the idea that biomass production could help restore degraded lands in developing countries, and allow lands enrolled in set-aside programs in developed countries to be productive, without increasing food supply (and therefore lowering prices for commodity crops). Since the early 1990s, many studies have been done to attempt to determine the maximum level of biomass the Earth could supply. Several of these studies incorporated Hall's land use ideas – assuming that biomass production on marginal lands could offer additional benefits such as improved environmental services, or avoid negative externalities, such as impacting the price of commodity crops.

Despite being widely used in academic literature relating to biomass, the term marginal is not supported by either a precise definition or research to determine which lands that fall into the category marginal. The same is true for alternative terms for lesser-quality lands, such as abandoned or degraded. In a review of 17 global biomass supply studies conducted from 1990 to 2001, including the Hall study, Berndes et al found that of those that promoted biomass on degraded lands “none … presents an autonomous assessment of the actual extent of degraded land that is suitable and available for plantation establishment” (Göran Berndes, Monique Hoogwijk, and Richard van den Broek 2003). Still, both the terms and arguments for and against biomass production on marginal or similar land continued to be used, often with some inconsistency.

Determining land suitability and availability for different purposes is an extremely difficult thing to do, even in a general way. As discussed in the previous chapter, land use is the result of complex decision making by individuals, even when the impacts of those choices have repercussions beyond the land owner. Land owners are bound only by the policies and regulations in place, and will make the choice that provides the most benefit to them, usually a financial benefit. Because economic conditions are constantly shifting, the set of opportunities open to a land owner, and their respective pay-offs are also shifting. Whether or not land is marginal to a given use such as agricultural production is a function of all the factors that determine land use choice and land use change, and is therefore sensitive to shifts in these factors. Though land quality is largely a static trait, prices, policies, and other factors that act to shape an owner’s land use decisions are not. Therefore, establishing a fixed inventory of available marginal lands, or determining where the marginal land base lies in any given moment is a tricky endeavor.

We reviewed 16 articles related to biomass production that incorporate the idea that certain types of land are preferable for biomass production, from an economic, social or environmental perspective. Our objective was to determine what terms are being used to describe these preferred lands, and how those terms are being defined. We looked for synergy among definitions, and sought to highlight contradictions, or areas where the definitions did not encompass the economic relationships implied by the economic definition of "marginal". The goal of this study is not to identify the preferred definition of marginal, but to consolidate and summarize the different definitions being presented in the literature, and the implications of those definitions.

Method

To determine how the concept of marginal lands is being presented across the academic literature we collected as broad a sample of studies as possible that discuss biomass production, and that at minimum mention the land resource to be used for biomass production. A study was added to the collection if it represented a different methodology, regional focus, or discipline. Studies that did not meet at least one of these criteria were culled. In choosing between two similar studies, we selected the one with more citations as being the more representative of that branch of the literature.

We chose 16 studies that discuss the land base that could be used for dedicated biomass production, in particular the types of land that could be used. In each study, we noted the terms used to describe land that was designated for biomass production, and land that was excluded from the set of biomass-suitable lands. None of the studies provided a precise or formal definition for the terms chosen. Some used additional descriptors, such as "agriculturally marginal," or "severely degraded," which give insight into how the authors conceptualize the marginal land base they refer to, but do not constitute a workable definition. Others cite the methods used to identify the land being defined, such as the Land Capability Classification system designation. This is a helpful context, but also does not constitute a definition.

We also noted what components of the economic definition of marginal were used by the study to determine which lands were marginal. In general, we were able to group studies as either defining marginal land in strictly physical terms (soil quality), or strictly by land use, or a combination of the two. We considered that categorizing land by current use represents the assumption that a profit maximizing owner has selected the optimal use from the range of opportunities available. Of those that cited land use or a combination of factors, we noted whether or not the authors included change of designation of marginal or change in total area of marginal land available as other changes occur, specifically, demand for land, and prices of land outputs. We also noted which studies attempted to quantify an area of land that could be categorized as marginal. Finally, we noted whether the authors made allowances in their categorization for non-market valuation of land services, or assumed utility maximizing land owners. This last category was split into two parts, recognition of public goods or services provided by the land, and recognition of non-market values that accrue directly to landowners, regardless of social benefits. The studies reviewed, elements assessed and their representation in each study are noted in Table 3.

Many studies referenced important components such as competition for land by different uses in their discussion. However, often the description of marginal land in a study did not incorporate the referenced idea, and so we did not credit the study with using that component in their description. For example, in the Lal study, the author references that "there are competing demands on the land resources for biomass production." However the study recommends that biomass be produced on "surplus cropland, agriculturally marginal lands and degraded or drastically disturbed lands"(Lal 2005). In this case, the definition was not considered to incorporate the possibility of change in the faces of shifting demand.

The argument for producing biomass on marginal lands arises from perceived additional benefits or problems that could be avoided through the use of marginal lands for biomass production. We reviewed the articles to record in a structured, if not fully objective fashion, the types of land identified, and the "extra" results expected. We then assess if a reasonable person could expect the hoped for extras given the land base identified.

Results

Terminology and Method of Identification

The terminology/methodology used to identify marginal lands in the 16 studies reviewed varies from a focus on physical characteristics to a focus purely on current use of the land with most definitions falling somewhere in between. "Marginal" is the most commonly used term, followed by "degraded." Also used are "abandoned," "idle," 'pasture," "surplus agricultural land," "CRP," "barren" and "carbon-poor." The terms are used in different combinations that can have very different implications for the land base being discussed. For example, Fargione et al. suggest "degraded and abandoned" land for biomass production (Fargione et al. 2008), while the Kort study describes the land likely to be chosen for biomass production as "marginal cropland, such as that now used for pasture and hay production, or idled under government programs"(Kort, Collins, and Ditsch 1998). In general, we assume abandoned lands refer to land that has been abandoned by crop producers. Neither of the categories in Kort et al. would necessarily qualify as "abandoned."

The word "marginal" itself can be used to describe both land of lesser physical quality for agriculture, as in Tilman (Tilman, Hill, and Lehman 2006), or land that is economically marginal, such as in the Kort study. Other terms are less ambiguous. "Barren" and "carbon-poor," land is incapable of supporting much vegetation, a physical characteristic. "Abandoned" implies land of poor quality, but explicitly refers to how the land is being used, and is therefore an economic term. Tang et al identify a series of highly specified land categories that other studies ignore, including road side land, land risers/boundaries, streamside land, and house surroundings (Tang, Xie, and Geng 2010), most of which are economic descriptors.

Most of the terms used to describe marginal land in some way describe how the land is being used. "CRP", "pasture" and "idle" are terms that refer to current land use, with a declining degree of specificity. "Abandoned" on the other hand, describes land that was once used for agriculture and currently is not, without addressing what the current use is. "Surplus agricultural land" is more difficult. We assume that authors use this term in a manner similar to abandoned cropland. It is land once used for agriculture that is no longer in demand by the agriculture producers. However, rather than referring to specific parcels that have actually been abandoned, “surplus” land seems to refer to a quantity of land not expected to be needed according to projected demand (Hoogwijk et al. 2003).

According to the model presented in Chapter 2, the relationship between use and quality is not a direct one. Use depends in part on quality, but may also depend on exogenous economic factors, owner preferences or other factors. The authors’ approaches to combining physical and economic components of marginality do not always conform to the theoretical framework we have presented. The studies can be examined in four general groups:

- those that established a category of land for biomass based primarily on physical quality;
- those that used land quality traits and land use characteristics as separate and non-overlapping categories;
- those that established a category of land for biomass based primarily on land use ;
- those that described biomass production on land as dependent on quality and market conditions, and did not attempt to categorize types of land by quality.

The Searchinger et al. study is the only one that uses a purely physical characterization for land to be used for biomass, recommending biomass be produced on carbon-poor lands. The recommendation fits with the article’s objective of pointing out that carbon release from land use change could present a potential negative externality of a biomass industry, unless a solution such as production only on carbon-poor lands is adopted (Searchinger et al. 2008). The study doesn’t classify the land resource by it production ability or an alternative use. Nor do the authors attempt to present an economic solution to the carbon problem they have identified. Thus they do not address most of the factors that affect utility gain from land use.

Two studies, Lal 2005 and Hoogwijk et al. 2003, presented land use terms and land quality terms as descriptors of separate and unrelated types of land. The Lal study presents the idea that surplus cropland, agriculturally marginal lands, and degraded or drastically disturbed lands be “specifically identified” for biomass production, without further discussion of how these lands are defined. The author’s focus in this study was that crop residues should not be viewed a major source of biomass because of the potential impact on soil quality, and so was non-economic in nature (Lal 2005). Thus, the economic consequences of specifically identified lands are not explored in the article. The Lal study diverges from our economic model by limiting the range of options available to land owners, and not considering the profit-making potential of biomass on the land considered.

Lal also creates confusion by not distinguishing between the quality of land implied by terms such as surplus agricultural land and degraded land, as he is using them. Lal cites yields from Hoogwijk et al. for what Hoogwijk et al refers to as “high-quality surplus land” (M. Hoogwijk et al. 2003), which implies land of better quality for agriculture than that implied by “degraded”. Lal continues by citing the Kort study that references 60 million hectares of agriculturally marginal land available in the US for conversion (Lal 2005) . Kort, however, was in turn citing a study by Robertson and Shapouri (1993) that estimated that 60 million hectares of land currently engaged in other uses could be converted to biomass production. This land is defined as of low quality for agriculture, and currently in use (therefore not "surplus"). Lal has therefore misrepresented the potential of agriculturally marginal lands to grow biomass.

The concept of surplus land is generally difficult to defend, from an economic standpoint. Hoogwijk et al. refer to surplus agricultural land as high-quality cropland remaining after food and materials production needs are met with no consideration of the role of supply and prices on demand. This land is then presented as a distinct set of lands from "deforested or otherwise degraded" land. In the model used by the study, surplus lands are allocated to perennial grasses and deforested land that is suitable for reforestation is allocated to short-rotation woody crops for biomass. Implicit in this differentiation is the idea that not all cropland will be wanted for future food and materials production, that biomass will be the least intensive cropping option, and that no deforested land is suitable for crops or would be used for crops or perennial grass biomass (M. Hoogwijk et al. 2003). These assumptions allow the study to accomplish its goal of providing an estimate of total potential supply, but limit the economic viability of its conclusions.

The Hoogwijk et al study uses "surplus" and "degraded" lands as separate and non-overlapping categories of land available for biomass. Their assumptions deviate from the economic theory presented in chapter 2 in basic ways that could have significant impacts on their results. Assuming high quality land would remain idle, high-quality land as surplus land does not fit the economic model presented in this paper. High-quality land will be the first land used, for the most intensive and valuable crops. Where land used for biomass would fall on this spectrum of quality depends on how profitable it is relative to other crops. In addition, the authors have neglected to allow for competition between biomass and other types of products. This creates a false sense of the cap on biomass supply. Supply could in fact be much greater if there is sufficient demand for biomass, and the current policy infrastructure has not been modified to prevent competition between food and fuel crops. As in the Lal study, the quantity, current use, and ownership of the lands identified are not addressed.

The majority of studies we reviewed first identify land as marginal relative to a select land use, and then may or may not refine that target set of lands with soil quality. Some studies do so in a conceptual manner, and others take additional steps to actually quantify the lands they are describing. Fargione et al, for example, presents two kinds of low-quality lands: land still in production that is of low value and land enrolled in the CRP program. Low value land in production is further qualified as degraded, distinguishing it from low value land in production that is not degraded. Land in the CRP program is labeled as "abandoned." The article does not attempt to quantify the land base described (Fargione et al. 2008).

Niu and Duiker (2006) takes a more quantitative approach. The objective of the study is to determine how much land is available for afforestation for carbon sequestration. In this study, the authors first identify what land is in agricultural production using the National Land Cover Database categories of pastureland and cropland. The article then uses the designation of prime versus marginal in the STATSGO database to identify marginal land (Niu and Duiker 2006).

The approach used by Fargione et al. and by Niu and Duiker allows the researchers to be more specific about the set of lands under consideration, but risks misidentifying the set of options open to those lands. In the Fargione article, the objective of identifying abandoned and degraded lands is to find land that is not being intensively used for another purpose. Some land not being used is neither currently cropped nor enrolled in the CRP program, but does not get included in the available land category as described by Fargione. The Niu article faces a similar problem. Land not actively being cropped might be suitable for afforestation. Eliminating land outside agricultural production could potentially eliminate a major source of land available for afforestation. In addition, the study does not explain the method used by the STATSGO database to determine prime versus marginal land. Given that the results allow for lands to be designated in seemingly contradictory categories such as “severely eroded prime agricultural land,” further explanation is warranted.

