Developing a Fair and Robust Energy Policy

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Introduction

We used a system dynamics model and statistical analysis to find an energy tax policy that is both fair and robust for all interested parties based on the assumptions made in this study. Regret analysis techniques were developed and used effectively to find a policy based on equivalent gains and losses for all stakeholders. The policy worked well under a wide range of uncertain future conditions. Our approach could be particularly effective when it is difficult or impossible to define or agree upon the probabilities of important events.

The goal of this work was to expand on ideas that were developed in our previous papers, as well as the work of other researchers in system dynamics, petroleum engineering and other disciplines. We focused our efforts on defining a policy development process, rather than on the potential complexities that might arise in real situations. However, we believe the approach described here can be adapted to more realistic situations. That will be the focus of future research.

Uncertain parameters (oil price, initial oil reserves) were varied for each future scenario and also allowed to vary with time. The results of our analysis provided a clear definition of the policy "playing field" bounded by the solutions that gave the stakeholders their maximum benefits. Within this field, we also found a fair policy that resulted in equivalent stakeholder gain and pain. Other policy alternatives could also be analyzed to see where they are on the playing field and how fair they might be.

We hope that our techniques may eventually be used to find ways to encourage the development of new energy resources in a way that is both fair and beneficial to all interested parties.

Background

Sound energy policies are difficult to develop because it is hard to accurately define all of the variables that can affect them. We chose to use a system dynamics approach to this problem because this technique encourages us to include a wide range of parameters in the model development process. In this paper, our model is an extended version of an earlier model developed to study energy policy issues[1-3].

System dynamics and regret analysis have been used extensively[4-7] in the last 10-20 years to develop and evaluate policies in the presence of "deep uncertainty", where the model input data and/or structure is uncertain and probability distributions are difficult to define, debatable and/or unknowable. This is particularly important when surprise events can have a large impact on system behavior and results. We believe that the best policies are those that are robust (work reasonably well even when bad surprises occur) and adaptable (have the capability to accept and adjust to new information). Our efforts described in this paper are an attempt to develop and test this type of policy in light of uncertain future conditions.

As in our earlier work, we have assumed that there are two main stakeholders – the State government and an oil producer (called Producer). The State collects fees (royalties and taxes) from the Producer as a function of the volumes of energy resources available and produced. In our model, these fees are the only source of revenue for the State and are used to maintain and improve the conditions of the society that the State represents. The Producer receives all of its revenue from one oil field and is solely responsible for the costs of field development and operation, fees levied by the State, and final abandonment of the field (e.g., restoration of the State lands to pre-development conditions).

We have also assumed that the State and Producer are completely separate entities and have not included any societal or corporate needs in the calculations at this point in time. This is an important simplification. For example, the State needs enough revenue to meet the needs of the society and the Producer needs a positive net cash flow to remain in business. A future version of our model might include the impact of population growth on the societal needs and the impact of corporate growth requirements on the energy provider's needs.

We believe that our approach to a fair and robust energy policy could be extended to address much more complex situations and help the State and Producer work together to meet the energy needs of society well into the future. Our longer-term goal is to investigate ways to encourage the development of untapped energy resources – both fossil-based and renewable.

The Model

A system dynamics (SD) model[8] from previous work was used to represent the process of developing and operating an oil reservoir that could typically exist in any oil-producing region. The field has already been discovered when the model starts and is ready to be developed.

