FINANCIAL MODELING OF SHORT ROTATION POPLAR PLANTATIONS IN MICHIGAN, USA

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ABSTRACT

Hybrid poplars (*Populus* spp.) are prime fiber and biomass producing crops around the world. Varietal adaptability varies from place to place and varieties exhibit differing growth trajectories under various cultural regimes. Ultimately, growers need to know *what* to grow and *how* to grow it, but most importantly they want to know if they will make money with this new short-rotation biomass crop. Genetics and cultural trials of various poplar varieties have been underway in Michigan for the past 25 years. We can now suggest optimal silvicultural systems to use and have experience with the performance of numerous varieties on multiple sites. Here a financial model is presented that projects the break-even farm-gate price for poplar biomass chips in Michigan. Users can modify the cost and yield inputs and vary rotation lengths used in the model to examine the financial consequences. Base values for all these parameters are supplied from field experience at Michigan State University's Forest Biomass Innovation Center.

In the base-case scenario modeled here, a fast growing, widely adapted *P. nigra* X *P. maximowiczii* variety (NM6) was projected to produce about 20 dry short tons/acre in six years at a break-even farm-gate price of $54/dry short ton. In this scenario where all work was done on a contract basis, production costs included 39% for establishment, 38% for harvesting, 16% return to the landowner, and 7% for system management.

Sensitivity analysis confirmed that break-even price is linearly sensitive to changes in costs. Establishment and harvesting costs have a greater effect than land rent or management costs because they represent a larger proportion of the total. Changes in yield have a non-linear effect on break-even price because establishment, management, and land rent costs are independent of yield. A 50% *increase* in yield produces a 20% decrease in break-even price but *reducing* yield by 50% results in a 60% increase in break-even price. Lost yield can easily happen through a combination of bad genetics, poor silviculture, disease, phytophagy, bad weather, or just bad luck. Yield reduction is the easiest way to lose money growing biomass, just like it is in agriculture. This uninsurable risk is one of the biggest barriers to commercialization of poplar biomass systems.

INTRODUCTION

Producing poplar (*Populus*) in Short Rotation Energy (SRE) plantations has become a viable method for augmenting the biomass feedstock demand of the emerging renewable energy industry around the world (Perlack and Stokes, 2011; Isebrands and Richardson, 2014). Poplar produced in SRE plantations can be combusted for the production of heat and power or upgraded to liquids or gases for transportation fuels and chemical production (Sannigrahi, *et. al.*, 2010). Biomass like poplar is the only source of *renewable* carbon on the planet and so will be a vital feedstock in replacing the fossil carbon on which we now so heavily depend.

SRE plantations require a different type of forest management (silviculture) than that traditionally employed by foresters. Traditional silviculture is optimized for the production of large trees on long cutting cycles (rotations). Although the underlying fundamentals remain constant, this new SRE plantation silviculture must account for unfamiliar varieties (taxa), short rotations, new landowner expectations, and be optimized for the rapid production of biomass – a low-value forest product. In order for growers to consider producing this energy crop, it is vital that they understand the financial costs and returns associated with this new silvicultural system.

The feasibility of producing biomass in SRE Plantations will depend largely on financial factors. Growers will not produce, and consumers will not buy biomass if they do not stand to make money. We developed a simple financial spreadsheet model to estimate the break-even cost of biomass production and to examine this cost’s sensitivity to changes in various factors within the model.

METHODS

A financial cost model was constructed using an Excel spreadsheet (Figure 1). Unit operation costs and crop yields can be varied. Costs and yields can also be proportionally increased or decreased to conduct sensitivity analysis.

Any attempt to model the finances of biomass production requires that numerous assumptions of costs and yields be made. The first assumption made here was that biomass will be produced on a contract basis. That is, the land will be rented and services (including site preparation, planting, management, and harvesting) will be provided by independent contractors. Thus, the profit for each participant in the production system (the landowner, the manager, and the logger) is included in the cost associated with each activity. In this way, this model attempts to predict the value of biomass at the farm-gate that would justify and incentivize its production. This is called the “*break-even*” cost here.

All costs are expressed in United States Dollars using 2014 as the base year. Weights and areas are expressed in English units because this model was intended for use in the United States.