The Rajagopal study is an example of a study that declined to draw a conclusion about ideal land type based on ideas about land use (Rajagopal et al., 2007). The authors discuss land use as determined by physical characteristics and price, and do not define categories such as marginal or prime. They note that biomass will cause an increase in demand for land, but do not specify what the likely result will be in terms of land use on specific land quality. They mention that in the case of “marginal lands” that are being used by the landless poor for subsistence activities that are not agricultural, biomass production on those lands would have a negative effect, but do not state that they expect biomass to be planted there. The authors declined to specify any type of land most likely or most recommended for biomass production (Rajagopal et al. 2007).

Perlack et al. 2005 uses primarily land use categories from the US Census of Agriculture to describe the types of land addressed in the study. Similar to the Rajagopol et al. study, this study notes that land for biomass plantations can come from a wide range of current uses, including current cropland. However the study takes all estimated food and materials production needs of a future population into account before calculating amount of land available for biomass (Perlack et al. 2005), thereby conceptually eliminating competition among uses. Although the study is not trying to model how land use would change under an active biomass crop, it does implicitly assume that biomass would not be competitive with traditional food and materials crops, similar to the approach taken by Hoogwijk et al.

Dynamic character of extensive margin

Marginal is a description that cannot be permanently ascribed to any particular unit of land. If identifying a marginal set of lands available for biomass is the goal, it must be done in a way that is relatively flexible, to account for changing land use, and shifting utility from different uses. Even though land use shifts can be small in terms of overall land availability, on a regional scale, they have great significance. A small shift can also be significant if it is out of or into a single particular crop. For example, researchers and land managers pay a great deal of attention to the amount of land shifting from farm to development use, even though development accounts for just 2.6% of total land use in the United States (Lubowski et al. 2006).

The majority of the studies reviewed here did not explicitly acknowledge that marginal is a non-permanent characterization of a parcel of land. If a study is presenting only a conceptual idea of a type of land, how the study identifies a specific parcel that matches that type is not important. However, studies that quantify the amount of marginal land should acknowledge the dynamic nature of land use. And yet, in many studies reviewed here, this was not the case. Only 5 out of 16 studies made explicit reference to the dynamic nature of the marginal land base, primarily by mention of competition for land. Of the eight studies that quantified land use, only three made reference to or allowance for a changing quantity of marginal land. Several studies noted that biomass could cause indirect land use change by utilizing land needed for other purposes, but attributed that effect only to planting biomass on traditional cropland (presented as a distinct set of lands from marginal cropland). In general, most studies presented marginal lands as a permanent stratification between undisturbed or restored native cover and active cropland.

Other exogenous determinants of extensive margin

We also assessed whether studies noted the impact of technological change, manager characteristics, policy or amenity benefits on farmer land use choice or the specification of the marginal land base.

Technology. Technology is a critical input in most land-based production scenarios, particularly in agriculture. In many models of land use choice that cover large areas, variables that represent differences in available technology are included to distinguish between regions where common machinery, production techniques, and other technological factors may vary (Palmquist, 1989). Technology can also be a dynamic variable over time, as innovations make production processes more efficient, or open new production opportunities to the landowner (Lichtenberg, 1989).

Several studies we reviewed relied heavily on the concept of technological innovation. The Hoogwijk et al., 2003 study assumed technology would have an impact on how much land was demanded by agriculture, and how productive different biomass crops might be through the year 2050. No studies reviewed noted that what level of land quality could be used for biomass would also be impacted by technology.

Manager characteristics. As noted in chapter two, managerial traits can have an impact on what land use options owners are willing to consider, and how well they will be able to optimize those options. Thus, how land owners currently use their land, the degree to which they gain monetary versus amenity benefits from the land and its current use, and general characteristics such as age, education, experience, etc., can all affect land use choice. This is especially relevant when discussing a new option being presented to owners, such as biomass production. Risk averse land owners will lag switching to biomass even if it is the most profitable option, even if the land is less productive (the opportunity cost is lower).

Among the studies we reviewed, Rajagopal discussed the difficulty of getting farmers to adopt biomass production (Rajagopal et al., 2007). Otherwise, manager characteristics were not mentioned. Given the noted behavioral component to technology transfer, it is striking that even conceptual studies made no reference to this issue.

Policy. It is likely that certain land uses, such as native cover or idle lands, or land in biomass production, provide environmental, economic, and social services that benefit the general public. However if such benefits to do not accrue to the landowner in a significant way, they would not likely affect the individual land owner's decision process Policies can be enacted that may either entice through subsidies or taxes on alternate uses, or force the landowner to choose a more socially beneficial land use. In addition, policies ranging from federal subsidies to local zoning laws, can affect the relative profitability and set of options available to landowners, which certainly would impact their decision process. It is therefore important to incorporate policy considerations into an analysis of optimal land use. Subsidies, taxes and fines should be included as variables in a land use model, zoning laws should be considered to select the range of alternate uses, and other policies that affect land use should be modeled where possible.

Most of the 16 studies discussed the potential public goods and costs that could arise from biomass production on marginal lands. However, only two studies discussed the potential outcomes of free competition between traditional land uses and biomass production. An additional two studies explicitly stated that policy intervention would be required to limit biomass to certain types of land (because if landowners were allowed to choose, a socially non-optimal outcome might result). In other studies, the role of policy was not addressed.

<u>Amenity benefits.</u> Several of the studies reviewed echoed the Hall et al. idea that biomass from certain types of land could provide "additional" benefits or mitigate negative externalities. Hall et al noted benefits in relation to offsetting use of fossil energy. The articles reviewed here cite costs and benefits of biomass on marginal land in relation to production of oil-based fuels, to biomass grown on prime cropland or to biomass grown on land previously under native cover. The benefits or costs that would accrue from biomass production on a given parcel of land depend on the list of factors we reference in this paper.

Most of the studies reviewed discussed at some level potential costs and benefits that could arise from biomass production on marginal lands. Many studies noted that using biomass for energy rather than oil would provide the benefits of reducing carbon emissions and providing a domestic source of energy. Additional benefits noted, provided by biomass grown on non-agricultural land relative to biomass on traditional cropland, include avoiding increased food prices, avoiding indirect land use change, sequestering carbon, improving soil quality, improved habitat, improved water quality, and economic rural development. Benefits from biomass on produced on so-called marginal lands instead of land that is forested or covered in grassland include avoiding destruction of habitat and avoiding release of carbon into the atmosphere. Potential costs of biomass on marginal land include increased erosion or soil compaction and hardship for landless poor currently using those lands. Table 4 presents the studies, the land type identified, and the expected externality, both positive and negative.

Surprisingly, however, none of the studies mentioned a private benefit that may be accruing to the owners of marginal lands. Part of the reason may be that the studies were often discussing the land base at a very aggregated level (such as nation-wide, or even globally). Owner idiosyncrasies would not have an impact at that level. However, such benefits, where they occur in patterns, could affect the overall availability of land to produce biomass at the county or state level, where policies and management decision are often made. If a landowner enjoys a direct benefit from a parcel of land, that owner will be reluctant to change uses even when a more profitable option becomes available. How lands that could be categorized as marginal are currently being used is not well understood, but it is likely that owners of these lands are deriving some benefits from them that are not captured in a profit function. Owner utility could have some impact on how willing a landowner may be to invest in biomass.

The basis of the idea of using marginal land for biomass is that marginal land would allow biomass to be introduced with minimal external impact on other systems, such as food production or environmental services. The implied stratification of the land base into cropland, marginal land, and undisturbed land fits well with biophysical assessments of land capabilities, but often does not correspond to the economic model of competition for land use. While there generally exists a portion of the land base that could be described as abandoned or idle from an agricultural standpoint, that land could provide other, non-agricultural services, and provides an option value for farmers. Without complicated government regulation, it will be very difficult to direct or entice biomass producers to use only certain land parcels for production. It is not clear if such policies should be put in place. How much land exists in this category, how volatile that amount is (how sensitive it is to crop demand shifts), and what other services it actually provides needs to be better understood.

Table 3. Studies reviewed and results of meta-analysis

	Author	**Title**	**Date**	**Reference to Physically marginal land**	**Reference to Economically marginal land**	**Benefits/ Positive Outcomes**	**Negative Outcomes**	**Terms included as marginal land base**	**Terms excluded from marginal land base**	**Impact of manager traits, technology, or policy**
1	Fargione, Joseph, Jason Hill, David Tilman, Stephen Polasky, Peter Hawthorne	Land Clearing and the Biofuel Carbon Debt	2008	degraded lands, marginal croplands (yields on marginal cropland better than yields on abandoned cropland)	degraded and abandoned agricultural land (abandoned lands represented by CRP)	Little or no carbon debt		"degraded and abandoned agricultural lands", "marginal cropland": CRP land represents abandoned cropland. Marginal cropland refers to degraded land still in production.	Cropland, Native habitats: rainforests, peatlands, savannas, or grasslands	None
2	Rajagopal, D, S E Sexton, D Roland-Holst and D Zilberman	Challenge of biofuel: filling the tank without emptying the stomach?	2007	marginal/ low quality lands	none		usurps lands used by impoverished people	marginal lands: lands that supply food and fodder to landless poor	none	Technology, Adoption decision (standard rational profit maximizer), policy
3	Lal, R	World crop residues production and implications of its use as a biofuel	2005	specially identified lands: degraded lands	specially identified lands: dedicated bioenergy crops can be grown on surplus cropland, agriculturally marginal lands and degraded or drastically disturbed lands	Produce high biomass; Minimal risk of degradation, enhance soil quality, sequester carbon, improved water quality		"specifically identified lands": surplus cropland, agriculturally marginal lands and degraded or drastically disturbed lands	current croplands (crop residues for biomass)	None

4	Kort, John, Michael Collins, David Ditsch	A review of soil erosion potential associated with biomass crops	1998	Discussion is of physically marginal lands currently uses as cropland, pasture or CRP. Uses LCC classes to distinguish land types. Discusses economic activity suitable for each class based on soil properties.				marginal cropland, such as that now used for pasture and hay production, or idled under government programs	None	None
5	Hoogwijk, Monique, Andre Faaij, Richard van den Broek, Goran Berndes, Dolf Gielen, Wim Turkenburg		2003	degraded land: marginal land suitable for reforestation	surplus agricultural land: land not used for other purposes (doesn't allow competition)	No competition with food materials production		high quality surplus agricultural land remaining after food and feed produced, deforested/ degraded or marginal land suitable for reforestation	Land for food, feed, materials according to future population demand scenarios, forest land,	Technology will increase food production intensity, making land available for biomass production.
6	Froese, Robert E., David R. Shonnard, Chris A. Miller, Ken P. Koers, Dana M. Johnson	An evaluation of greenhouse gas mitigation options for coal-fired power plants in the US Great Lakes States	2009		defined as economically marginal land, identified by land cover	carbon sequestration		Author uses "idle or abandoned agriculture land," identified as herbaceous open land and upland shrub	crop and forage land	None
7	Field, Christopher, J. Elliott Campbell1 and David B. Lobell	Biomass energy: the scale of the potential resource	2007		Land that was previously used for agriculture or pasture but that has been abandoned and not converted to forest or urban areas	Reduce net warming, avoid competition with other materials production, avoid habitat destruction		Land that was previously used for agriculture or pasture but that has been abandoned and not converted to forest or urban areas	cropland, urban lands	Technology can affect demand for land from agriculture, impacting land dedicated to biomass. Policy can restrict biomass plantations.