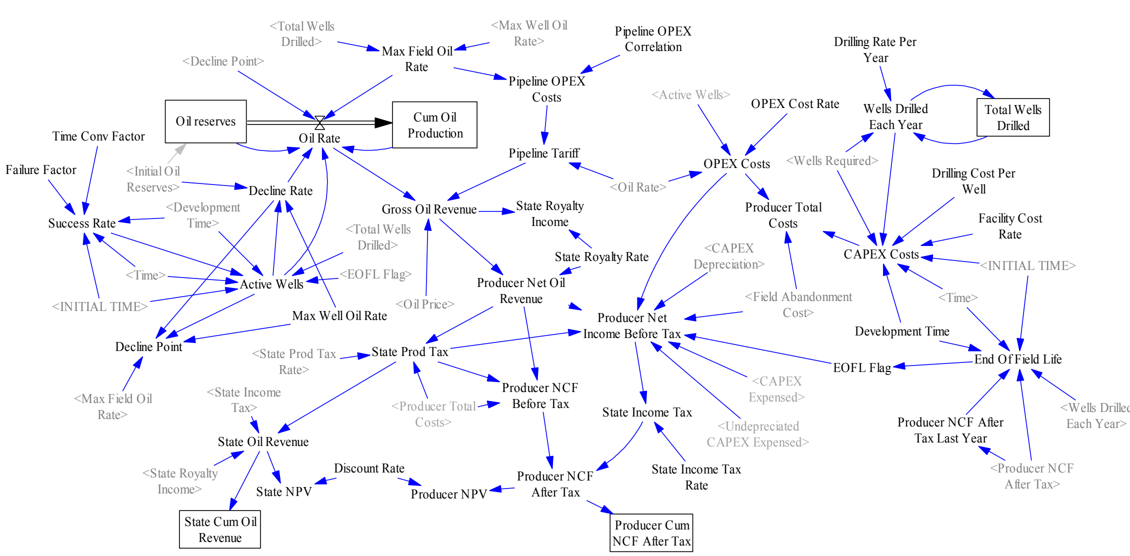

Figure 1 – System Dynamics Model Schematic – "model" view

Figure 1 shows the upper level design ("model" view) of the current SD model. This view represents the oil production and economics of the field and the stakeholders. Oil is produced from facilities built and wells drilled by the Producer, who pays a tariff to the pipeline to transport the oil to market and fees to the State (as already described).

End of field life (EOFL) occurs when the Producer net cash flow (NCF) becomes negative at least one year after development has ended. At that time, any remaining depreciation from capital investments (CAPEX) is expensed and field abandonment costs are incurred. The State only receives revenue as long as the Producer continues to have a cash flow.

