ASCENT 001(D) Alternative Jet Fuel Supply Chain Analysis of the Mid-Atlantic

Project Lead Investigator

Investigating Team:

- Leads: Katherine Y. Zipp – PSU

Other Lead Personnel:

- Tom Richard – PSU, Caroline E. Clifford – PSU, Lara Fowler – PSU, Michael P. Wolcott – WSU, Manuel Garcia-Perez – WSU, Tim Rials – UT, Burt English – UT, Kristin Lewis – Volpe

Penn State Lead:

Katherine Y. Zipp
Assistant Professor of Environmental and Resource Economics
Department of Agricultural Economics, Sociology, and Education
The Pennsylvania State University
112-F Armsby
University Park, PA 16802
814.863.8247
kyz1@psu.edu

University Participants

Penn State University: Project Title "Alternative Jet Fuel Supply Chain Analysis of the Mid-Atlantic".

Project Co-Director: Katherine Y. Zipp (PSU)
Other researchers: Tom Richard – PSU, Caroline E. Clifford – PSU, Lara Fowler – PSU

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Period of Performance: August 1, 2016 – July 31, 2017

Task(s):

1.5.1 (Lead: Richard; supported by Zipp, Rials, and English) – Delineate the sustainability impacts associated with various feedstock choices (switchgrass, oilseeds and winter grasses) including land-use effects for the mid-Atlantic region, including the Chesapeake Bay watershed.

1.5.2 (Lead: Zipp, supported by Richard and Lewis) - Evaluate the supply chains associated with switchgrass, oilseeds and winter grasses for the mid-Atlantic region.

3.3.1 (Lead: Clifford; supported by Garcia-Perez) - Report on preprocessing requirements and refinery insertion points for various bio-oil and biomass feeds.

3.3.3 (Lead: Garcia-Perez, supported by Clifford) – Simulate satellite biomass-to-liquid processing (e.g. gasification/F-T catalysis, pyrolysis, hydrothermal liquefaction or vegetable oil processing)

7.1.4 (Lead: Richard, supported by Wolcott) - Updated Data Management Plan and Status Report

8.1 (Lead: Zipp, supported by Fowler, and Richard) - Analysis of ecosystem service valuation, law and policy drivers, and potential policy design of water quality improvements associated with perennial grasses and cover crops.

Project Funding Level

- FAA Funding: $200,000.
- Matching:
  - Penn State - $200,000
- Total Funding: $400,000

Investigation Team

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7.1.4 **(Lead: Richard, supported by Wolcott)** - Updated Data Management Plan and Status Report

8.1 **(Lead: Zipp, supported by Fowler, and Richard)** - Analysis of ecosystem service valuation, law and policy drivers, and potential policy design of water quality improvements associated with perennial grasses and cover crops.

Project Overview

1.5.1 Delineate sustainability impacts associated with various feedstocks, including land use effects for mid-Atlantic region/Chesapeake Bay watershed. Includes subtasks addressing erosion and sediment delivery and water quality.

1.5.2 Evaluate the supply chains associated with switchgrass, oilseeds and winter grasses for the mid-Atlantic region.

3.3.1 Report on preprocessing requirements and refinery insertion points for various bio-oil and biomass feeds.

3.3.3 Simulate satellite biomass-to-liquid processing (e.g. gasification/F-T catalysis, pyrolysis, hydrothermal liquefaction or vegetable oil processing)

7.1.4 Updated Data Management Plan and Status Report

8.1 Analysis of ecosystem service valuation, law and policy drivers, and potential policy design of water quality improvements associated with perennial grasses and cover crops. Includes subtasks 8.1.1, a literature review, and 8.1.2, a report analyzing Chesapeake Bay opportunities as a co-product market opportunity.

Task 1.5

Penn State

Objective(s)

Evaluate the supply chains associated with switchgrass, oilseeds and winter grasses for the mid-Atlantic region.