8	Perlack, Robert D. Lynn L. Wright, Anthony F. Turhollow, Robin L. Graham, Bryce J. Stokes, Donald C. Erbach	Biomass as a feedstock for a bioenergy and bioproducts industry: the technical feasibility of a billion-ton annual supply	2005		cropland, idle cropland, and cropland pasture are land base for biomass. no stratification into marginal/non-marginal	Reduce dependence on foreign oil, support agriculture and forest industries and rural economies	erosion on some soils,	cropland, idle cropland, and cropland pasture are land base for biomass. no stratification into marginal/non-marginal		Technology.
9	Tilman, David, Jason Hill, Clarence Lehman	Carbon-Negative Biofuels from Low-Input High-Diversity Grassland Biomass	2006	agriculturally degraded and abandoned nitrogen-poor sandy soil		Carbon sequestration, net energy positive, avoid habitat destruction, avoid competition with food		agriculturally degraded and abandoned nitrogen-poor sandy soil	fertile land, natural land	None
10	Ya Tang, Jia-Sui Xie, and Shu Geng	Marginal Land-based Biomass Energy Production in China	2010	Categories identified as marginal include physical and economic criteria		Large quantity of mulberry able to be grown. Additional uses for already existing tree crops on marginal lands. Additional income for farmers.		Marginal land will, therefore, include wasteland, land riser/boundary, road side land, stream side land, house surroundings, land along highways/roads, etc.	Sparse forestland, scrubland, and winter-fallowed paddy (not economically marginal)	None
11	Niu, Xianzeng, Sjoerd W. Duiker	Carbon sequestration potential by afforestation of marginal agricultural land in the Midwestern U.S.	2005	physically poor land being actively cropped		Reduces ag-related pollutants, soil erosion, improved water and air quality		marginal land is High LCC number being actively cropped	Low LCC number being actively cropped	None

12	Searchinger, Timothy, Ralph Heimlich, R. A. Houghton, Fengxia Dong, Amani Elobeid, Jacinto Fabiosa, Simla Tokgoz, Dermot Hayes, Tun-Hsiang Yu	Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change	2008	carbon-poor		Avoids indirect GHG emissions from LUC (plowing up native cover to grow crops)		carbon-poor	Land in agriculture, grassland and forests. (Including once cropped land that has reverted to grassland or forest).	Technology will impact how much land is available for biomass (demand from agriculture). Policy is a possible tool, but difficult to use effectively.
13	Hill, Jason, Erik Nelson, David Tilman, Stephen Polasky, and Douglas Tiffany	Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels	2006	agriculturally marginal lands	land of low agricultural valued	net energy benefit		land of low agricultural value, agriculturally marginal lands	fertile land	Technology.
14	Yang, Hong, Yuan Zhou, Junguo Liu	Land and water requirements of biofuel and implications for food supply and the environment in China	2009	marginal land and "barren mountain"			costs of loss of biodiversity, hydrological functioning, water quality and quantity and soil	marginal land and "barren mountain"		
15	Johansson, D.J.A. and Azar, C.	A scenario based analysis of land competition between food and bioenergy production in the US	2007	high-yield grazing land, low-yield grazing land (reference to degraded land)			[does not note outcomes	high-yield grazing land, low-yield grazing land (reference to degraded land)	crop land	technology (yields), manager characteristics, policy changes
16	De la Torre Ugarte, Daniel, Marie E. Walsh, Steven P. Slinsky, Hosein Shapouri	The Economic Impacts of Bioenergy Crop Production on U.S. Agriculture	2003		cropped, idle, and pasture acres, as well as some less sensitive Conservation Reserve Program acres		[does not note outcomes	cropped, idle, and pasture acres, as well as some less sensitive Conservation Reserve Program acres	Other categories (Census of Ag categories)	Policy

Table 4 describes the range of expectations of impact from use of marginal land to produce biomass on different characterizations of low-quality land. The rows in this table represent terms for land types commonly used in the studies reviewed. The columns represent categories of externalities generally expected. In each cell, we have noted the author, and whether the author expected the impact of biomass to have a positive or negative effect in relation to that externality.

Table 4. Impact of land converting from one use to biomass production

	Carbon sequestration	**GHG emissions**	**Habitat/ Deforestation**	**Air/water quality**	**Erosion**	**Soil quality**	**Resource for landless people**	**Food price**	**Recreation**
Marginal land	Niu +	Hill +	Hill + Yang -	Hill + Yang -	Tang + Hill + Yang -	Hill + Yang -	Raj -		
Marginal cropland		Fargione +	Fargione +		Kort + (perennial) Kort - (woody crops)		Hoogwijk +	Hoogwijk +	
Pasture		Johansson +	Perlack +					Johansson + Perlack +	
Degraded land	Lal + Field +	Johansson + Tilman +	Lal +	Tilman + Lal +		Tilman + Lal +	Hoogwijk + (reforested)	Johansson + Tilman +	Tilman +
Abandoned		Field +	Froese + Tilman +	Tilman +		Tilman +		Tilman +	Tilman +
Idle/Surplus/CRP			Froese +		Kort + (perennial) Kort - (woody crops)			Froese +	
Barren			Yang -	Yang -	Yang -	Yang -			
Carbon-poor	Searchinger +		Searchinger +					Searchinger +	

Chapter 4: Empirical analysis of factors determining land use choice and land use change

The theory presented in Chapter Two states that the extensive margin is defined relative to a given land use, rather than a particular unit of land. In order to determine what quality of land marks the extensive margin for a certain production system, all production possibilities must be optimized and compared, as shown in equations 3 and 4. This study of agricultural land use determinants applies the conceptual model of land use to detailed GIS data from southern Michigan. The study tests the relative impact of output price, land quality and location on land use choice and change in land use choice. In this case, the data available included GIS land use analysis at two time periods (2001 and 2006), land quality data and county-level price data. We are able to compare the relative impact on land use choice of price, land quality and location, and to determine what portion of land use choice and land use change into or out of cropland is explained by each of these variables.

Model

Marginal land is land that is on the cusp of transition from one use to another. This transition occurs when the owner feels there is greater utility to be gained from engaging the land in a different use. The first step to determining which land is marginal, then, is to determine what factors are considered in making a land use choice. The second step is to determine which of those factors could change, and to what degree the change impacts land use choice.

As discussed in Chapter 2, the representative land owner will optimize utility by balancing marketed and amenity benefits earned off the land. Because different land uses can impact amenity benefits in different ways, both positive and negative, the land use choice that optimizes utility may not be the same as the land use choice that maximizes profit, depending on the available amenity benefits.

$$\text{Equation 5:} \quad U^*_i = \max\left(C(\pi_{ijr}), \alpha_{ijr}\right), \qquad \text{s.t. } C \leq \pi^*$$

This study will focus on profit as the measureable component of utility. Many variables contribute to the profitability of a production system, some of which are inherent to the unit of land *i*, some of which are characteristics of the production system *j*, and some of which are dependent on the time period *t*. As was discussed in Chapter 2, profit is a function of land quality, manager traits, and technology available, prices for inputs and outputs, and finally, the policy framework in which the land owner is operating.

$$\text{Equation 3:} \quad \pi^*_{ijt} = g(q_i, l_{it}, m_{ij}, \tau_j, p_{yt}, p_{xijt}, \lambda_t)$$

The conceptual model illustrates that land use choice among profit-maximizers is determined by the use that, optimally managed, produces the greatest profit, as demonstrated in Equation 4. Due to external factors, optimal production can vary across both time and space.

$$\text{Equation 4:} \quad \pi^{*j} = \max\left(\pi^{*1}, \pi^{*2} \ldots \pi^{*n} \mid q_i, l_{it}, m_{ij}, \tau_j, p_{yt}, p_{xijt}, \lambda_t\right)$$

Assuming factors that determine profit remain unchanged, land use choice should also remain unchanged. However, shifts in dynamic factors of profitability can result in shifts in land use. The probability of land use change, therefore, is dependent on the probability of change in the dynamic exogenous variables, which include price and policy variables.

Several of the determinants of land use choice are static over the short term. Land quality, manager characteristics and technology all hold fairly steady over a five year period. For agricultural uses, seed, chemicals and other inputs in addition to land are under the control of the manager, and can be adjusted to fit a nearly infinite number of ratios, some more profitable than others. However, to analyze a single land use, these endogenous variable must remain constant. A shift in one such variable could potentially disguise the effect of the shift in land quality. Therefore, in order to examine the relative profitability of a single land use over a range of land quality, all endogenous inputs (those within the control of the land manager) must remain constant. Because they are static or held constant these variables can cause a shift in the landowner's perception of the value of the land use.

Prices and policies, on the other hand, are both dynamic variables which, all else equal, can cause land use to shift at the extensive margin. To determine the impact of the dynamic factors on land use and land use change, we create a model that relates the probability of land use changing from one use into another use, such as cropland, to the change in prices or policy, while controlling for differences in other factors of production. Equation 6 demonstrates this relationship.

$$\text{Equation 6:} \quad \Pr(\Delta j = 1) = h[q_i, m_{ij}, \tau_j, (p_{yt}\text{-}p_{y(t-1)}), (\lambda_t - \lambda_{(t-1)})]$$

The exogenous variables present in equation 6 that define the extensive margin, and are responsible for shifts in land use, are presented in Table 5.

Table 5. Variables included in the model for profitability of land use choice j, with their empirical measure

Symbol	Variable	Description	Empirical Measure
Pr (Δj = 1)	Probability of land use change	Change (Δj = 1) occurs if land use j shifts use from 2001 to 2006. In this study we review the specific examples of change into cropland and change out of cropland.	Land use 2001 and land use 2006, CCAP
π	Profit	The net gain from production of product j, used here as a proxy for utility	n/a
q	Land quality	A cardinal index of land quality values	Land Capability Classification (SSURGO, 2010)
l	Location	The relative location of markets	County
m	Manager traits	Characteristics of the land manager such as education, experience, family size, other income, etc., that impact his ability to adopt land use options.	n/a
τ	Available technology	Technology available in the area (for use when comparing across regions)	n/a
p	Price	Price includes separate prices for inputs (p_x) including land price, and output (p_y).	P_y= Annual corn price, county level (Cash Grain Bids, 1998-2008)
λ	policy	Policies at a national, state or local level that impact the land use choice. Policies can be in the form of taxes, subsidies, prohibitions, etc.	n/a
α	Amenity values	Any benefit that is generated by the land, and enjoyed by the owners, but not able to be directly converted to a financial value (may be incorporated into land value as an amenity)	n/a
i	Land unit	In this study, land unit is a 30m pixel (.25 acre)	30m pixel (SSURGO, 2010 and CCAP, 1996-2006)
j	Land use	The full set of land use options open to the land owner	30m pixel (CCAP, 1996-2006)
t	Time period	Period in which observations are taken	5-year timesteps (2001 and 2006 observations.)

By modifying the above equations, we can test some of the relationships in the theoretical model using available data. We use a probability statement to test whether j^* = cropland. Using average corn prices over previous three years (*PRAVG*), year of observation (YR), county (*COU*), and land quality (land capability class = *LCC*) as explanatory variables, we are able to test to what degree each variable affects the probability that a parcel will be used as cropland.

$$\text{Equation 7:} \quad P\,(LU_i = 1) = f(PRAVG, YR, COU, LCC)$$

No data is available to represent major policy changes across time or differences over space in this study, and so no policy variables are included in the empirical model. However, most policies that affect individual land use choice do so by affecting the profitability of a given crop, which in turn is passed on to the buyer of that crop through the output price. Some taxes and subsidies may affect the output price directly, other affect input prices but are passed onto the buyer through the output price. Therefore, most of the dynamic considerations for land use choice – and thus the determinants of land use change – are captured in a price variable. The output price variable, PRAVG, should then contain some information about how price subsidies or taxes are affecting the dependent variable, the probability of a unit of land being used as cropland.

The COU variable controls for the effect of different county attributes, including proximity to markets, local ordinances, road quality and other factors on the local corn price. Because we are concerned primarily with agricultural land use, and at a relatively high level, we assume that average corn price over three years is a reasonable proxy for the drift of other agricultural prices in the area over the period in question. We use the lagged average to give a better representation of the landowner's perception of earning potential. The year in which the land use was observed serves as the time period. The land capability class designation is the measure of land quality. We create a binary variable, LU_i to indicate whether or not the pixel is used as cropland. We assume that although cropland is actually a category of land use, rather than a single land use, the analysis can identify trends that are relevant across agricultural uses. We use a probit model to estimate the coefficients for each of the explanatory variables.

All variables with the exception of price are binary. There are 18 county binary variables, 7 LCC binary variables, and binary variable representing the year the land use was recorded. The binary variables representing Allegan County, LCC 4, and 2001 are not explicitly included in the regression, and serve as the baseline against which the coefficients can be compared. Given that the number of observations is in the millions, degrees of freedom are not limited.