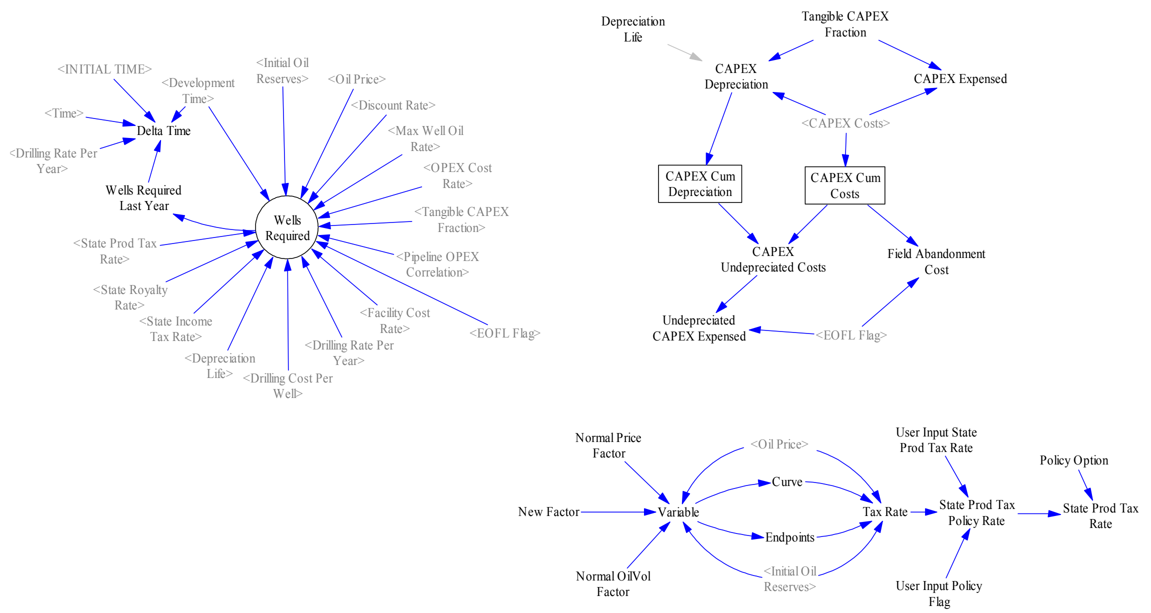

Figure 2 – System Dynamics Model Schematic - "planning" view

Figure 2 shows the "planning" view from the SD model, which includes three different calculations that are used in the "model" view described above.

The Wells Required variable (shown as a circle) is an external function that simulates the Producer's field development planning efforts with the objective of determining the number of wells that should be drilled to maximize the Producer's net present value (NPV). Each time step, this calculation takes the currently available information about the field (e.g., Initial Oil Reserves estimate) and other important variables (e.g., Oil Price) and uses them to adjust the Wells Required result.

CAPEX depreciation, undepreciated CAPEX and field abandonment costs are also calculated in the "planning" view and passed to the "model" view to complete the economic calculations during each time step. These variables are shown in the upper right corner of Figure 2.

The State Production Tax Rate (State Prod Tax Rate in Figure 2) is also calculated in the "planning" view. Depending on the type of case being run, the user can input the State Prod Tax Rate directly or the model can use correlations based on normalized curves and endpoints as functions of important input variables (e.g., Oil Price, Initial Oil Reserves) as shown in the lower right corner of Figure 2.

Figure 3 shows the "surprise" view from the SD model. This view contains variables that can be used to simulate fluctuations in the variables that are particularly difficult to estimate (e.g., uncertain probability distributions) and can vary with time or with other events that can occur in the model during a scenario.

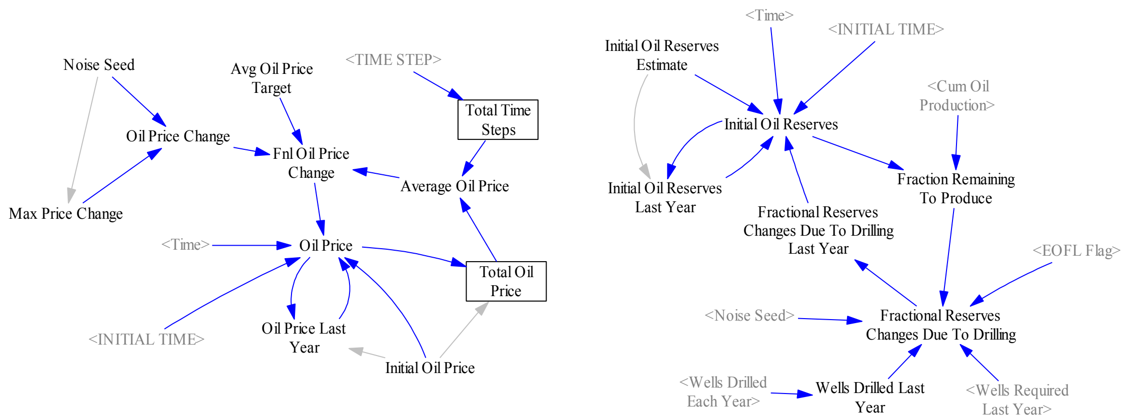

Figure 3 – System Dynamics Model Schematic – "surprise" view

In our current model, the Oil Price can change with time as a function of changes that might occur outside the model. The Initial Oil Reserves can change as new wells are drilled that confirm, raise or lower previous estimates. These parameters can have an impact on the Wells Required and, as a result, on the total wells drilled in any scenario.

Parameter Sensitivity Analysis

The policy development process begins with identifying the most important model variables that can influence the results we are interested in. The parameters are either "drivers" (strongly affect outcomes, not under direct user control) or "levers" (strongly affect outcomes, under user control).