Research Approach

Determine the price-supply curves to determine crop acreages at different price points. This task is informed by our new Task 8.1, and will apply the UT estimates of erosion, sediment, and water quality impacts for perennial grasses and cover crops in the Chesapeake Bay region. This objective will also leverage ongoing work by the USDA funded NorthEast Woody/warmseason Biomass (NEWBio) Consortium to evaluate sustainability impacts of switchgrass and winter rye. See Task 8.1 for a description of the returns to biomass needed to induce conversion.

Milestone(s)

Determined the returns needed to induce farmers to convert to switchgrass. This is the first step to estimate the price-supply curves.

Major Accomplishments

Economic model to motivate land use conversion has been developed and demonstrated at ASCENT and CAAFI meetings

Publications

NA

Outreach Efforts

NA

Awards

NA

Student Involvement

One graduate student is a major contributor to this project, drafting both the literature review, and the coding to estimate our model.

Plans for Next Period

Future work will use these boundaries to determine the price-supply curves for perennial grasses and winter cover crops.

References

See Task 8.1

Task 3.3

Penn State and Washington State

Objective(s)

Evaluate commercial options for biofuel intermediates insertion into petroleum refineries for conversion to AJF.

Research Approach

Using an extensive literature review, PSU identified and evaluated commercial biomass feedstocks and bio-based intermediates that could be inserted in a refinery or be converted to alternative jet fuel with minimal processing. The evaluation considered bio-based liquids at three insertion points: 1) “bio-crude” introduced at the front of the refinery for crude processing with petroleum, 2) refinery-ready liquids inserted after crude processing and utilizing conversion and/or finishing unit operations to upgrade the bio-based liquids into fuels, and 3) blend-ready fuels that are inserted during blending to upgrade low-value refinery streams, improve specifications, and take advantage of blending, storage and distribution capacity. Unit operations and process opportunities and constraints were assessed for a range of bio-based liquids relevant to alternative jet fuels.

Milestone(s)

A draft of the first literature report was completed in July 2015 and shared with Delta Airlines in October 2015. The report was posted in 2016 for the group. Currently we are working on report focused on oxygen removal of bio-based fuels and intermediates.

Major Accomplishments

The accomplishments of this task (Task 3.3) will provide the project and stakeholders with a clearer understanding of the options, pros and cons of integrating bio-based feedstocks in a conventional petroleum refinery. Our hope is that Delta will implement one or more of these options for a demonstration at their refinery. This report is the basis for the project work in the coming year. Oxygen in biomass intermediates may discourage petroleum-refining facilities from pursuing the use of intermediates, so how to remove the oxygen is critical. We are working on a literature review of how to remove oxygen using conventional processes and catalysts as well as suggesting alternative catalysts.

Publications

A Technical Report was developed for discussion with Delta Airlines. We have written a publication on this material that will be submitted in the next couple of months.

Outreach Efforts

Results and recommendations from the Literature Review were communicated to Delta Airlines in October 2015. We have also initiated discussions with Rich Altman of the Commercial Aviation Alternative Fuels Initiative (CAAFI) and the Farm to Fly 2 (F2F2) program. Rich is working with the University of Virginia on distribution systems of alternative fuels to airports in the greater Washington DC area. We had an introductory teleconference with that group in September 2015 had a face-to-face meeting with that group in Virginia in October 2015. We are currently working on a publication to submit in early 2017 to the journal Energy and Fuels.

Awards

NA

Student Involvement

NA

Plans for Next Period

Delta Airlines has not been involved with the AJF aspect in the last year. In recent conversations with Delta, we have learned that Delta is involved again; further discussions with Delta will continue.

References

See technical report.

Task 7.1

Penn State and Washington State and ORNL

Objective(s)

Update Data Management Plan and provide status report.