Price fluctuations from year to year are a common occurrence for agricultural products. The price in any given year is not understood by landowners to be the price they will receive in the coming year. Landowners base their expectations on a more complicated set of information, including price trends over time. Therefore, to better represent landowner expectations for output prices, the price variable in this model is represented by a lagged average county price, using the annual county prices of the three previous years. This average price was calculated to correspond to both timesteps included in this study, 2001 land use observations and 2006 land use observations. For example, the three-year average lagged county price for county *i* in 2001 is

$$\text{Equation 8: } PRAVG_{it} = (price_{i1998} + price_{i\,1999} + price_{i\,2000})/3)$$

For 2006, the price variable is the average of 2003-2005. The lag allows for farmers to respond to trends in price levels between 2001 and 2006, rather than expecting them to react to a single year. As with the COU variable, the main focus here is the spatial difference in price change over the single time change.

Equations 3 and 5 estimate the effect of each of the variables on land use change. In equation 7, we model the probability that a unit of land is being used in a particular use. To create an empirical model of equation 6, the probability that land use changes from one use to another (crosses and extensive margin), we create a new regressand. $LUC_i = 1$ if the pixel has transitioned into cropland, and 0 if not.

$$\text{Equation 9:} \quad P(LUC_i = 1) = g(COU, LCC, \Delta PR)$$

We also model the opposite effect, to test if change in price would also be responsible for land moving out of cropland ($\Delta\Omega i = 1$). Because the price rose over the time period we analyze, the price change variable should have a negative coefficient in this regression. Equation 8 represents land moving out of cropland.

$$\text{Equation 10:} \quad P(\Delta\Omega_i = 1) = h(COU, LCC, \Delta PR)$$

Change in price, ΔPR, is calculated as the lagged average price for 2006 (average of prices from 2003 to 2005) minus the lagged average price for 2001 (average of prices from 1998 to 2000).

$$\text{Equation 11:} \quad PriceDelta = (price2003_i + price2004_i + price2005_i)/3) - (price1998_i + price1999_i + price2000_i)/3)$$

The sign of this figure signifies whether the lagged average price had been higher or lower in 2006 than in 2001, indicating the sign of the price signal to the farmers. A positive value is expected to correlate to land coming into cropland from all land class levels, and a negative sign is expected to result in land transitioning out.

Statistical analysis challenges for this model

The primary challenge for this analysis is that the data reveal only spatial variation, rather than temporal variation. Because the data set includes only two timesteps (2001 and 2006), and so only the single measure of change that occurs between those two timesteps, there can be no comparison over multiple changes over time. Land use change over time is of primary importance to land managers, and is likely much greater than land use change over space, due to differences in relative costs due to location price variation. Exceptions would be major centers of supply or demand that caused a more significant effect in surrounding land use. No such variation is known to exist inside the sample area.

Omitted variable bias is a concern with land use data. In this study, several of the variables included in the conceptual model are absent from the empirical model. These include variables to represent technology available, other inputs used, yields, and amenity values. Some of these may be partially captured by the variables that are included. For example, local ordinances or taxes that vary from county to county may be captured in the binary county variable, COU. Any cultural differences that affect and owner behavior, perhaps between rural and more urban counties, could also be captured to an extent in the county variable. Others likely have only small impact on agricultural land use in Michigan, such as technology available. Technology available to different landowners may depend on their contacts, on the size of the farm or on other factors, but similar technologies are generally broadly available to landowners who expend the time to seek them out. Thus, technology available may have only slight impact on the land use choice in this region.

However, policy variables, a more representative output price (such as an index of agricultural prices) and variables that may indicate land owner traits (such as land ownership boundaries) are potentially significant omissions. Omitted variables can cause bias in the coefficients, if they are correlated with the error term or with variables that have been included. There were no major policy shifts between 2001 and 2006 that would have restricted a landowner's use options, with regard to farming, and some local policy factors may be captured by county boundaries. Nevertheless, the significant omissions mentioned may cause some bias in the resulting coefficients.

The empirical model does not include variables to explicitly represent technology available, managerial characteristics, or precise location. That data is unavailable, and so was necessarily omitted. If this variable is highly correlated with the use-change variable, into cropland or out of cropland, the coefficients may be biased. The bias would show that other factors have a greater positive effect on change into cropland, or lesser positive effect on change out of crop land, since owner experience is not controlled.

Land ownership boundaries, which will impact profitability (economies of scale from management, machinery), information on land manager characteristics, and a range of prices for possible crops are potentially significant omitted variables. Land price can also be an indication of the potential value from the optimal use of the land, in a well-functioning land market, though speculation and option value can distort the price from a simple calculation of rent from the land quality.

Endogeneity can be a problem for land use data, particularly for policy variables. Policies can have a significant impact on land use, but are often set – especially at the local level – in response to land use, and so can cause endogeneity if not explicitly addressed in the econometric model (Irwin 2001). As we did not have policy data available to include in this study, this particular problem does not need to be addressed here.

Data

The base dataset was generated by a geographic information system (GIS) incorporating the Coastal Change Analysis Program (CCAP) land use maps for 2001 and 2006, land classification data from national Soil Survey Geographic Database (SSURGO), and county. Price data was supplied by the private firm Cash Grain Bids for 19 counties from 1998 through 2006. The daily price data collected at dozens of locations was aggregated up to a county-annual level. CCAP and SSURGO are both constructed at a 30m resolution, and so the 30m pixel was used as the unit of observation.

The 30m pixel, defined consistently for each period of observations, does provide for an incredibly rich dataset at a very detailed level. The GIS provides data for all 30m pixels in the 19-county area evaluated in this study. Thus, the data actually represents the full population of observations. We drew a 5% sample from the available data in order to be better able to manipulate the data in the statistical software package. 5% of observations still number in the millions, so degrees of freedom was not an issue, and p-values were either decisively low or high in general. The data set consists of observations for 2001 and 2006 pooled, and totals 3,712,112 pixels. When observations for 2001 are dropped, the dataset falls by half. The sample was stratified by county, so proportionally more observations are included for larger counties. The sample was drawn by isolating the data for each county and using the sample function in STATA 10 2010.

CCAP

The NOAA Coastal Services Center uses Landsat remote sensing data to conduct land cover analysis, producing the CCAP land cover database. The land area is reevaluated and the database extended every five years. Landsat images provide a 30m resolution, which is used as the minimum mapping unit in the land cover analysis. Spectral reflectance for IR, UV and visible light off each 30m pixel is analyzed to determine probable land cover, and the dominant land cover within the pixel is assigned to the entire pixel in the mapping data. Each 30m pixel is analyzed, though in some cases, where determination of land cover is difficult, analysis may occur at a 60m resolution level (in which case, each pixel in the four-pixel blocks are all assigned whatever land cover is determined to be dominant in that area). The analysis assigns one of 22 land cover classes (depending on year) ranging from high-density urban to bare land. The land classes were designed to both represent key indicators of ecosystem functionality and be features that can be consistently identified through remote sensing across observation periods. CCAP analysis includes field verification of land cover selection, and meets an 85% accuracy specification overall, though some areas are more accurate than others. The primary purpose of CCAP is to identify where land use change may be posing long-term impacts on coastal habitats, but the data can also be used to identify land use change more generally.

The CCAP periods of observation are 1992 (not for all locations), 1996, 2001, and 2006, with 2011 in production. Only observations from 2001 and 2006 were used for this analysis. CCAP is used to populate coastal areas of the National Land Cover Database, which includes land cover data for the 48 conterminous states. Because Michigan has so much coastline, the CCAP analysis covers the whole state.

Many studies that recommend using marginal land for biomass broadly describe marginal land as not currently used for development or agriculture, and often as land that is distinct from native grassland or forested land. Therefore, the goal of this study is to determine what factors influence the extensive margin of agriculture writ large, rather than any particular crop within the agriculture sector. Other categories were similarly collapsed to facilitate the interpretation of results. We do not consider that any critical information was lost through this aggregation of data. The 22 categories were aggregated into 5 that reflect general categories of land use. Aggregation is reflected in Table 6. (See Appendix 6 for map of CCAP data for 2006.)

Table 6. Aggregation of CCAP land cover categories with 2001-2006 pooled land area by aggregate class in 19 counties

CCAP Original Category	Aggregate Category	km2 (Pooled)
2 to 5, Developed	Developed	337
6, Cultivated crops	Cropland	1433
7, Pasture/hay	Pasture/hay	436
8, Grassland/ herbaceous, 12, Scrub/shrub	Grassland/scrub	310
9 to 11, Forest	Forest	618
13 to 19, Wetland and shore 21 to 23, Water, estuary 20, Barren	Other	207

Land Capability Class

The Land Capability Class (LCC) is an index developed in the early part of the 20th century by the US Department of Agriculture to categorize farmlands in the United States (Agriculture Handbook No. 210, USDA, 1961). The index groups soil by its limitations for production of common crops without danger of deterioration of the soil for agricultural use, rather than its productivity per se. Classes 1 through 4 are considered suitable for production, with Class 1 being soil with no limitations and Class 4 having significant limitations. Classes 5 through 7 are considered generally not optimal for agriculture but capable of supporting vegetation, with class 5 being less limited than class 7. Class 8 is generally barren or covered in water (i.e., sand, swamp).

LCC classification is assigned by local soil scientists according to nationally established criteria. Yield levels are not included as a criterion at the classification level, nor are other economic factors such as distance to markets. (Agriculture Handbook No. 210). Although the LCC is intended to represent suitability for agriculture, the actual on-going use of the land does not affect the determination of class. Thus, it is common to find land of classes 5-8 that are engaged in agricultural production. See Appendix 4 for map of LCC data for study area.

LCC is one of several interpretive groups included in Soil Survey Geographic Database (SSURGO). SSURGO is the publicly accessible archive of data collected as part of the National Cooperative Soil Survey, and maintained by the US Geological Survey.

Metadata for SSURGO data, available at www.data.gov, notes that SSURGO was published in 1976 and released in 1997, though in fact soil surveys are constantly ongoing. Soil data is generally static, and does not need to be updated on a regular basis. Soil survey schedules therefore are structured to avoid repeat surveys, rather than monitor a pre-established set of points. Updates are made by state and local soil survey agencies on varying schedules. The information was collected from secondary sources, including digitizing existing maps and updating already digitized maps using remote sensing data, and then field verified. The data is collected by map unit, which is the smallest repeatable soil pattern on the landscape. SSURGO records only features on or near the surface.

Price

This study incorporates the average annual elevator price for corn, which is the major crop in the 19-county area. Other price data was not available. Price data, collected at dozens of grain elevators across the sample area several times throughout the year, are rolled up into an annual county level variable. All prices were converted to real 2004 dollars. Prices by county by year are included in Appendix X.

County

The GIS identified each pixel by the county in which it is located. Counties contain more information than simply relative location. They also contain information on any spatial variation there may be across this dataset other than price, which is controlled. Though it is not possible to tell from the dataset where in the county the pixel is located. The 19 counties included in the analysis are listed in Table 7.

Table 7. Counties included in the empirical analysis

Code	**County**	**Code**	**County**
2	ALLEGAN	45	LENAWEE
8	BAY	57	MONROE
10	BERRIEN	61	NEWAYGO
12	CALHOUN	69	OTTAWA
22	EATON	72	SAGINAW
28	GRATIOT	73	ST. CLAIR
32	INGHAM	74	ST. JOSEPH
33	IONIA	75	SANILAC
40	KENT	80	WASHTENAW
43	LAPEER		

Hypotheses

If the static and dynamic characterizations we introduced for the variables mentioned in Equation 6 are accurate, then once land use is established, the dynamic variables should be the strongest drivers of land use change, while all variables – average price (PRAVG), land class (LCC) and county (COU) should have some impact on land use.

1. *Land use choice*
   a. In the model of land use, equation 7, we anticipate that all land class (LCC) and county (COU) variables will be significant determinants of probability.
   b. The sign for the LCC categories is expected to be positive for categories 1-3, as those are the categories considered suitable for agriculture, and negative for LCC 5-8. The sign on the county variables is expected to vary, as some are closer to urban areas – and central markets - than others. Land capability class binaries are included as a control for variations in land quality. One might expect a correlation between the land class and the likelihood for change. However, the land use is roughly evenly distributed over the land classes available (see Figure 6), evidence that land class alone is not a sufficient determinant of land use. There the overall magnitude of land class is expected to be low relative to other factors.
   c. Price (PRAVG) should not be significant, because there is no alternative cross-sectional opportunity cost included in the model (there is no way for the model to know if there was a change in price from earlier levels. Absolute price with no sense of how it relates to other prices contains no real information on value.