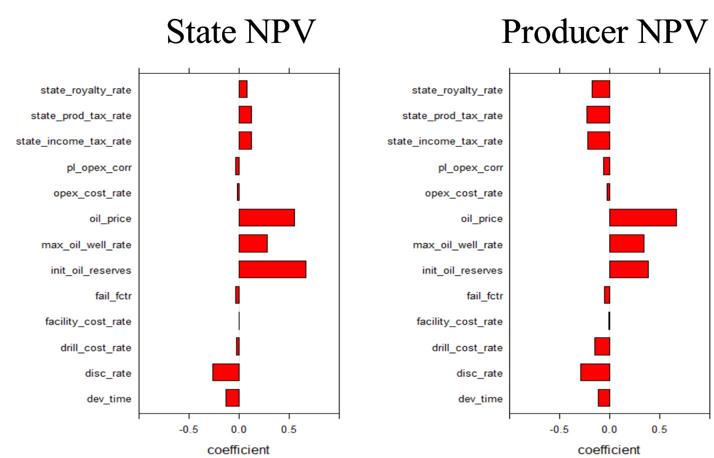

Figure 4 - State NPV and Producer NPV Sensitivity Analysis

We assumed that our energy policy would be a function of NPV and identified the main policy drivers and levers by using a single parameter sensitivity analysis technique. Each parameter was assigned a likely range of values and sensitivity runs were made varying each parameter one at a time. These SD model results were post-processed using an R[9] script and the results are shown for the State and Producer NPV on Figure 4.

Longer bars indicate more important input parameters. Positive values suggest that the parameter impact and NPV are positively correlated. Negative values suggest a negative correlation.

As described in our earlier papers, the three State revenue sources (State Royalty Rate, State Income Tax Rate and State Prod Tax Rate) are the primary levers that affect State and Producer NPV. The three primary drivers are the Oil Price, Initial Oil Reserves and the Max Oil Rate. To simplify our analysis in this paper, we used the State Prod Tax Rate as our policy lever and Oil Price and Initial Oil Reserves as our policy drivers. More variables will be included in our future research efforts and may require more sophisticated analysis techniques[10] to identify the important drivers and levers.

Regret Analysis

Regret analysis is a powerful technique for finding policy strategies that can reduce the impact of a "worst-case surprise" scenario. We developed these strategies by running our SD model with numerous scenarios in which we varied the State Prod Tax Rate, the Oil Price and the Initial Oil Reserves systematically. The tax rate varied from 0 to 100%, the oil price varied from 0 to 300 $/stb (US dollars per stock-tank barrel), and the oil reserves varied from 0 to 2 bstb (billion stock-tank barrels). In these cases, the variables were held constant with time.

We post-processed the SD model results and calculated Regret for the State and for the Producer as follows:

Model Regret(s,f) = Maximum Model NPV(f) – Model NPV(s,f)

Each future (f) was defined by an Oil Price and Initial Oil Reserves value. We generated different scenarios (s) for every future by varying the tax rate and calculating the State and Producer NPV values from the SD model. As expected, the maximum State NPV required a large State Prod Tax Rate value. However, above a certain tax rate, the State and Producer NPV became negative and both stakeholders failed. The Producer NPV was maximized with a State Prod Tax Rate equal to zero.

The regret values for the stakeholders were then normalized as Relative Regret values using the following relationship:

Relative Model Regret(s,f) = Model Regret(s,f) / Maximum Model Regret(f)

We believe that it is fairer to all stakeholders to compare fractional regret values since the maximum obtainable NPV for each may be quite different.

From these results, we were able to calculate the Equivalent Regret as follows:

Equivalent Regret(s,f) = | Relative State Regret(s,f) – Relative Producer Regret(s,f)|

Equivalent Regret values close to zero reflected a compromise between the two extreme cases and suggested a policy solution in which the State and Producer would experience very similar NPV losses (i.e., deviations from their optimal NPV cases).