Future costs are inflated by a user-defined discount rate (5% per annum was used here). Break-even costs are discounted to 2014 dollars using the same discount rate. When modeling costs in this way, the value of the discount rate is immaterial since costs are inflated forward and the break-even cost is discounted backward at the same annual rate. Trends discussed later in this paper are independent of the units associated with model inputs or outputs.

Cost and yield assumptions used here were derived from the experience gained and the data collected at Michigan State University's Forest Biomass Innovation Center (FBIC) in Escanaba, Michigan, USA during the past 25 years. Any user of the model is free to choose their own cost and yield figures, but the values used in the base case scenario modeled here are explained below.

MODEL ASSUMPTIONS

Rotation Length and Planting Density Assumptions:

This model is built to generate break-even farm-gate costs for hybrid poplars at rotation lengths ranging from 4 years to 10 years. It was assumed that while it is possible to grow poplar in high-density, micro-rotation systems, where 7,300 stems/acre are harvested every 3 years (Miller & Bender, 2014), that it will be more likely that lower-density, short-rotation systems will be deployed in Michigan. Here we assume a planting density of 777 trees/acre and that trees will be too small to harvest until at least the fourth year, and that harvesting will take place before the tenth year (Miller & Bender, 2016).

Plantation Establishment Assumptions:

- Site preparation begins in the year before planting with one application of a "burn-down" herbicide in the summer and one mechanical cultivation in the fall. A second cultivation is performed immediately prior to spring planting in the second year. Each cultivation event was assigned a cost of **$20/acre** and the herbicide application was assigned a cost of **$6/acre** for equipment and operator plus the **$7/acre** cost of the chemicals. These costs were based on actual herbicide prices and published standard agricultural machine rates (MSU Extension, 2013).
- Plantation Establishment. Planting density was modeled assuming 777 cuttings per acre. Cutting costs were assumed to be **12¢ each** (Hramor Nursery advertised cost) and hand planting costs were assumed to be **5¢ per cutting** (a rate paid locally for the contract-planting of forest seedlings).
- Weed control. Post-planting weed control consisted of one spring "pre-emergence" herbicide application (**$6/acre** for equipment and operator plus **$75/acre** chemical costs) and two mechanical cultivations in summer (**$20/acre**) in the first and one mid-season cultivation in the second growing season. These costs are the same as in #1 above.

Annual Plantation Management Assumptions:

- <u>Professional Management.</u> It was assumed that a plantation management company would oversee the entire project (from site preparation through harvesting) for an annual fee of **$10/acre**. This service is not commercially available today so this rate was chosen arbitrarily. A management company charging this rate could expect to receive gross revenues of approximately $360,000 if managing enough land to supply all the biomass needed by a 25 MW power plant[1]. This may be overly generous, but provides a conservative figure for modeling.
- <u>Land Rent.</u> Annual land rent was assumed to be **$25/acre**. For comparison, FBIC actually rents university land to agricultural producers in Delta County, Michigan for $14/acre and holds a 10-year lease for privately-owned agricultural land in Onaway County, Michigan for $20/acre. Forest landowners often receive "stumpage" payments at the time of harvest rather than land rent. If they received rent payments of $250 during one 10-year rotation ($25/acre X 10 years), and if the harvest yielded 35 dry tons/acre (3.5 dry tons/a-yr X 10 years) this would be the equivalent of a stumpage rate of $7/dry ton. Michigan State University recently received stumpage rates of $4/dry ton for hybrid poplar trees and Michigan Technological University received $5/dry ton for Jack pine trees that were made into fuel chips. The $25/acre value for land rent chosen for the model's base case is therefore quite generous.