2. Land Use Change: Change Into Cropland

a. Price change is expected have a positive and significant impact on land use change into cropland. Because there is a large amount of primarily agricultural area in most of the counties studied here, the land use response to changes in agricultural prices is expected to be higher than it might be in a more diversified environment. At the same time, the price variation explored in this study is necessarily variation from county to county, a spatial variation. Spatial price variation is not expected to be as great as the price variations over time. The temporal effect is not picked up in the price variable used her, PRAVG, because it only contains prices for one shift, from 2001 to 2006. These effects are picked up by the constant.

b. In general, the land quality classifications are expected to be less significant than the dynamic variable in a model of probability of land use change. Higher land quality (lower classifications) should not be significant, because they are static factors, and not expected to be near the extensive margin. Lower quality land may be near the extensive margin, and so lower land quality may be a significant factor of likely land use change.

c. The county binaries will likely be significant, because they control for all spatial disparities other than price and land quality, not only transportation costs. The general regional disparity would be both positively and negatively differentiated from the base case of Allegan county, and of varying magnitude.

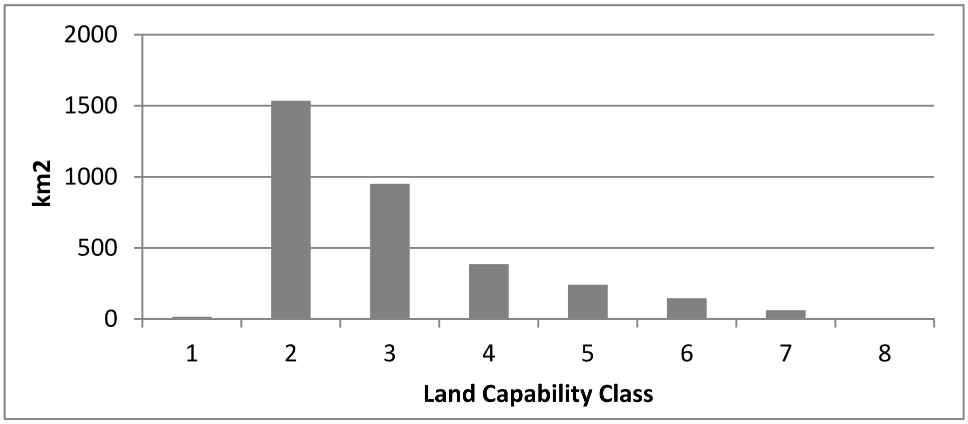
3. Land Use Change: Transition out of Cropland

Land Use Change into or out of a given use is dependent on the profitability of that use relative to all other uses. Therefore, the model should apply equally to change from any one use to another. Specifically, in the model of transition out of cropland, each variable is expected to have significance and magnitude roughly equal to its counterpart in the model of transition into cropland, but with the opposite sign.

Descriptive statistics and tables, and basic information

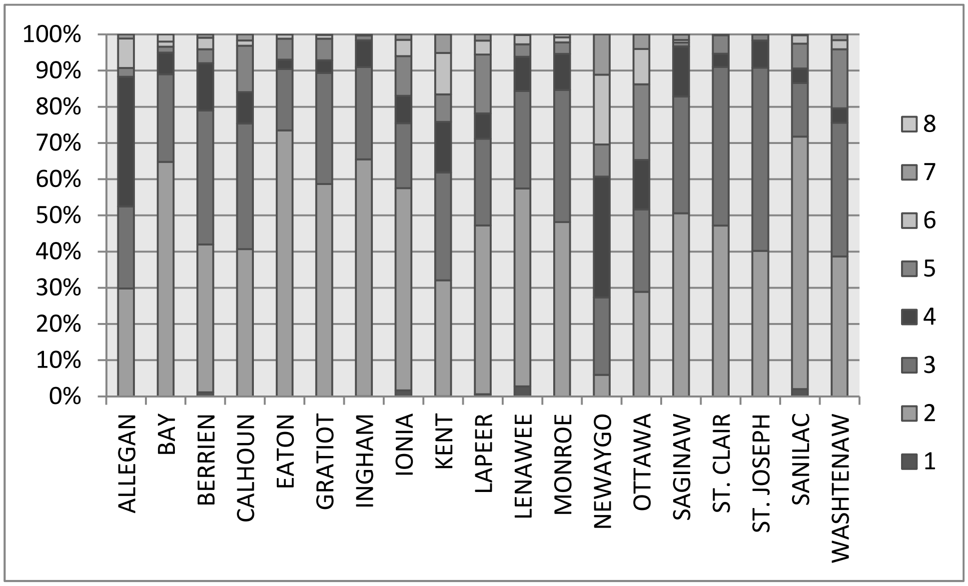
The 19-county area included in the analysis contains each of the 8 land capability classes. The majority of the land area is class 2, with area of land declining to class 8. Just 16 km^2 are class 1. Figure 3 displays magnitude of land area per land capability class.

Figure 3. Total area by land capability class, 19 counties in southern Michigan, (SSURGO, 2010)



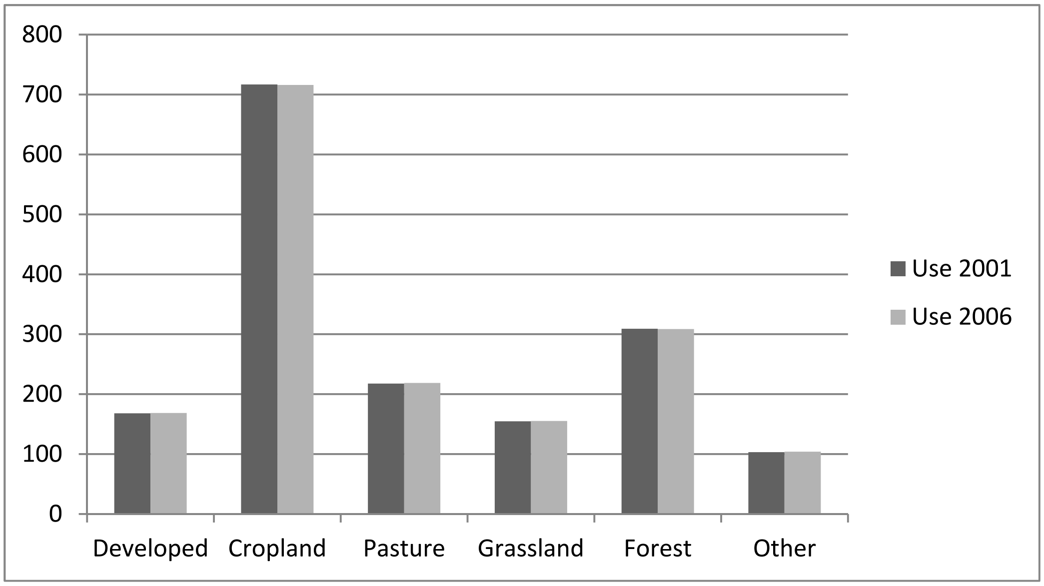
The counties are generally of reasonably uniform composition in terms of percentage of land class, with the exceptions of Allegan, Kent, Newaygo and Ottawa counties, all of which are on the Michigan west coast and have significantly lower percentages of class 2/class 3 land and more class 4/class 5 land than the other counties. Appendix 3 provides a table showing the quantity and proportion of each land class in each county.

Figure 4. Land class as percentage of county land area, 19 counties in southern Michigan, (SSURGO, 2010)



As shown in Figure 5, land use in the study area is dominated by agriculture (cropland and pasture), followed by forest. While there was some net land use change over the time period studied here, Figure 5 shows how little change there was relative to total land area.

Figure 5. Land use in 2001 and 2006 in 19 Michigan counties (CCAP 2001 and CCAP 2006)



Some land from each class is engaged in each of the five land categories analyzed in this study. Most land of classes 2 and 3 was used as crop land in 2001, and most cropland was on class 2 and class 3 land. However, most developed land was also on class 2 and class 3 land. Because there are only relatively small amounts of land in classes 4-8, it is not surprising that they make up only a small fraction of the land in each class. The exception is forest land, which has as much class 4 land as class 2 and class 3. As is the case statewide, there is very little of either LCC 1 or 8 in the 19-county area. Figure 6 shows the amount of land of each class dedicated to each use category.

Figure 6. Land use as distributed across land capability class, pooled data (SSURGO 2010 and CCAP 2001 and 2006)

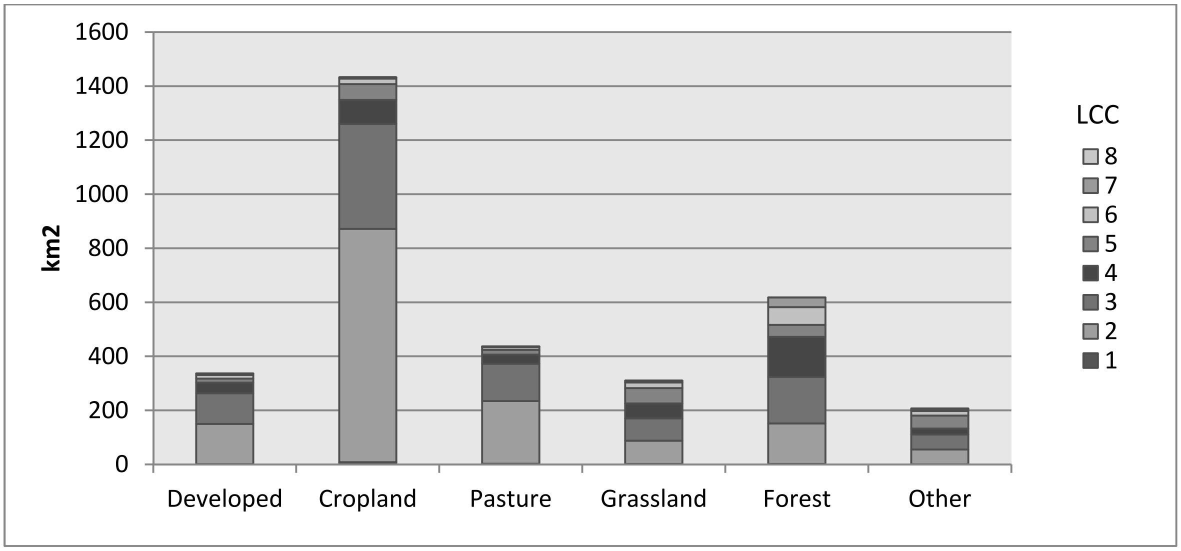


Figure 7. Correlation between each land use and land class scale, pooled data (SSURGO, 2010 and CCAP 2001 and 2006)

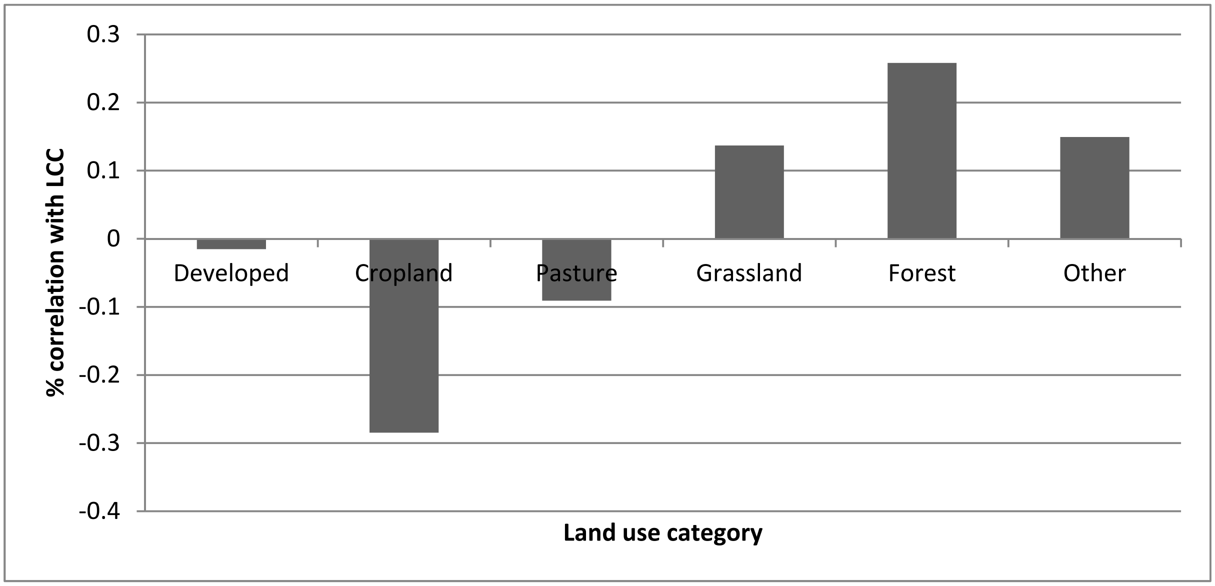


Figure 7 illustrates the correlation of each land use with an increase in land capability class. As one would expect, land classification, which increases as the quality declines, is negatively correlated with cropland. Likelihood of use for cropping declines as the land capability class increases, indicating land of poorer quality soil is less likely to be used for agriculture, as either crop land or pasture. Instead, it is more likely to be used as grassland, forest, or other uses such as wetlands or beaches, all of which show positive correlation with Land Capability Class. The negative correlation is stronger for cropland than for pasture, and the positive correlation is stronger for forest than for grassland. One might assume that grassland is easier to transfer into cropland or pasture than forest. Pasture and grassland are more likely to be on the extensive margin of agriculture, and so may not be used as consistently for one purpose as high-quality cropland is.