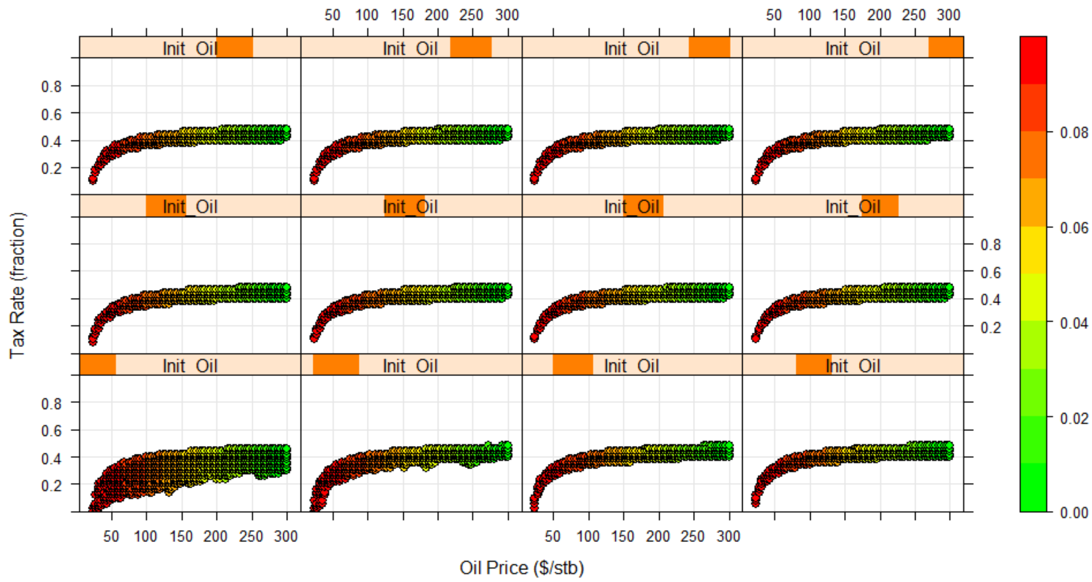

Figure 5 – Equivalent Regret with Initial Oil Slices

We analyzed the Equivalent Regret solution space by plotting the 3-D results using 2-D slices. Figure 5 shows the results using slices with various ranges of Initial Oil Reserves values, highlighted as orange bars in each panel. Small reserves values are shown in the