Harvesting Cost Assumptions:

1. <u>Harvesting.</u> Contracted harvesting was assumed to cost **$21/dry ton**. Srivastava, *et. al.* (2011) estimated that energy plantation harvesting costs in Michigan could range from $14.81 to $25.72/dry ton (average $20.26/dry ton) depending on assumptions applied in either the EcoWillow model (developed at the State University of New York by Buchholz, *et. al.* 2010) or a poplar plantation cost model developed by Oak Ridge National Laboratory. Srivastava also modified the Fuel Reduction Cost Simulator model developed by Dykstra *et. al.* (2009) to provide an estimate of biomass harvesting costs in Michigan's natural forests. Using actual time-and-motion observations of biomass harvesting operations and a survey of the state's loggers, they arrived at natural forest harvesting cost estimates that ranged from a low of $13.50/dry ton to a high of $31.00/dry ton (average $22.25/dry ton). We chose to use $21/dry ton, a cost that represents the average modeled overall value for Michigan's natural forests and energy plantations. In contrast, Berguson, *et. al.* (2010) chose to use a harvesting cost of $25/dry ton when he modeled Minnesota poplar SRE Plantations.

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[1] Revenue calculations assume: a 25 MW power plant would consume 125,000 dry tons of biomass per year. If annual productivity was comparable to that experienced here (3.5 dry tons/acre-year), approximately 36,000 acres of SRE Plantations would be needed to supply such a plant.

2. Transportation. In an attempt to estimate Mill Gate prices, this model adds $15/dry ton to the FARM GATE prices calculated elsewhere. This figure assumes transportation of chips up to 50 miles from the farm to the mill (Berguson, *et. al.*, 2010).

Yield Assumptions:

Biomass growth was determined using data from three replicated large-plot yield studies at the FBIC. All three trials were established using similar protocols and on similar sites, within ½-mile of each other. One trial was established in 1998 (Miller, 2004) another in 2008 (Miller & Bender, 2016) and the third in 2009 (Miller, 2016b). Each had several poplar varieties planted in replicated 64-tree plots. Diameter at breast height measurements were made annually beginning in the third year of each test. Diameters taken in years 3 through 7 were used to compute standing-tree biomass using an algorithm developed at FBIC (Miller, 2016a). Plot total biomass weights were converted to an areal biomass yield in oven-dry short tons per acre. A faster growing variety (NM6) and a slower growing variety (NE222) were selected for modeling. Regression equations were developed to predict biomass yield from plantation age. Estimates of NM6 and NE222 average performance across all three tests were developed. Estimates of an optimistic NM6 and pessimistic NE222 yield were also made (Table 1).

TABLE 1: Yield Calculations Used in financial model of poplar biomass production in Michigan.
NM6 represents a fairly good grower and NE222 represents a slow grower. The average projections are based on three replicated trials at Escanaba, Michigan (established in 1998, 2008, and 2009). The optimistic and pessimistic projections are made from the single trial established in 2008. (biomass predictor equations for each scenario are shown)

Growing Season	**Average NM6**	**Average NE222**	**Optimistic NM6**	**Pessimistic NE222**
	biomass=33.928-(87.087/year)	**biomass=22.270-(64.789/yr)**	**biomass=37.295-(90.218/year)**	**biomass=19.329-(53.957/yr)**
	Standing Biomass (dry tons/acre)	*Standing Biomass (dry tons/acre)*	*Standing Biomass (dry tons/acre)*	*Standing Biomass (dry tons/acre)*
	NM6ave	*NE222ave*	*NM6fast*	*NE222slow*
4	12.16	6.07	14.74	5.83
5	16.51	9.31	19.25	8.53
6	19.41	11.47	22.26	10.33
7	21.49	13.01	24.41	11.61
8	23.04	14.17	26.02	12.58
9	24.25	15.07	27.27	13.32
10	25.22	15.79	28.27	13.92

ANALYSIS USING THE MODEL

Break-even farm gate price curves were constructed for each yield scenario in Table 1. This was done by holding all costs in the model constant at the assumed levels described above and allowing the plantation to grow at the rates described in Table 1 (Figure 2). The assumed costs and the average yield of NM6 were used to establish a reasonable expectation for break-even farm gate prices of poplar in Michigan and to examine the distribution of costs within the system (Table 2). A sensitivity analysis was performed by varying one cost at a time within the model. Similarly break-even cost sensitivity to yield was modeled by holding costs constant and allowing yield to change (Figure 3).