Research Approach

The primary goal of this task is to develop a common framework that facilitates transparent and open data access for supply chain model intercomparison and improvement, specifically targeting the needs and opportunities of the AJF sector. This effort requires coordination of all team members, many of whom have independent models and datasets, some of which are proprietary. The team will develop a consensus approach to data use and model access and then establish appropriate agreements and documentation. The participating DOE labs have extensive experience with this activity in other applications, including with Dr. Richard and other university team members working on regional biofuel projects funded by DOE and USDA. Expanding these efforts to include alternative aviation fuel supply chains will allow intercomparison and improvement of supply chain models and increase the confidence of the aviation sector in model predictions.

Milestone(s)
Our goal this year was to have multi-institutional participation in the data management system. That milestone was exceeded, although not all PIs are participating.

Major Accomplishments
Several actions toward implementation of the Data Management plan have been accomplished. PIs and students working on the project have reviewed signed the Data Use Agreement document and the Data Use Acknowledgement document, file naming conventions and meta data documentation have been developed, and over 2200 files have been uploaded into the system. Most of these files are journal articles, but 70 of the files are datasets that have been classified and logged in our Common Data needs document for internal data sharing and eventual public release.

Publications
None

Outreach Efforts
NA

Awards
NA

Student Involvement
NA

Plans for Next Period
Continue to encourage participation.

Task 8.1
Penn State

Objective(s)
Analysis of Ecosystem service valuation and policy design of water quality improvements associated with perennial grasses and cover crops. Includes subtasks 8.1.1 (Literature review) and 8.1.2 (Report analyzing Chesapeake Bay opportunities as a co-product market opportunity.

Research Approach

We develop a land use conversion contract model following the general land conversion model by (Song, Zhao, & Swinton, 2011), while also incorporating subsidies in the form of payments for ecosystem services and incentive compatibility constraints. Specifically, we expand the model by considering that the potential payoff for farmers who choose to initiate land use conversion and adopt biofuel crops consists of not only the monetary values of crop outputs, but also a one-time lump-sum payment and subsidies that are depended on the consequential environmental benefits. The one-time lump-sum welfare transfer (denoted as T_{cs}) includes monetary compensation as well as technological assistance from government agencies to offset any fixed costs that farmers might incur if they convert their cropland from a corn-soybean rotation (denoted as *c*) to biofuel crops such as switchgrass (denoted as *s*). For simplicity, consider that $\{c, s\}$ is the only set of crop choices for a risk-neutral farmer with a unit of cropland, and any one-time land use conversion from *i* to *j* would incur a lump-sum cost $C_{ij}, i, j \in \{c, s\}$. Hence, it is necessary that $T_{cs} \geq C_{cs}$ holds for any conversion from *c* to *s* in order for farmers to participate.

The farmer's payoff consisted of two components. First, the monetary values of crop *i* outputs in period *t* is denoted by $\pi_i(t)$ which follows a stochastic process with evolution of a general form (Song et al., 2011), as follows:

(1) $$d\pi_i(t) = \theta_i(\pi_i, t)dt + \sigma_i(\pi_i, t)d\varepsilon_i,\ i \in \{c, s\}$$

where the drift term $\theta_i(\pi_i, t)$and variance $\sigma_i(\pi_i, t)$ are observable nonrandom functions, and $d\varepsilon_i$ is the increment of a Wiener process[1] which assumes that farmers would be able to learn about and predict future returns in each new period based on information updated in previous period. The correlation coefficient between *c* and *s* is denoted as ρ, such that $\mathrm{E}[d\varepsilon_c d\varepsilon_s] = \rho dt$. Farmers' expected present value payoff from crop returns on land use *i* at period *t* is denoted $V^i(\pi_c(t), \pi_s(t))$, which depends on the distribution of future returns of both land uses and farmers make decisions between keeping land use *i* or convert it into alternative *j* (Song et al., 2011), as:

(2) $$V^i(\pi_c(t), \pi_s(t)) = max \begin{Bmatrix} \pi_i(t)dt + e^{-rdt}EV^i[\pi_c(t+dt) \times \pi_s(t+dt)], \\ V^j(\pi_c(t), \pi_s(t)) - C_{ij} \end{Bmatrix}$$

Second, farmers who agree to convert land use from corn-soybean to switchgrass (thus a $c \rightarrow s$ process) can receive, by the end of each period *t* of this particular conversion process, a subsidy from government agencies based on the generated environmental values. Switchgrass and many other biofuels have the potential to provide a variety of environmental benefits such as soil nitrogen sequestration, water nutrient reduction, and biodiversity conservation. These benefits, although often not traded with market values, can be utilized by government agencies and regulators as a part of the efforts on environmental protection and ecosystem restoration. For simplicity, we denote the environmental performance level of land use alternative *i* as a stochastically continuous and twice differentiable function $\phi_i(e_t), i \in \{c, s\}$, such that:

$$\frac{d\phi_s(e_t)}{dt} > 0, \qquad \frac{d^2\phi_s(e_t)}{dt^2} \leq 0$$
$$\frac{d\phi_c(e_t)}{dt} \leq 0, \qquad \frac{d^2\phi_c(e_t)}{dt^2} \leq 0$$

This restriction allows us to differentiate the environmental performance of the two land uses so that switchgrass would generate increasing environmental benefits, while corn would generate limited (but not necessarily negative) environmental benefits.

Suppose that $\phi_i(e_t)$ is observable to government agencies at the end of period *t*, and a subsidy is paid to farmers based on the perceived environmental performance level. Without loss of generality, we define a subsidy rate, m, as a per unit compensation rate paid to farmers according to the perceived environmental performance level at the end of period t. Hence, the total subsidies paid to farmers in each possible land use scenario in period *t* are as follows:

(3-1) grow corn in period $t-1$, and convert land use to switchgrass in period t:

$$-C_{cs} + T_{cs} + m\phi_s(e_t) = m\phi_s(e_t), \text{ since } T_{cs} = C_{cs}$$

(3-2) grow switchgrass in period $t-1$ and period t:

$$m\phi_s(e_t)$$

(3-3) grow corn in period $t-1$ and period t:

$$m\phi_c(e_t)$$

(3-4) grow switchgrass in period $t-1$, and convert land use to corn in period t:

$$-C_{sc} + m\phi_c(e_t)$$

Since we assume that $\phi_s(e_t)$ is increasing over time, it is necessary that the total subsidy paid to farmers of land use type *s* by government at the end of each period *t* is strictly higher than farmers of land use type *c*.

Hence, the optimal land use decision problem in Equation (2), for value functions V^i and $V^j, i, j \in \{c, s\}$, must satisfy the following conditions along with the IC and IR constraints:

[1] The Wiener pdf is $f_{W_t}(x) = \frac{1}{\sqrt{2\pi t}}\exp(-\frac{x^2}{2t})$, following normal distribution with zero mean and variance *t* at any fixed period *t*. The covariance between any *s* and *t* is $cov(W_s, W_t) = \min(s, t)$, and $corr(W_s, W_t) = \sqrt{\frac{\min(s,t)}{\max(s,t)}}$.

(4-1) $$LV^i(\pi_c(\mathrm{t}),\pi_s(\mathrm{t})) \geq 0, i,j \in \{c,s\}$$

where $LV^i(\pi_c(\mathrm{t}),\pi_s(\mathrm{t}))$ is the second order Taylor expansion of $V^i(\pi_c(\mathrm{t}),\pi_s(\mathrm{t}))$ by applying Ito's lemma, as:

$$LV^i(\pi_c(\mathrm{t}),\pi_s(\mathrm{t})) = \mathrm{r}V^i(\pi_c,\pi_s) - \pi_i(\mathrm{t}) - \sum_{p=c,s}\alpha_p(\pi_p,\mathrm{t})\frac{\partial V^i}{\partial \pi_p} - \sum_{p=c,s}\frac{\sigma_p^2(\pi_p,\mathrm{t})}{2}\frac{\partial^2 V^i}{\partial \pi_p \partial \pi_p}$$

$$-\rho\sigma_c(\pi_c,\mathrm{t})\sigma_s(\pi_s,\mathrm{t})\frac{\partial^2 V^i}{\partial \pi_c \partial \pi_s}$$

