Biomass and Bioenergy 105 (2017) 107–115

Contents lists available at ScienceDirect

Biomass and Bioenergy

journal homepage: http://www.elsevier.com/locate/biombioe

Research paper

Adoption of switchgrass cultivation for biofuel under uncertainty: A discrete-time modeling approach

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ARTICLE INFO

Article history:
Received 30 March 2017
Received in revised form
31 May 2017
Accepted 21 June 2017

Keywords:
Switchgrass
Bioenergy
Uncertainty
Profitability
Cellulosic

ABSTRACT

Production of biofuels from cellulosic sources, such as switchgrass, is being encouraged through mandates, incentives, and subsidies. However, uncertainty in future prices coupled with large establishment costs often inhibit their cultivation. Owing to their inability to incorporate uncertainty and dynamic decision-making, standard discounted cash flow techniques are ineffective for analyzing such investments. We formulate a discrete-time binomial framework to model output prices, allowing us to incorporate price uncertainty, stand age, and variable crop yields into the analytical framework. We analyze the feasibility of investments in switchgrass cultivation under varying price transition paths, evaluate the relationship between risk and profitability, and estimate the value of flexible decision-making options wherein the farmer can alter cultivation choices. We find that switchgrass cultivation is only 32% likely to be profitable in the base model and infer that on-farm management could play an important role in entry and exit decisions. We also find that subsidies are important for project viability and policymakers could consider incorporating payments for ecosystem services to encourage adoption.

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1. Introduction

The continued consumption of fossil fuels is considered to be unsustainable owing to the non-renewable nature of the resource and the environmental consequences associated with fossil fuel use. As a result, biofuels have emerged as a favored alternative in several countries because they can enhance a country's energy security by displacing imported fuels with domestically produced alternatives, provide support to domestic agricultural markets, and possibly reduce environmental impacts through greenhouse gas (GHG) emission reductions [1]. In addition, it is believed that the physical and chemical properties of liquid biofuels require relatively limited modifications to engine technology and fueling infrastructure [2]. However, first generation biofuels, such as grain-based ethanol, could lead to an increase in food prices and competition for prime land between food crops and biofuel crops [3]. In addition, whether biofuels can result in carbon savings depends on how they are produced [4,5]. As a result, second-generation biofuels could make a substantial contribution to the energy supply mix in the future [6].

A variety of materials ranging from wood and forest residues to energy crops and grasses can be used to produce second-generation biofuels. Potential feedstocks include short-rotation woody sources such as poplar and loblolly pine, agricultural residues including straw and corn stover as well as grasses such as miscanthus, switchgrass and reed canary, among others [7,8]. In the U.S., Switchgrass (*Panicum virgatum*), a native perennial warm-season grass has been identified as a high-potential energy crop following a series of screening trials and assessments [9]. These trials and assessments were carried out across several crop species, soil types, and geographic locations because agricultural productivity and crop growth are highly dependent on such factors. Although most evaluations of switchgrass are focused primarily on its use in the production of cellulosic biofuels, it has been widely recommended for soil and wildlife conservation, summer grazing in pasture systems for beef cattle, and co-firing with coal to produce

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http://dx.doi.org/10.1016/j.biombioe.2017.06.012
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electricity [10]. Under favorable conditions, switchgrass can reach heights of up to 3 meters and its deep-root system that produces substantial below-ground biomass also helps in lowering soil erosion. Switchgrass is known to adapt well in nutrient-deficient systems and does not require an extensive use of fertilizers and pesticides. Studies also suggest that switchgrass cultivation results in a significant level of carbon sequestration and improves soil productivity and nutrient cycling [11–13].

In the U.S., the initial volumetric production targets set under 2007 Energy Independence and Security Act (EISA) and the renewable fuel standards (RFS) have been lowered on many occasions owing to lower fuel consumption for vehicles resulting in lower demand, and slower than expected development of cellulosic biofuel production, among other factors [14]. Along with technological advancement in the feedstock-to-fuel conversion process, a competitive, year-round supply of biomass feedstock is a major constraint in the commercial deployment of advanced biofuel production [15]. Supply-side aspects, such as feedstock cultivation intended for biofuel production and the decision making process of a landowner with regards to the cultivation of a dedicated bioenergy feedstock are critical [16].

An important aspect for feedstock cultivation relates to its profitability and opportunity costs. It is worth noting that land devoted to switchgrass cultivation could come out of land already being used for row crops, forage crops, or land that is considered marginal and considered not suitable for row crop production. However, in order to compare the economic viability of a long-duration crop such as switchgrass, the time horizon needs to be selected carefully. The establishment period for switchgrass ranges between 2 and 3 years after which the crop reaches full production levels. However, once established it is recommended that switchgrass crop be replanted after 10–15 years to maintain productivity levels [17].