Figure 8 shows the quantity of land use change into and out of the different land use categories from 2001 to 2006. Table 8 shows the change in corn price over the same time steps. Though it is difficult to tell how much of this change is simply random fluctuation, and how much is due to price change, it is evident that an upward trend in price from 2001 to 2006 corresponds to a net gain in cropland. However, the majority of the land that transitioned out of cropland from 1996 to 2001 does not transition back in. (Land use change from 1996 to 2001 is included as appendix 2).

Figure 8. Quantity of land use change, 2001 to 2006 (CCAP 2001 and 2006)

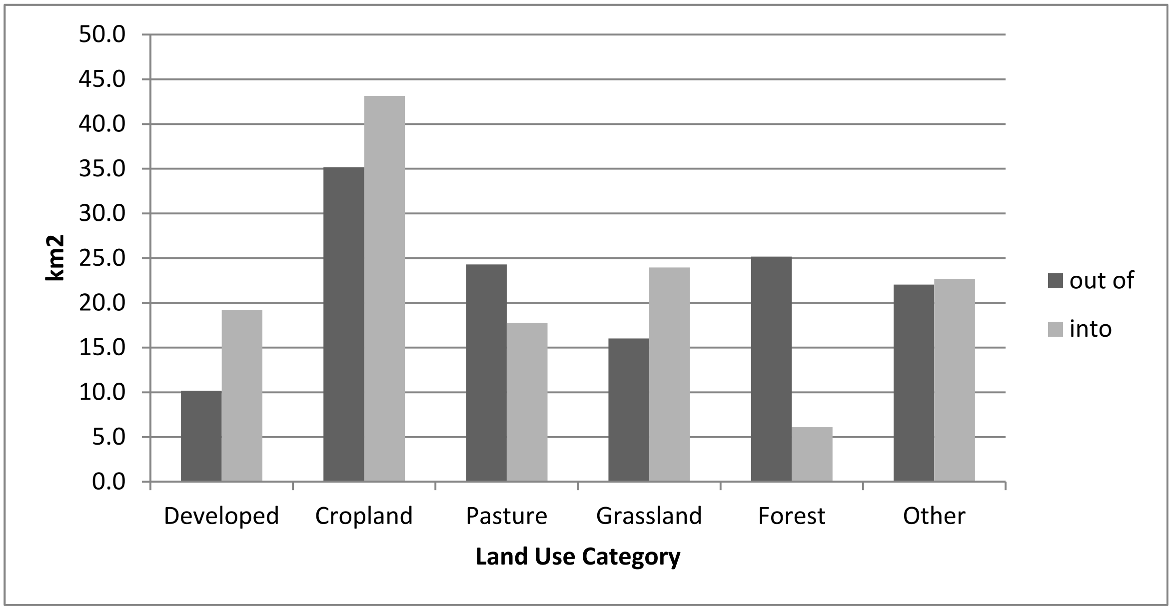


Table 8. Change in county-level corn price in cents per bushel, 1998 to 2000 and 2003 to 2005, in 2004 dollars (Cash Grain Bids, 2010)

	Cents per bushel
Average 3-yr lagged price for 19 counties, 1998-2000	180
Average 3-yr lagged price for 19 counties, 2003-2005	215
Average change in 3-yr lagged average price, 2001-2006	35 (20%)

Prices spikes in 2003 and 2004 are reflected in the averages, though the price had dropped back to near 2000 levels in 2005. The lagged average price for 2006 therefore corresponds to an increase in crop area from 2001 to 2006. A 20 percent price increase is not negligible, and should be enough of a change to signal to landowners to put land into production.

Results

Equations 7,9, and 10 were run as probit regressions in STATA 10. The regression results are presented in the tables 9, 10 and 11 below.

Table 9. Determinants of probability of land use as cropland, probit marginal effects, 19 counties of southern Michigan, 2001 and 2006 (pooled).

Variable	**Marginal Effect at Mean**	**Standard Error**
PRAVG	0.000143**	0.0000725
LCC1	0.215***	0.00375
LCC2	0.315***	0.000909
LCC3	0.190***	0.001
LCC5	0.0333***	0.0014
LCC6	-0.103***	0.00163
LCC7	-0.198***	0.00231
LCC8	-0.155***	0.00787
year2006	-0.00620**	0.00261
BAY	0.0382***	0.00194
BERRIEN	0.00438**	0.00174
CALHOUN	-0.0433***	0.00175
EATON	-0.0460***	0.00171
GRATIOT	0.171***	0.0019
INGHAM	-0.134***	0.00147
IONIA	0.0526***	0.0018
KENT	-0.176***	0.00133
LAPEER	-0.120***	0.00146
LENAWEE	0.0651***	0.00155
MONROE	0.0511***	0.0017
NEWAYGO	-0.169***	0.00142
OTTAWA	0.00172	0.00165
SAGINAW	0.0420***	0.00162
ST. CLAIR	-0.115***	0.00148
ST. JOSEPH	0.0708***	0.00176
SANILAC	0.0945***	0.00164
WASHTENAW	-0.184***	0.00139
Constant	-0.701***	0.0345
Observations	3,711,112	
Log likelihood	-2,285,837	
LR chi2 (25)	497,959	
Prob > chi2	0	
Pseudo R2	0.0982	

Table 10. Determinants of probability of land use change to cropland from a different use, probit marginal effects, 19 counties of southern Michigan, 2001 to 2006

VARIABLES	**Marginal Effects at Mean**	**Standard Error**
ΔPRAVG	0.0000242***	-0.00000333
LCC1	-0.000342	-0.000294
LCC2	0.000916***	-0.0000921
LCC3	0.000678***	-0.00011
LCC5	-0.000125	-0.000121
LCC6	-0.0000142	-0.000143
LCC7	-0.000390**	-0.000167
LCC8	0.00425***	-0.00136
BERRIEN	-0.0000955	-0.000127
CALHOUN	-0.000630***	-0.0000569
EATON	-0.000657***	-0.0000484
GRATIOT	-0.000293***	-0.000087
INGHAM	0.000395**	-0.000155
IONIA	-0.000650***	-0.0000512
KENT	-0.000364***	-0.0000702
LAPEER	-0.00101***	-0.0000306
LENAWEE	0.000695***	-0.000152
MONROE	0.000526***	-0.000148
NEWAYGO	-0.000570***	-0.0000664
OTTAWA	-0.0000555	-0.000106
SAGINAW	-0.000240***	-0.0000843
ST. CLAIR	-0.000825***	-0.0000378
ST. JOSEPH	-0.000774***	-0.0000468
SANILAC	-0.000956***	-0.000035
WASHTENAW	-0.000567***	-0.0000526
Constant	-3.358115	0.0561287
Observations	1,855,327	
LR chi2(25)	1,685.24	
Prob> chi2	0	
Pseudo R2	0.0453	

Table 11. Determinants of probability of land use change out of cropland into a different use, probit marginal effects, 19 counties of southern Michigan, 2001 to 2006

VARIABLES	**Marginal Effects at Mean**	**Standard Error**
ΔPRAVG	-0.000014***	0.0000034
LCC1	0.00114**	0.000564
LCC2	0.000780***	0.0000792
LCC3	0.000566***	0.0000939
LCC5	0.0000837	0.000109
LCC6	0.000125	0.00013
LCC7	-0.000337***	0.000126
BERRIEN	-0.000168**	0.0000829
CALHOUN	-0.000584***	0.0000359
EATON	-0.000354***	0.0000496
GRATIOT	-0.000713***	0.0000284
INGHAM	-0.000186***	0.0000717
IONIA	-0.000535***	0.0000388
KENT	-0.000236***	0.0000569
LAPEER	-0.000660***	0.0000318
LENAWEE	0.0000521	0.0000815
MONROE	0.000564***	0.000128
NEWAYGO	-0.000611***	0.0000383
OTTAWA	0.000423***	0.000117
SAGINAW	-0.000327***	0.0000525
ST. CLAIR	-0.000656***	0.0000318
ST. JOSEPH	-0.000740***	0.0000268
SANILAC	-0.000744***	0.0000296
WASHTENAW	0.0000522	0.0000758
Constant	-2.919662	0.0666022
Observations	1,853,435	
LR chi2(25)	1689	
Prob> chi2	0	
Pseudo R2	0.0529	

Discussion

The results largely support the theory outlined in Chapter 2. Although the goodness of fit is relatively low for each regression, the LR statistic is very high, indicating that we can reject the null hypothesis that the coefficients are equal to zero. Therefore, though they explain only a little of what determines land use choice, the regressions are valid. The low R squared value is likely due in part to the low percent change in the dynamic variables, which may not be dramatic enough to overcome the “noise” in the data, despite the large number of observations. With observations over time (multiple changes) or a broader area, these numbers might increase.

The base scenario in each regression is Allegan county, Land Capability Class level 4. In the land use choice model, the base year is 2001. Allegan county is on the western edge of the state, bordering Kent county, which is the home of Grand Rapids, a large urban area. The county contains far less of the class 2 and 3 land than most of the counties included in the study. See Figure 4 for a comparison of the land quality proportions in each county. (See Appendix 4 for map of counties included in analysis).

We notice in general that the results are very clear. That is, most variables are either significant at the 1% level, or not significant at all. This precision is due to the extremely high number of observations included in the data set.

Probability land is used for crops

This model attempts to measure the impact each dependent variable has on the likelihood that a given parcel will be used as cropland. The theoretical framework presented in chapter 2 says that many factors contribute to the likelihood that land will be cropland.

Of these, the available data allowed us to measure the influence of only the price, location and land quality, controlling for time period.

Hypothesis 1.a: All LCC and COU (county) variables will be significant.

According to the data in this analysis, the strongest determinant that land will be used for cropland is land quality. Land quality variables have markedly higher marginal effect than county binary variables, and are strongly significant. For example, being of land class 1, 2 or 3 results in a 21%, 31% or 19% greater probability of being engaged in cropland than class 4 land. Land capability classes 6, 7, and 8 are 10% to 20% less likely to be engaged in cropland than LCC 4. Class 5 land, at 3%, results in the least deviation from the baseline of Class 4 land. Classes 4 and 5 are contiguous, and in the middle of the spectrum, below what is considered ideal cropland. The limitations on production between the two classes may not be readily distinguishable to owners.

As expected, results indicate that location has a consistently significant influence on land use. All of the counties were strongly significant except Berrien in the southwest and Ottawa, which borders the base county of Allegan. The greatest marginal effect was .171, indicating an increase in probability of being cropland of 17 percent for land in Gratiot County, which is indeed a primarily agricultural county in central Michigan. The strongest negative impact on probability of being used as cropland is -.184, or a decrease of -18 percent of the probability of being used as cropland for land in Washtenaw County. Again, this is unsurprising given that Washtenaw is a very developed county containing the city of Ann Arbor.

Hypothesis 1.b: The sign for LCC of 1, 2 or 3 will be positive. The sign for LCC 6, 7, or 8 will be negative. The signs on the county variables will vary.

Better land quality is a stronger determinant of probability of use as cropland than poorer land quality, which is to be expected. All land quality variables of class lower than 4 are positive, and all land classes higher than 4 are negative. Not counting Ottawa, which was not significant, 9 counties resulted in a positive deviation from the baseline, and 8 resulted in a negative deviation, indicating that Allegan is roughly the median county in terms of probability of land used as cropland.

The county variable carries the influence of factors other than strictly the relative location of the land unit. They also contain regional differences that affect technology available (some counties are closer to supply outlets, have larger populations of farms and so a greater consistency and quality of supply options, etc.), manager characteristics and preferences (cultures vary between largely developed counties and largely rural counties, among other differences, ethnic diversity varies by county), and policy regime (local zoning ordinances, tax policies vary). It is not surprising then that the variables are significant, but the resulting impact cannot be strictly ascribed to relative location.