(4-2) $$V^i(\pi_c,\pi_s) \geq V^j(\pi_c,\pi_s) - C_{ij}, i,j \in \{c,s\}\ and\ i \neq j$$

(4-3) Either (4-1) or (4-2) holds with strict equality.

Parameter Calibration and Estimation

The model can be parameterized and solved by collocation using OSSOLVER (Fackler, 2008) and estimated with CompEcon package in Matlab (Miranda & Fackler, 2002). Value functions can be approximated using a linearized combination of a sequence of known basis functions, such as:

(5) $$\widetilde{V^i}(\pi_c,\pi_s) = \sum_{j_c=1}^{n_c}\sum_{j_s=1}^{n_s} c_{j_c j_s}\,\psi_{j_c j_s}(\pi_c,\pi_s)$$

where $c_{j_c j_s}$ is obtained when the decision optimality conditions are satisfied. The optimal decision rule is determined by solving and evaluating the approximated value functions at $\{c,s\}$ as well as the return minus the conversion costs, and based on the results the best payoffs from converting are then compared with the best payoffs from not converting (Fackler, 2008).

The empirical method involves solving the parameters in the return equation and calibrating parameters in the value functions. Return from land use is assumed to follow stochastic processes, with unknown parameters including the drift term θ_i, variance σ_i and correlation between the two alternatives ρ, which can be re-parameterized by linearization approximation. Two stochastic processes are often used. If return follows geometric Brownian motion (GBM), the analytical representation is as follows:

(6) $$d\pi_i = \theta_i\pi_i dt + \sigma_i\pi_i d\varepsilon_i,\ i \in \{c,s\}$$

Discrete approximation of the inter-temporal return difference gives:

(7) $$\ln \pi_{i,t} - \ln \pi_{i,t-1} = \left(\theta_i - \frac{{\sigma_i}^2}{2}\right) + \sigma_i\varepsilon_i,\ i \in \{c,s\}$$

Denote $\alpha_i = \theta_i - \frac{{\sigma_i}^2}{2}$, then α_i, σ_i and ρ can be estimated by maximum likelihood estimates.

If the returns follow mean reversion (MR), the analytical representation is as follows:

(8) $$d\pi_i = \theta_i(\widetilde{\pi_i} - \pi_i)dt + \sigma_i\pi_i d\varepsilon_i,\ i \in \{c,s\}$$

where $\widetilde{\pi_i}$ is the historically observed average return of land use *i*, and θ_i here measures speed of reversion. Discrete approximation of the inter-temporal return difference gives:

(9) $$\frac{\pi_{i,t}-\pi_{i,t-1}}{\pi_{i,t-1}} = \theta_i(\widetilde{\pi_i} - \pi_{i,t-1}) + \sigma_i\varepsilon_i$$
$$= \theta_i\widetilde{\pi_i} - \theta_i\pi_{i,t-1} + \sigma_i\varepsilon_i, \qquad i \in \{c,s\}$$

Denote $\beta_{1i} = \theta_i\widetilde{\pi_i}$, $\beta_{2i} = -\theta_i$, , then β_{1i}, β_{2i}, σ_i and ρ can be estimated.