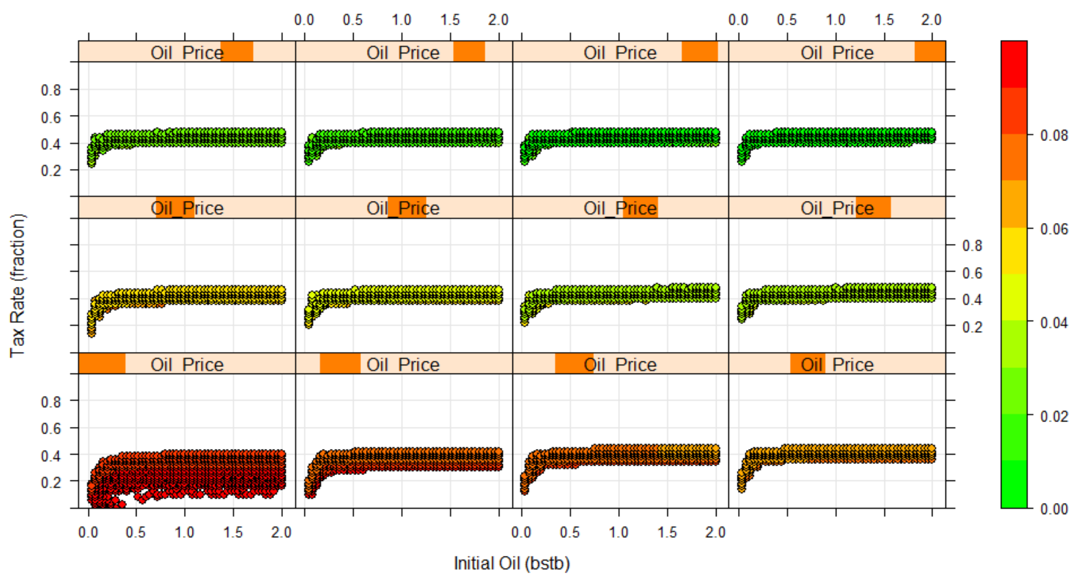

Figure 6 - Equivalent Regret with Oil Price Slices

bottom left panel. Large reserves values are shown in the upper right panel. The color scale represents Equivalent Regret values varying from 0 to 0.1. Values greater than 0.1 were not plotted to avoid unnecessary clutter and to help us identify important trends.

Similarly, we plotted the Equivalent Regret results with Oil Price slices in Figure 6. Low oil prices are shown in the lower left panel and high oil prices are shown in the upper right panel.

We used these model results to generate a correlation for use in the SD model to simulate various tax policies, using normalized curves and endpoint correlations as functions of Oil Price and Initial Oil Reserves. The SD model structure for this correlation is shown in the “planning” view on Figure 2.

Model Results

We tested the model tax correlations by running several thousand cases with randomly generated Oil Price and Initial Oil Reserves values (held constant with time) to see how well the State Prod Tax Rate correlation would perform. The results from 10,000 possible futures are shown on Figure 7 as density and cumulative density plots in the right and left panels, respectively. The upper panels show the results for the Producer NPV and the lower panels show the results for the State NPV.

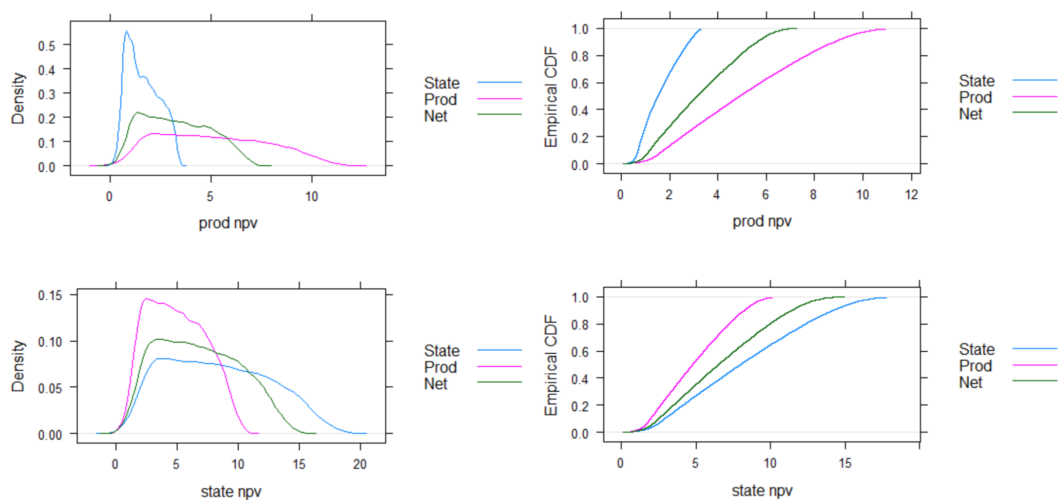

Figure 7 - State and Producer NPV Distributions - No Time Variations

The tax policy based on Equivalent Regret (shown as Net in green) appeared to be fair to both the State and the Producer. It generated better results for the State than the tax policy based on the lowest Relative Regret for the Producer (shown as Prod in pink). It also generated better results for the Producer than the tax policy based on the lowest Relative Regret for the State (shown as State in blue). In effect, both parties gained and lost by the same relative amounts. This is just one compromise solution that might exist between the extreme State and Producer solutions that define the “playing field”.