Hypothesis 1c: Price (PRAVG) should not be significant.

Price was significant at the 5 percent level, which is some indication of impact on the probability of land used as cropland. It is important to remember that the model captures the spatial difference in prices from one county to the next, controlling for other regional factors (included in the COU variables). Given the large number of variables, the impact of price must be somewhat ambiguous to be only significant at the 5 percent level.

The relative location of grain elevators, and supply depots, which is dependent on the concentration of grain farmers, could have some impact on the relative price and profitability of corn from county to county. Other special industries, such as corn ethanol biorefineries, may impact price around the regions where they are located. Over the time period analyzed, there was only one plant operational in Michigan, in the town of Caro in Sanilac county.

Probability that land transitions into cropland

Hypothesis 2.a: Price change will be a positive and significant impact on probability of land use change, of magnitude greater than other variables included in the regression.

The model was expected to reveal that the change in output price of corn had the largest effect on the probability of land use change into cropland. Price change was expected to induce land use change in all lands at the extensive margin, which is not expected to be restricted to a single class of land. Land quality should not be a significant driver of change, because it is a static factor.

As expected, the change in output price is strongly significant, though of low magnitude. The sign is positive, indicating that an increase in the price of corn will result in an increase in land used as cropland. This validates our assumption that corn was a suitable proxy for agriculture prices in general, as well as our hypothesis that price shift drive land use shifts. However, the marginal effect is very small both in absolute terms and relative to the LCC and COU variables. The marginal effect of a $1.00 change in price from one county to the next would have just a 0.2% impact on the probability of a unit of land going into cropland (the price data used was in cents). Actual annual corn prices from 1998 to 2006 by county are shown in Appendix 1.

It should be noted that a $1.00 jump in price is highly unusual from county to county, but less unlikely in a temporal comparison. Since temporal price changes are known to be greater than spatial price variation, an analysis of price changes over time, especially over recent years when there was a great deal of price volatility, might reveal that temporal price change has a greater effect on probability of land use change. In this model, there is no term to control for the fixed temporal effect of price change, and so that effect is contained in the constant term. Surprisingly then, the constant term in Table 10 was not significant. This may be due to the low level of price change from 2001-2006 in the context of long-term price variability. If price change did nt cross a threshold that signaled to land owners a rise in price beyond what could be expected from normal price fluctuations, it might not trigger much land use change.

Hypothesis 2.b: Land Capability Class variables (LCC) are expected to have lower magnitude that the price change variable. Less volatility is expected in lower land class (classes 1-3), where land best suited to agriculture should already be in agriculture.

Unexpectedly, the results show that land capability classes 2 and 3 are more likely to transition into cropland than land class 4. These classes were also more likely to already be cropland than the lower quality lands were, as shown in Table 9. This raises the question of whether the extensive margin closely corresponds to land capability classes. Classes 5 and 6 are not significant, perhaps indicating there is no impact to the probability of transitioning to cropland between classes 4, 5 and 6. Land class 7 is less likely to transition to cropland than class 4, with strong significance. Land class 8 is more likely than class 4 to transition into cropland.

The overall magnitude of these variables is very low. In general, land was simply not likely to transition over the period and area examined. In terms of magnitude, the marginal effect of land class 2 is the highest of the land class effects. Still it is only a 0.09% increase in probability of change into cropland.

Hypothesis 2.c: The county binary variables will be significant, as they control for all regional variation from county to county. Counties will deviate both positively and negatively from the baseline of Allegan county.

Effects for the county dummies were again strongly significant, except for Berrien and Ottawa. It is surprising that the binary for Berrien county would not be significant, given its rural location and high percentage of class 2 and 3 lands (similar to the other 18 counties). However, as the home of the twin cities of Benton Harbor and St. Joseph, Berrien has a similar percentage of land dedicated to the developed land use category as Ottawa county. In addition, Berrien county agriculture is largely devoted to orchard crops such as peaches, pears and grapes. This type of agricultural land use does not readily transition. Ottawa county is located on the west coast of Michigan, and has significant development, including the city of Holland and other suburbs of Grand Rapids.

Lenawee and Monroe counties, both in the southeast corner of the state, showed the strongest tendency to transition to cropland, with marginal effects around 0.05%-0.07% increase in probability. Sanilac county and Lapeer county showed strongest negative effect on probability of transitioning to cropland, at around -0.10%. As these counties are relatively rural, this could be an indication that all land that is adequate for agriculture is already in agriculture.

Probability that land transitions out of cropland

Hypothesis 3a: The marginal effects of the variables in Table 11, which shows the marginal effect of each variable on land use change out of cropland, are expected to have magnitudes roughly equal to their counterparts in Table 10, which shows the marginal effect on probability of land use change into cropland. The sign of the effect of each variable, however, is expected to be the reverse of what it is in Table 10.

This holds true for the sign of output price, which is negative. A $1.00 increase in corn price would result in just a 0.1% decrease in probability of land use change out of cropland. The magnitude is much lower than the impact of price on probability of a shift into cropland. This could relate to the appropriateness of the corn price as an index for all agricultural prices. As the corn price falls, landowners, once engaged in cropland, may find it easier to into producing a different agricultural product.

The results for some of the county binary variables are surprising. They do not the mirror of the previous regression. Monroe continues to be positive, showing a 0.05% increase in probability of transition out of cropland, almost equal to its positive effect on transition into cropland. Sanilac and Lapeer continue to show a negative impact on probability, at -0.07% and -0.06%, respectively. This indicates that land is transitioning out of cropland as readily as it is transitioning into cropland, which may be a result of land owners in those areas having more or different competing opportunities for their lands.

Although county was included primarily to represent the locational differences in the costs of agricultural production, the variable actually embodies all regional differences from county to county, including differences in the availability of other economic activities. Many of the counties included in the study have significant development activity occurring as well as agriculture. Land could be transitioning into development as those earnings increase, even as in other areas, land is transitioning into cropland as agricultural prices increase. The county as regional unit is not precise enough to differentiate between these different activities.

Land quality was not expected to be a significant driver of change either into or out of cropland, although it would not be unusual to see a correlation between high land quality and land used for agriculture, as is evident in the first model. Unexpectedly, this model shows that high land quality has a strongly significant positive effect on probability of transition out of cropland, relative to class 4 land. Because other uses are not incorporated in the model, there is no way to determine if there is a strong correlation between land class and location relative to another economic activity that could drive change out of cropland, such as development. Historically, cities often developed near good quality agricultural land so as to feed their populations. Thus, it is possible a correlation between land class and a factor included in the error term, such as proximity to urban areas, is causing a distortion in these coefficients. Though classes 5 and 6 are not significant, the Class 7 effect on probability of transition out of cropland is negative, and significant at the 1% level. It is not clear what might cause this unexpected result, though it may be a lack of alternatives.

Conclusion

The goal of this study has been to investigate possible definitions and means of identifying what land is truly marginal for its given use. The assumption that a marginal land resource exists has the potential to be a detriment to making sound policy with regard to energy biomass production if that resource cannot be defined and identified. What is needed is a better understanding of how and why different kinds of land are used, and what attributes or relationships are most likely to drive land use change, in order to understand what land would actually be dedicated to biomass use under current or proposed policy.

"Marginal" land is casually referenced in several recent studies. However, the term is often defined in vague terms, and the resource so delimited has been little researched. Marginal land is often assumed to correspond to land of poor quality. However, this is contradicted by theory, which states that marginal land is so defined by its ability to generate utility, which is determined only in part by land quality. Other disciplines, such as ecology, and other professions, including policymakers, have not demonstrated a consistent understanding of how economic activity actually relates to land quality. The studies reviewed here revealed how other researchers casually apply the concept of marginal, assuming that resources are inefficiently allocated. It is more likely that current land owners have some reason for using the land as it is being used. Shifts in policy could direct this land to be used in one way or another, with taxes and subsidies and other tools. But it is unlikely there exist large tracts of land that would be very useful for agricultural production but that is not engaged in either agriculture or some other use that is of equal or more value to the owners.

Even accepting the theory that other factors have some influence on land use choice, one might ask if it is probable that land quality is a decent proxy indicator for marginal land. To an extent, this may be true. The analysis conducted here demonstrates that in fact, land quality is a significant factor in how land is used and when it transitions from one use to another. The results of this study indicate that while land quality is a consistent and significant factor in determining land use, it is not a dominant factor. Only a very small portion of land use choice and land use transition is determined by land quality. Locational differences appear to be equally as important. The results of this study, especially for land use transitioning out of cropland, were inconsistent with theory, and require further investigation. There may be useful links between the volatility of land of a certain class relative to certain economic uses or volatility of land in certain locations, such as proximity to urban areas.

The magnitude of responsiveness to price is surprising. Price is generally one of the strongest drivers of economic behavior. Nevertheless, the data above appear to show that land use is highly inelastic. There are many potential reasons for this, including the low percent change in the price, and the nature of farming. Asset specificity may keep farmers engaged in agriculture despite price fluctuations. Additionally, this study was unable to measure non-market amenities that may affect behavior. Regardless, land quality, location and an output price vector fail to explain even 10% of land use choice and land use change behavior.

This study was limited in scope by the availability of data, which allowed a comparison across only the county unit, a spatial distribution. Spatial prices do not usually vary much. Because there was no explicit control for temporal fixed effects, the constant terms in this study carries this information. Temporal price shift are likely much stronger determinants of probability of land use change. Without a mechanism for isolating the effects of price shifts over time on land use trends, it is impossible to judge their magnitude.

The field of economics has long been able to define theoretically what land is at the extensive margin of any land-based industry. The problem with using land at the extensive margin as a basis for policy making, even if the term is well understood, is that this status of “marginal” is by definition relative, and changeable. Land that is marginal for one use may not be for another, and land that is marginal at one point in time, may no longer be marginal as prices or policies shift. Identifying which land is marginal would be difficult for government agencies to manage.

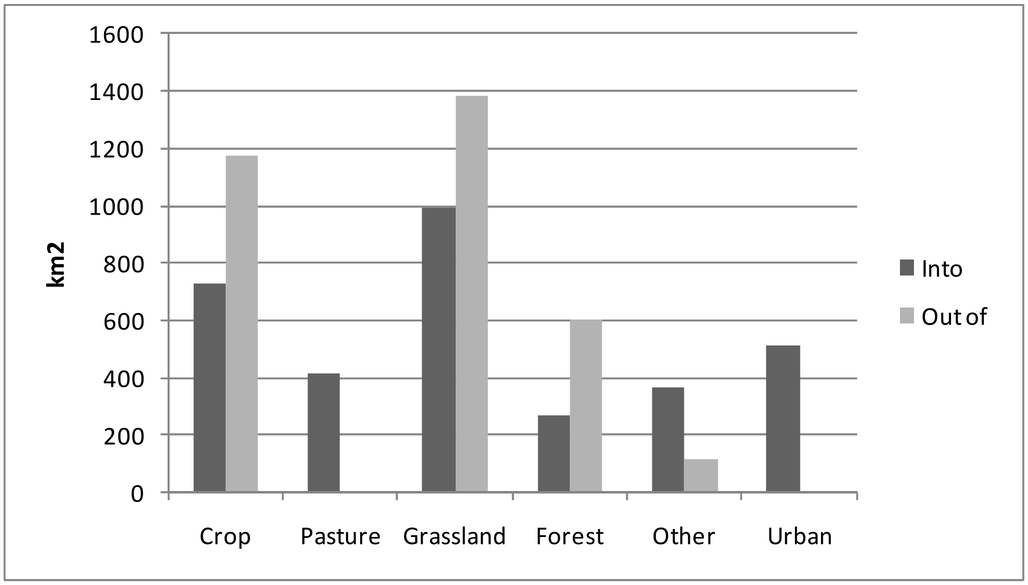
The results of the empirical analysis in this study confirm that price shifts drive land use change. Further, the results of this very general model show that it is not easy to capture the effects of changes in price and policy. This study had access to a large volume of data, but for only two time periods (representing one shift), and for a limited number of variables. Actually identifying what lands are on which extensive margin requires a large variety of variables recorded at many time periods, and probably over a significant length of time or a large and heterogeneous area. The single shift available for analysis here did not allow for any analysis of the effect of price changes over time to drive land into and out of crop production. Temporal effects should be much greater, and may in fact be a major driver of land use change. In addition, corn prices may not be the best indicator of the attractiveness of all agricultural activities. Additional price variables or an index of agricultural prices would make the results more accurate. Output prices for competing activities would allow the model to better evaluate what is the external pull that attracts the land when the agricultural price is no longer enough to maintain the land as cropland.