Parameters

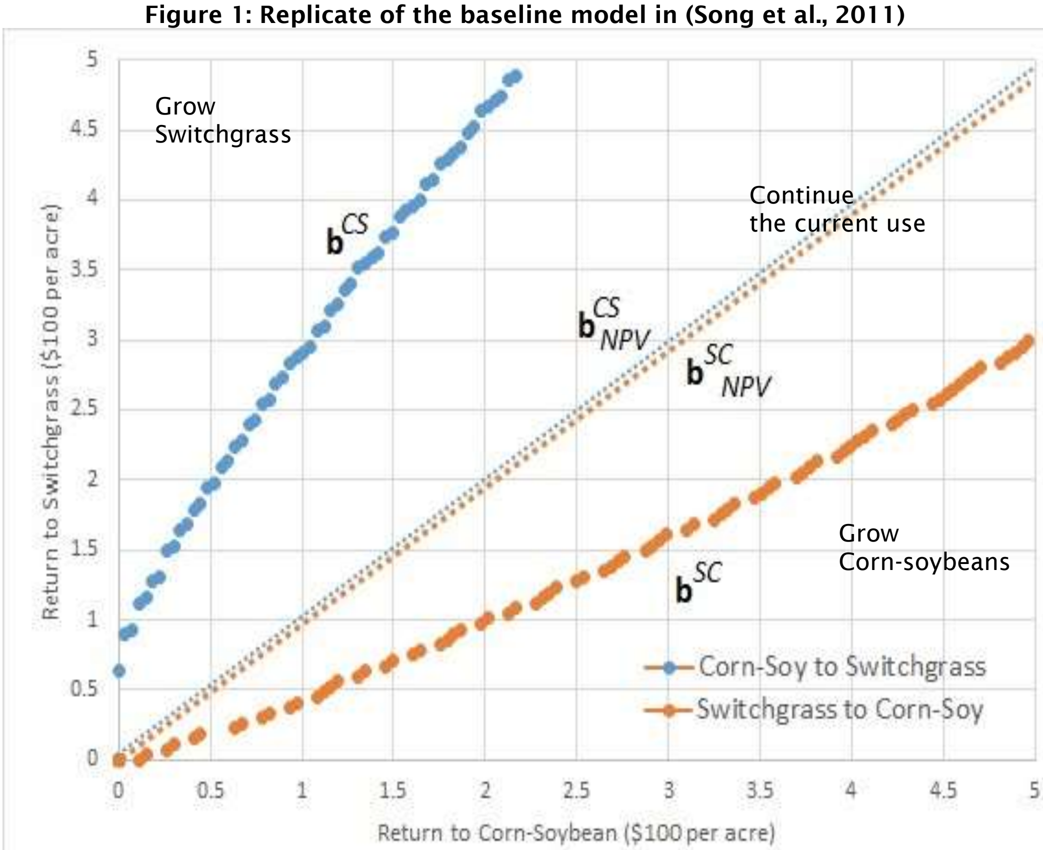
Table 1: Parameter assumptions

			Source
Corn-soybean returns	$229/acre		(Song et al., 2011)
Switchgrass returns (approximation, calculated from data below)	$423/acre		(Song et al., 2011)
Switchgrass yield mean	5.35 tons/acre		(Duffy & Nanhou, 2002)
Switchgrass yield variance	0.20 tons/acre		
Maintenance costs year 2-10	$192/acre		
Transportation costs	$8/ton		(Babcock, Gassman, Jha, & Kling, 2007)
Ethanol yields from one ton of switchgrass	79 gallons		(Schmer, Vogel, Mitchell, & Perrin, 2008)
Ethanol price	$1.46/gallon		NE Govt. 2016 (http://www.neo.ne.gov/statshtml/66.html)
Ethanol conversion costs	$0.91/gallon		(DiPardo, 2000)
Price subsidy for switchgrass from USDA (one time subsidy)	$45/ton		(Song et al., 2011)
	Corn-soybean	Switchgrass	
Drift ($\hat{\theta}_i$)	0.018	0.026	
Variance ($\hat{\sigma}_i$)	0.198	0.294	
Correlation ($\hat{\rho}$)	-0.098		
Conversion costs ($100 per acre)			
Corn-soybean to switchgrass	Switchgrass to corn-soybean		
1.36	0.47		(Song et al., 2011)
Discount factor	0.08		(Song et al., 2011)
Subsidies to environmental benefits ($\$m$ per unit ϕ_i)			
To corn-soybean	To switchgrass		
$0	$100/acre		(Woodbury, Kemanian, Jacobson, & Langholtz, n.d.)