RESULTS AND DISCUSSION

Break-even Price Trends:

Break-even farm gate price for poplar is highly dependent on the variety being grown and on the rotation length. Faster growing varieties like NM6 tend to reach financial maturity by age 6 while slower growing varieties like NE222 don't reach that point for at least 8 years (Figure 2). Biomass from faster growers can be produced for between $50 and $55 per dry ton while slower growers require break-even prices between $72 and $80 per dry ton to be feasible. Conservative assumptions lead to an expected break-even farm gate price of $55 per dry ton or an expected mill gate price of approximately $70 per dry ton. That is the equivalent of about $35 per green ton and is comparable to delivered pulpwood prices in the Lake States and on par with biomass prices being paid in New England in the United States today.

Partitioning of Costs:

The cost of production falls into three general categories (Table 2). The cost of plantation establishment represents about 39% of total costs and is fixed and independent of rotation length or harvested yield. Annual payments to landowners and plantation managers represent about 23% of total costs and are also unrelated to harvested yield but do depend on rotation length. Harvesting represents about 38% of the total cost. In this model it is completely dependent on the amount of biomass at the end of the rotation because harvesting costs are calculated on a per-ton basis rather than a per-acre basis. The difference in the nature of these costs becomes apparent when examining the sensitivity of break-even prices to changes in various model inputs.

Table 2: Distribution of hybrid poplar biomass production costs within the modeled scenario for NM6 under base-case assumptions and average yield values (Table 1).

Activity	*Cost/acre*	*Proportion of total*
Establishment	$ 566	39%
Land	$ 234	16%
Management	$ 94	7%
Harvesting	$ 546	38%
TOTAL	$ 1,440	

Sensitivity to Costs:
Break-even farm gate biomass prices respond linearly to input cost changes. Harvesting and establishment costs have the greatest impact since they represent large proportions of total costs. A 25% change in either of those costs causes a 10% change in the break-even price. A 50% change in either of those costs causes a 20% change in the break-even price. Annual payments for rent and management have a similar albeit smaller impact (Figure 3).

Establishment and harvesting costs can be reduced through conscientious application of best silvicultural practices and continued improvements informed by new research and equipment development. These costs can also be shifted using subsidies, or other similar mechanisms, to great effect. For example, the break-even cost of 6-year-old NM6 biomass can be lowered to about $41 per dry ton by subsidizing half of the establishment costs, or to $32 per dry ton if establishment costs are fully subsidized.

Sensitivity to Yield:
Changes in biomass yield have a distinctly non-linear and strong impact on break-even farm gate prices (Figure 3). A 25% increase in biomass yield drives the break-even cost down by 12%, or about $6 per dry ton. Biomass yield can be increased by employing improved cultural practices and new elite genetic varieties. Both improvements rely on sustained and lengthy research and development projects. While these improvements are under development, subsidies can provide growers and purchasers with similar cost benefits, thus incentivizing adoption of this otherwise risky production system. A 30% subsidy of establishment costs produces a similar $6 per dry ton reduction in break-even costs. Subsidies like that could be reduced gradually as new systems and varieties are developed and commercially adopted.

Yield increases drive the cost of biomass down but yield losses result in a dramatic and non-linear increase in break-even biomass price. Recall that a 25% *increase* in yield *lowers* break-even price by 12%. A 25% *loss* in yield *increases* break-even biomass price by 20%. A 50% reduction in yield increases break-even price by 61% and a 75% yield reduction raises break-even price by a bank-breaking 176% (Figure 3)! This happens because total system cost falls into two distinct categories; *fixed* and *variable*. Establishment, management, and land costs are fixed and independent of yield. 62% of total costs in the base-case are *fixed* (Table 2). Harvesting costs in the base case represent 38% of the total but depend on the amount of biomass produced and so are *variable*. As biomass yield decreases, fixed costs become a greater and greater share of the total so the production cost of each remaining ton of biomass increases non-linearly.

Clever genetic, engineering, and management tricks to decrease break-even costs can quickly be overwhelmed by the factors that reduce yield. The easiest thing a grower can do is to plant the wrong clone on the wrong site, to employ poor silvicultural practices, or to simply have bad luck with the weather; all of which result in poor yield. So, it takes a great effort to increase yield while it takes no effort at all to decrease yield. In other words, a savvy and lucky grower can make money growing biomass but *any fool can lose money*. In fact, the less effort one applies the more money one can lose. Any plan to subsidize or otherwise support biomass growers should take this into account and ensure that growers have adequate technical support and that only the best available planting stock and production systems are employed. Only in this way can both the grower and the agency offering the support benefit from these programs.