Meanwhile, uncertain future crop yields and prices, coupled with relatively large upfront establishment costs, are characteristics of perennial crop production [18]. Allocating land for switchgrass cultivation requires a long-term commitment from the farmer and is often characterized with substantial entry and exit costs. Coupled with low yields in the early stages, there is limited revenues from agricultural activity, at least in the initial years. On the other hand, converting the land back to its traditional use might necessitate some exit costs associated with completely removing switchgrass root-stocks and limiting competition for subsequent crops. Thus, a financial analysis of investments in switchgrass cultivation is, like other long-term investments, fraught with various types of uncertainties. Along with the biological uncertainty associated with growing crops, factors such as climate change, an evolving policy environment, and volatile input costs, add to the complexity of analyzing economic attractiveness of switchgrass cultivation. While standard discounted cash flow techniques such as the net present value (NPV) have been commonly used to evaluate investment decisions, they are relatively rigid and do not incorporate uncertainty and dynamic decision making [19,20]. In their general framework examining entry and exit decisions of a firm, Dixit and Pindyck [21] assumed that output prices are uncertain and follow a geometric Brownian motion. In this paper, we extend the theoretical framework developed by Dixit [22], and focus on a discrete time version of the model while accounting for the option to reverse the decision and convert the land back to its original use.

Our paper contributes to the existing literature in multiple ways. We utilize a discrete-time model which allows us to incorporate the biological aspects of switchgrass cultivation whereby we accommodate for switchgrass age and corresponding yields over the life of the project. Furthermore, we vary our cost assumptions to account for higher upfront establishment costs and lower operational costs in subsequent time-periods. While Song *et al.* [19] highlight the importance of switchgrass age and establishment costs, their continuous-time model does not account for these factors. Our analysis is an improvement over results obtained from purely deterministic analyses as we incorporate uncertainty into the price transition for switchgrass. We evaluate the potential price transitions and associated cash flows and compute corresponding probabilities for return on investment in a dynamic setting. We use a recent time series for ethanol prices to estimate the parameters of the model, making our work both relevant and timely against the backdrop of recent declines in global gasoline prices. We introduce flexible decision making at the farm level wherein the farmer has the option to increase area under switchgrass cultivation or exit the investment during the project life after observing the corresponding output price, following the principle of adaptive management. By allowing for reversibility of land-use, our model highlights some of the conditions under which a farmer could alter his/her cultivation choices and underscores the importance of active on-farm management decisions. From a policy perspective, these insights could be used to design a program that can provide incentives and accommodate for the uncertainty associated with entering the market for advanced bioenergy. Finally, this framework can be utilized to evaluate investment decisions for other bioenergy feedstocks in different parts of the world.

2. Model framework

2.1. Binomial model and analysis of net present value

Under the framework of a binomial model, the per tonne price of switchgrass is assumed to evolve as a multiplicative binomial distribution in discrete time. Fig. 1 depicts a binomial tree that extends across two time periods. The model adopted in this paper is based on a similar binomial tree that extends across ten time periods, spanning the productive age for a switchgrass stand. At time $t = 0$, the per tonne price of switchgrass is assumed to be P. In time period $t = 1$, the price either moves up by a multiplicative factor u with probability q to reach P_u or moves down by a factor d with probability $(1 - q)$ to P_d. The binomial tree is referred to as a recombining tree because an up-move followed by a down-move yields the same value as a down-move followed by an up-move. Thus, at time $t = 2$, the price is given by one of three potential values: P_{uu}, P_{dd}, or $P_{ud} = P_{du}$.

In this framework, we assume that the volatility in prices σ is known and remains constant. The risk-neutral probabilities, i.e. the probabilities of future outcomes adjusted for risk, q and $(1 - q)$ are also known. Based on these assumptions and the general framework developed under the Cox-Ross-Rubenstein Binomial Option Pricing Model [23], the respective values for q, u, and d can be given by

$$q = \frac{e^{(r\Delta t)} - d}{u - d}, \tag{1}$$

$$u = e^{\sigma\sqrt{\Delta t}}, \tag{2}$$

$$d = \frac{1}{u}, \tag{3}$$

where Δt is the step size and r is the risk-free rate of interest. As $\Delta t \rightarrow 0$, the multiplicative binomial process described above converges to the geometric Brownian motion (GBM) [20] and the evolution of P can be described by

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