Preliminary Results

The preliminary results[2] are presented as conversion boundaries. If a farmer is growing corn-soybeans they will convert to growing switchgrass when annual returns to switchgrass are above the line b^{CS}. If a farmer is growing switchgrass they will convert to growing corn-soybeans when annual returns to corn-soybeans are greater than the line b^{SC}. Because of uncertainty, risk, and the option value (the value of continuing the current use and having the option of converting crops in the future when it is more profitable to do so) the annual returns to switchgrass have to be higher than the net present value (b_{NPV}^{CS}) of the annual returns to switchgrass to induce conversion.

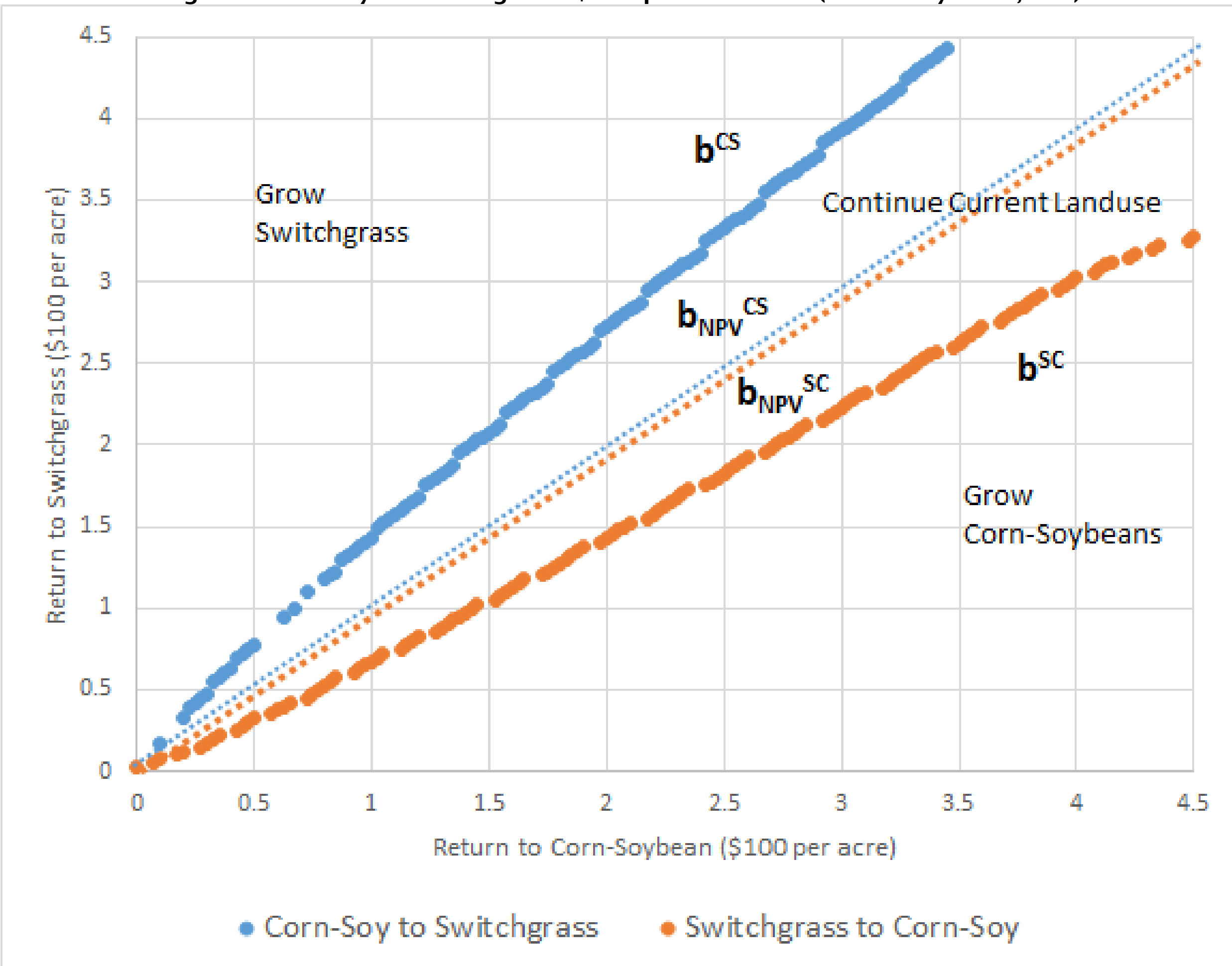
Figure 1: Replicate of the baseline model in (Song et al., 2011)