LITERATURE

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Figure 1: Break-even analysis of hybrid poplar production in a short-rtation, medium-density system.

Values shown here use base-case assumptions and average yield projects from several field trials of NM6 conducted in Upper Michigan (Table 1).

Discount rate	*5%*												
Activity	Price (2014 dollars)	Unit	*Calendar Year within project*										
			2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
			site preparation	plant	Tend	Idle	1st possible harvest	Subsequent years in which harvesting may occur					
Number of Interest Periods or Growing Seasons			0	1	2	3	4	5	6	7	8	9	10
Establishment Costs													
Pre-plant Herbicide Chemical	$ 7.00	$/acre	$ 7.00										
Herbicide Application	$ 6.00	$/acre	$ 6.00										
Pre-plant Tilliage	$ 20.00	$/acre	$ 20.00	$ 21.00									
Plantation Layout	$ 15.00	$/acre		$ 15.75									
Post-plant Herbicide Chemical	$ 75.00	$/acre		$ 78.75	$ 82.69								
Herbicide Application	$ 6.00	$/acre		$ 6.30	$ 6.62								
Post-plant Tilliage	$ 20.00	$/acre		$ 42.00	$ 22.05								
Planting Stock	$ 0.12	$/cutting		$ 97.90									
Planting Labor	$ 0.05	$/cutting		$ 40.79									
Sub-Total Establishment Costs		$/acre	$ 33.00	$ 302.49	$ 111.35								
Adjusted Establishment Cost for sensitivity	100%	% of base cost	$ 33.00	$ 302.49	$ 111.35								
Establishment subsidy	0%	% of full cost/a	$ -	$ -	$ -								
Recurring Operating Costs													
Land Rent	$ 25.00	$/acre	$ 25.00	$ 26.25	$ 27.56	$ 28.94	$ 30.39	$ 31.91	$ 33.50	$ 35.18	$ 36.94	$ 38.78	$ 40.72
Plantation Management	$ 10.00	$/acre	$ 10.00	$ 10.50	$ 11.03	$ 11.58	$ 12.16	$ 12.76	$ 13.40	$ 14.07	$ 14.77	$ 15.51	$ 16.29
COST SUMMARY													
Annual Expenses		$/acre	$ 68.00	$ 339.24	$ 149.94	$ 40.52	$ 42.54	$ 44.67	$ 46.90	$ 49.25	$ 51.71	$ 54.30	$ 57.01
Accumulating Future Value of Costs		$/acre	$ 68.00	$ 410.64	$ 581.12	$ 650.69	$ 725.77	$ 806.72	$ 893.96	$ 987.91	$ 1,089.02	$ 1,197.77	$ 1,314.66
Accumulating Biomass													
Projected Biomass Yield (see codes on Biomass Curves tab)	*NM6ave*	dry tons/acre					12.16	16.51	19.41	21.49	23.04	24.25	25.22
Adjusted Yield (for sensitivity analysis)	0%	% incr. or decr.					12.16	16.51	19.41	21.49	23.04	24.25	25.22
Harvesting Cost per dry ton	$ 21.00	$/dry ton					$ 25.53	$ 26.80	$ 28.14	$ 29.55	$ 31.03	$ 32.58	$ 34.21
Harvesting Cost per Acre		$/dry acre					$ 310.30	$ 442.52	$ 546.33	$ 634.92	$ 714.92	$ 790.07	$ 862.67
TOTAL future value FARM GATE cost		$/dry acre					$ 1,036.06	$ 1,249.24	$ 1,440.30	$ 1,622.83	$ 1,803.94	$ 1,987.83	$ 2,177.34
FARM GATE BREAK-EVEN Price (Present Value)		**$/dry ton**					**$ 70.12**	**$ 59.28**	**$ 55.36**	**$ 53.68**	**$ 52.99**	**$ 52.84**	**$ 53.00**
Hauling cost for biomass to Mill	$ 15.00	$/dry acre					$ 221.64	$ 316.08	$ 390.24	$ 453.52	$ 510.66	$ 564.33	$ 616.19
TOTAL future value MILL GATE cost		$/dry acre					$ 1,257.70	$ 1,565.32	$ 1,830.54	$ 2,076.35	$ 2,314.59	$ 2,552.17	$ 2,793.53
MILL GATE BREAK-EVEN Price (Present Value)		**$/dry ton**					**$ 85.12**	**$ 74.28**	**$ 70.36**	**$ 68.68**	**$ 67.99**	**$ 67.84**	**$ 68.00**