The model would benefit from greater variety of data overall, including more information on policy variation, and variables to indicate key manager traits and key amenity values that impact land owner decision. Such a model could add clarity to what this study has shown, which is that land quality by itself is not enough of an indicator of appropriate land use to serve as the basis for economic policy related to land use. The value of land is dependent on many factors in addition to land quality. Because these factors are largely exogenous to land quality, their impact on the extensive margin keeps it from aligning closely with the spectrum of land quality. Policy that attempts to drive specific behaviors on lands that are on the extensive margin should rely on some indicator other than exclusively land quality to identify that marginal land.

Appendix 1: County prices 1998 to 2006 in the 19 counties included in the empirical analysis

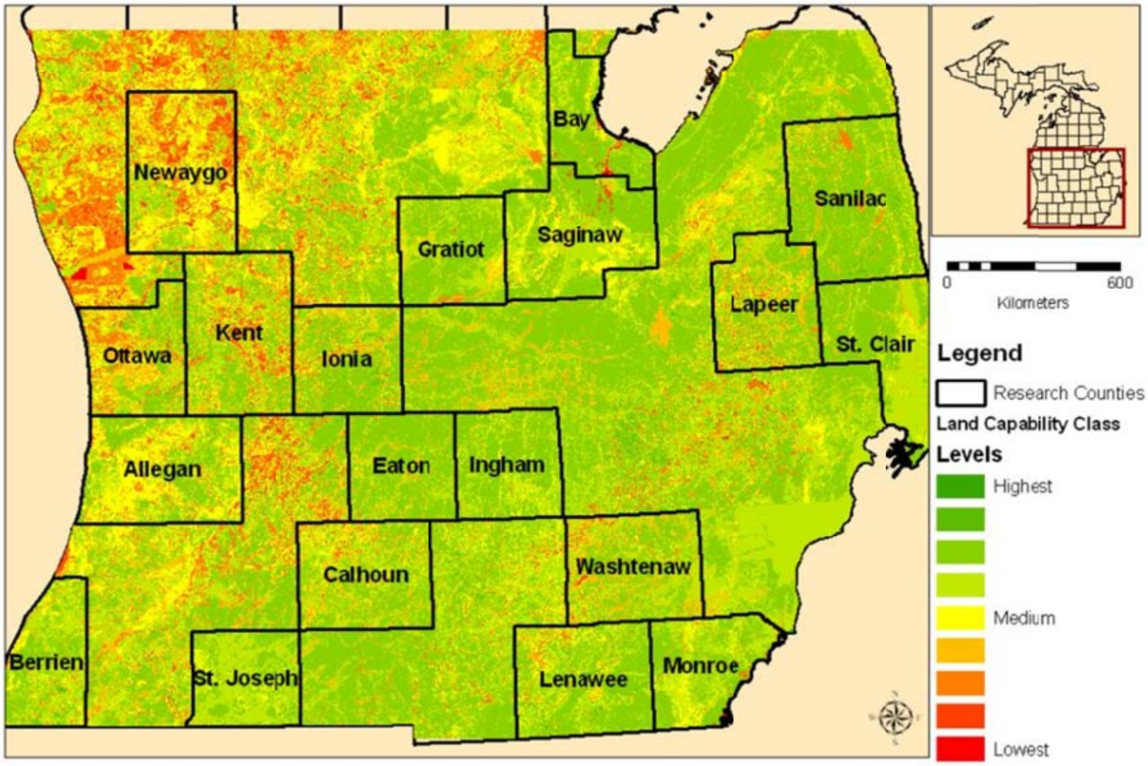
	Cents per bushel								
County	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Allegan	184.67	185.02	186.07	192.26	219.91	229.37	240.40	188.75	227.39
Bay	181.06	178.49	183.07	182.31	204.19	243.71	.	.	241.84
Berrien	183.93	183.50	182.79	183.79	209.62	209.92	229.52	173.58	213.74
Calhoun	175.22	176.56	169.70	173.87	205.96	213.84	228.08	175.43	227.01
Eaton		166.22	181.10	189.31	213.14	223.93	237.61	177.69	227.36
Gratiot	177.58	174.51	172.67	180.97	203.93	222.68	221.52	170.95	219.20
Ingham	189.06	186.82	182.98	189.33	218.41	227.06	233.00	178.79	228.56
Ionia	176.11	172.71	173.02	175.63	205.66	222.18	235.01	180.43	219.31
Kent	178.17	180.51	176.57	184.69	211.31	225.83	235.71	178.90	218.89
Lapeer	179.00	180.39	179.24	189.45	216.45	228.12	253.17	175.77	221.73
Lenawee	183.72	187.23	184.98	189.95	216.68	230.49	237.99	181.49	231.39
Monroe	190.17	195.66	186.83	191.05	225.23	233.79	245.62	189.08	239.78
Newaygo	182.17	178.53	178.09	188.98	221.98	228.19	232.79	176.81	225.73
Ottawa	186.12	184.55	186.20	193.76	217.80	228.70	239.76	188.72	228.24
Saginaw	181.78	180.18	175.32	184.08	211.34	223.97	231.07	174.05	216.57
St. Clair	173.82	177.29	172.41	192.48	214.63	229.35	241.74	179.32	229.90
St. Joseph	185.17	182.53	173.23	185.98	224.77	225.92	230.24	181.61	228.34
Sanilac	176.61	172.74	171.77	184.62	210.70	225.38	233.93	176.48	223.61
Washtenaw			173.44	.	.	221.02	270.04	153.72	210.25

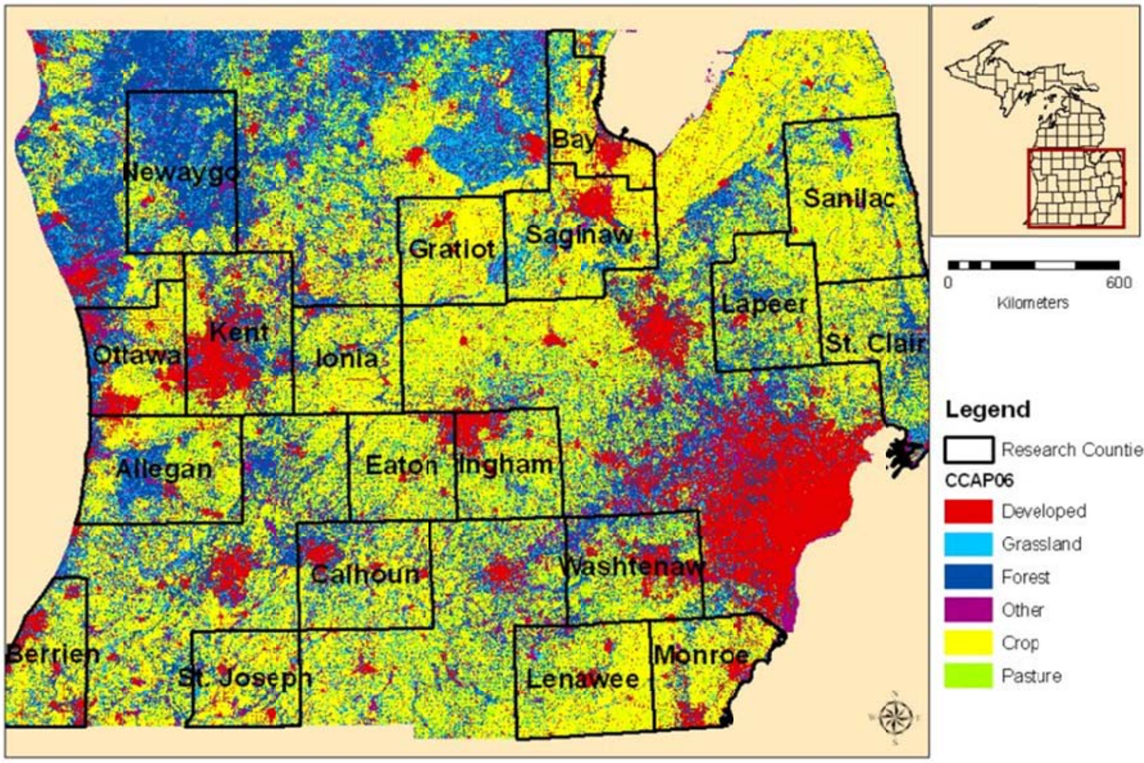
Appendix 2. Quantity of land use change, 1996 to 2001



Appendix 3: Table of quantity and proportion of land class by county

LCC	1		2		3		4		5		6		7		8		Total
ALLEGAN	0.00	0%	64.98	30%	49.41	23%	78.07	36%	5.34	2%	17.70	8%	2.52	1%	0.00	0%	218.02
BAY	0.00	0%	75.09	65%	28.04	24%	6.92	6%	1.91	2%	1.64	1%	0.00	0%	2.31	2%	115.90
BERRIEN	1.67	1%	61.08	41%	55.39	37%	19.55	13%	5.75	4%	4.80	3%	1.36	1%	0.00	0%	149.61
CALHOUN	0.00	0%	75.64	41%	64.52	35%	16.12	9%	23.78	13%	2.77	1%	3.09	2%	0.00	0%	185.91
EATON	0.00	0%	110.05	73%	25.46	17%	3.84	3%	8.64	6%	1.81	1%	0.00	0%	0.00	0%	149.80
GRATIOT	0.00	0%	86.87	59%	45.43	31%	5.17	3%	8.87	6%	1.54	1%	0.21	0%	0.00	0%	148.09
INGHAM	0.01	0%	95.14	65%	37.04	25%	10.69	7%	1.95	1%	0.44	0%	0.00	0%	0.00	0%	145.27
IONIA	2.48	2%	83.83	56%	26.96	18%	11.33	8%	16.49	11%	6.74	4%	2.27	2%	0.00	0%	150.08
KENT	0.01	0%	72.29	32%	67.20	30%	31.47	14%	17.19	8%	25.79	11%	11.55	5%	0.00	0%	225.49
LAPEER	1.00	1%	79.94	47%	41.05	24%	11.99	7%	27.88	16%	6.58	4%	2.95	2%	0.00	0%	171.39
LENAWEE	5.48	3%	107.66	55%	53.03	27%	18.64	9%	6.79	3%	4.99	3%	0.37	0%	0.00	0%	196.95
MONROE	0.00	0%	69.33	48%	52.63	37%	14.33	10%	4.59	3%	2.04	1%	0.00	0%	1.11	1%	144.03
NEWAYGO	0.00	0%	13.20	6%	47.66	21%	74.30	33%	19.78	9%	42.93	19%	24.84	11%	0.00	0%	222.71
OTTAWA	0.00	0%	43.12	29%	33.97	23%	20.44	14%	31.21	21%	14.54	10%	6.01	4%	0.00	0%	149.30
SAGINAW	0.00	0%	106.42	51%	67.93	32%	29.10	14%	2.29	1%	1.45	1%	3.26	2%	0.01	0%	210.46
ST. CLAIR	0.00	0%	88.47	47%	82.27	44%	6.81	4%	9.61	5%	0.21	0%	0.20	0%	0.00	0%	187.57
ST. JOSEPH	0.00	0%	54.24	40%	68.30	51%	10.12	8%	2.25	2%	0.00	0%	0.00	0%	0.00	0%	134.91
SANILAC	5.05	2%	173.66	70%	36.91	15%	10.00	4%	17.04	7%	5.89	2%	0.52	0%	0.00	0%	249.07
WASHTENAW	0.00	0%	72.26	39%	69.08	37%	7.42	4%	30.52	16%	4.70	3%	2.97	2%	0.00	0%	186.95


Bay
Newaygo
Sanilac
Gratiot
Saginaw
Lapeer
St. Clair
Kent
Ottawa
Ionia
Allegan
Eaton
Ingham
Calhoun
Washtenaw
Berrien
St. Joseph
Lenawee
Monroe
0
600
Kilometers
Legend
Research Counties
Land Capability Class
Levels
Highest
Medium
Lowest


Newaygo
Bay
Gratiot
Saginaw
Sanilac
Lapeer
St. Clair
Ottawa
Kent
Ionia
Allegan
Eaton
Ingham
Calhoun
Washtenaw
Berrien
St. Joseph
Lenawee
Monroe
0
600
Kilometers
Legend
Research Counties
CCAP06
Developed
Grassland
Forest
Other
Crop
Pasture

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