First, we replicated the baseline model in (Song et al., 2011). The optimality condition for conversion decisions are solved using Compecon toolbox (Miranda & Fackler, 2002) in MATLAB. The nodal points for the state variables (returns to corn-soybean and switchgrass, respectively) are evenly scattered over a revenue interval [0, 5] in hundred dollars ($100) in $1982. The output diagram shows the two boundaries in solid lines for conversions from corn-soybean to switchgrass (b^{cs}) and from switchgrass to corn-soybean (b^{sc}).

[2] These results are preliminary so please do not cite.

Figure 2: Subsidy to Switchgrass: $100 per acre from (Woodbury et al., n.d.)



In this modification, we applied a subsidy of $100 per acre to farmers if the crops are converted from corn-soybean to switchgrass.

Converting all units to 2016$, without a government subsidy if farmers can earn $230/acre per year with a corn-soybean rotation and $337/acre per year with switchgrass, then they will not convert to switchgrass unless they can earn more than $512/acre per year. Uncertainty, risk, and the option value to convert in the future increase the minimum return from switchgrass needed to induce farmers to convert to switchgrass. With a $100/acre per year payment for ecosystem services (PES) subsidy, farmers would only need $399/acre per year returns to convert their land to switchgrass. Therefore, farmers do need more than the real annual returns to incentivize them to grow switchgrass but a $100/acre subsidy for ecosystem services reduces the uncertainty and risk and therefore reduces the returns need to convert by more than $100/acre.

Table 2: The real annual returns (Song et al. 2011) vs. the dynamically optimal conversion boundary

Subsidy to grow switchgrass	Real annual returns for corn-soybeans	Minimum return from switchgrass needed to convert from corn-soybean to switchgrass
$0/acre	$229/acre	$498/acre ($103/Mg, $5.74/GJ, $0.76/gallon)

$100/acre	$229/acre	$308/acre ($63/Mg, $3.55/GJ. $0.47/gallon)

Milestone(s)

A draft of a review of the ecosystem benefits of perennial grasses and winter cover crops (water quality improvements, soil improvements, and biodiversity improvements) has been started. A draft of a manuscript to estimate the effects of payments for ecosystem services (PES) subsidies on the willingness to convert to biomass has been started.

Publications

None

Outreach Efforts

NA

Awards

NA

Student Involvement

One graduate student is a major contributor to this project, drafting both the literature review, and the coding to estimate our model.

Plans for Next Period

The plans for next period include: (1) working with a law student or staff member to complete a law and policy review of optimal payments for the ecosystem services provided by biomass crops, (2) updating the assumptions of biomass yields and prices, (3) comparing other types of land use instead of corn-soybeans to include marginal lands, (4) collect data at a finer scale to be able to use the estimated conversion boundaries to simulate land conversion decisions and thus the supply of biomass.

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