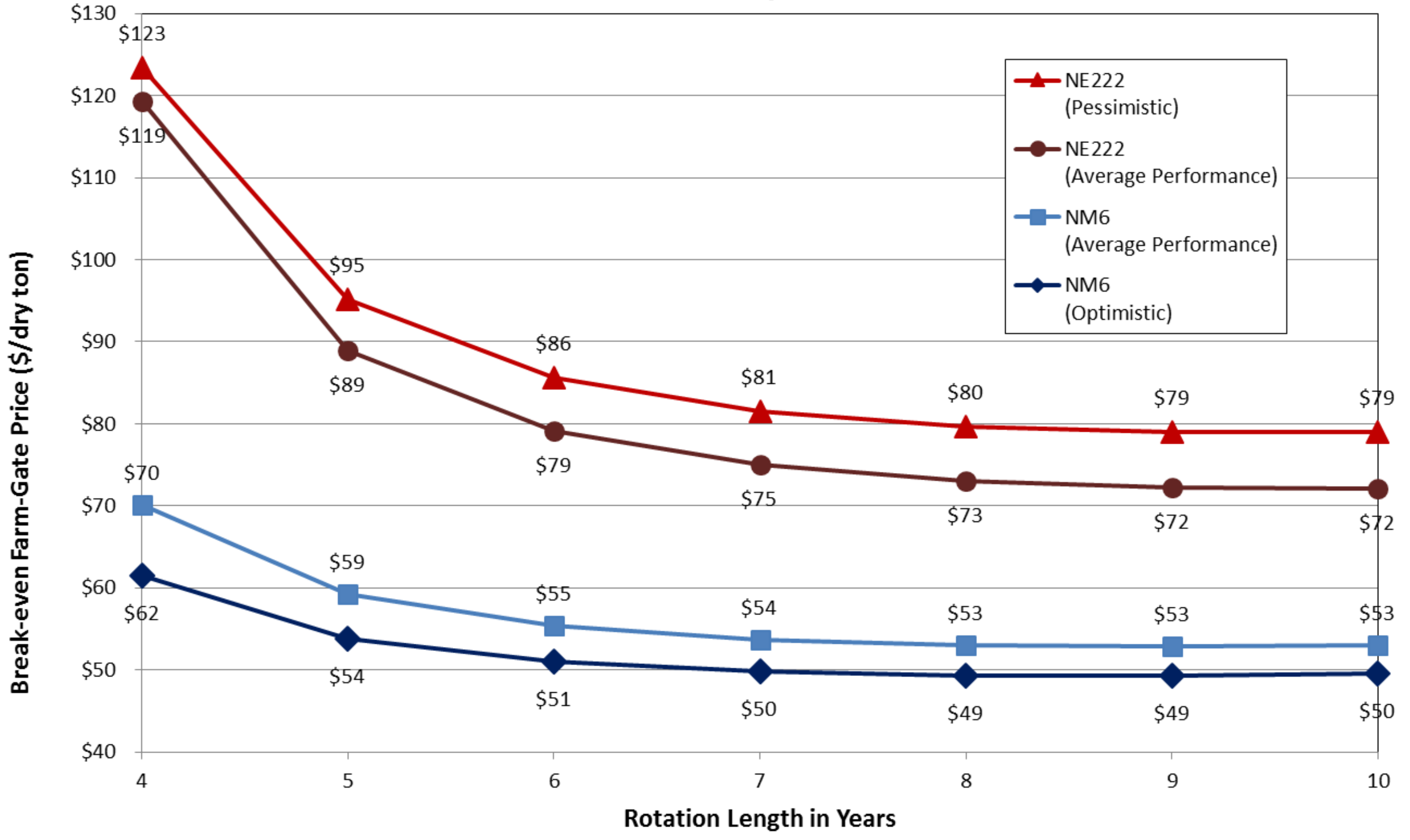

Figure 2: Farm Gate break-even price for poplar biomass of 2 varieties over various rotation lengths (2014 dollars)

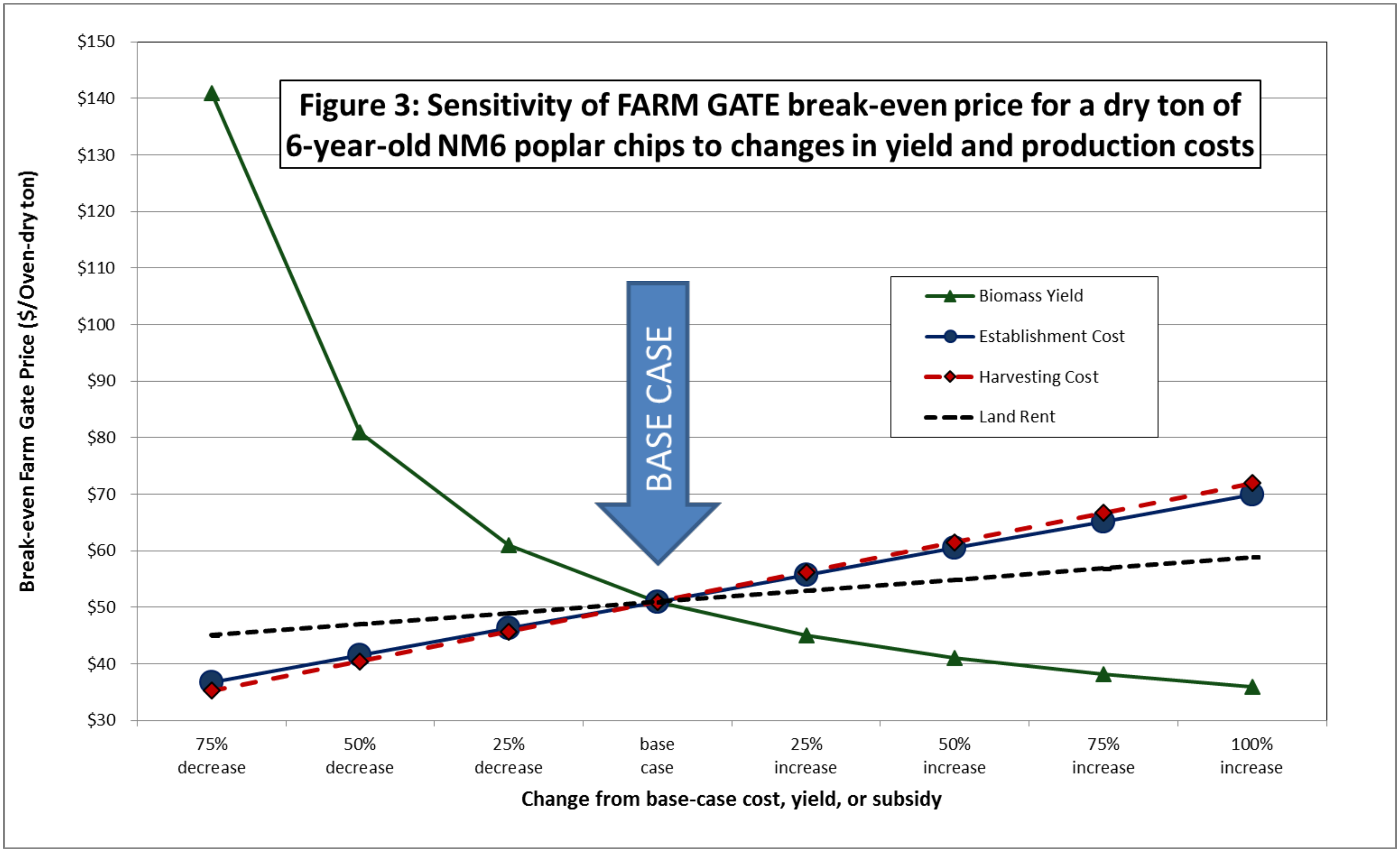

Figure 3: Sensitivity of FARM GATE break-even price for a dry ton of 6-year-old NM6 poplar chips to changes in yield and production costs