The Net tax policy might also be called robust because none of the 10,000 cases resulted in a failure, where failure is defined as an economic loss for either the State or the Producer. The final State and Producer NPV values were greater than zero for all 10,000 futures modeled.

It is important to stress that robustness was defined here only as a positive model NPV. In a more realistic model, the needs of the State and Producer should be included in our definition. There may be many cases in which the final NPV is positive, but the economic needs of either stakeholder may not be met. As stated earlier, the State needs revenues to meet the needs of society. The Producer needs revenues to grow profitability with time. This suggests that the tax policy developed here is only one component of a more comprehensive energy program, which could include additional fossil fuel development, renewable energy resources, conservation, etc.

Variable Uncertainties with Time

To more rigorously check the robustness of our calculations, we ran a series of additional model runs with the State, Producer and Net tax policies in which we allowed the Oil Price and Initial Oil Reserves to change with time. Figure 3 shows the model structures used to generate synthetic Oil Price and Initial Oil Reserves variations.

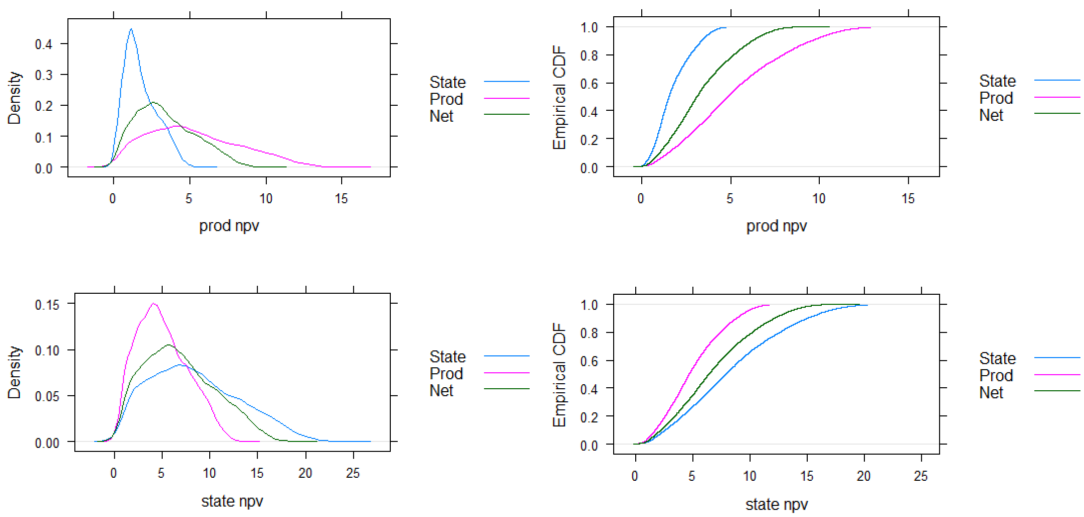

Figure 8 - State and Producer NPV Distributions – Time Variations

The results on Figure 8 show that the Net tax policy continued to do a reasonable job of generating model results that were between those generated using the best State and Producer policies over the entire range of NPV results obtained. The left panels show the distribution of model results as densities and the right panels show results as cumulative densities. Upper panels show results from the Producer's perspective and lower panels show results from the State's perspective.

As for the cases shown on Figure 7 above, the Net policy met our fairness criteria because it resulted in equivalent gains and losses for both the State and Producer. However, all three policies were less robust than those in the earlier cases. Of the 10,000 futures studied, the best State policy failed (i.e., had a negative final NPV) 48 times, the best Producer policy failed 25 times and the Net tax policy failed 28 times. Since the Producer policy used a zero tax rate, it seems reasonable to conclude that most of the Net tax policy failures were not caused by the tax rate. The overwhelming majority of Net tax policy failures were due to field economics failures due to a rapid drop in the Oil Price and/or drilling that found less Initial Oil Reserves than was originally expected.

Policy Implications

As mentioned above, the technique described here can effectively create a policy "playing field" with boundaries defined by the best tax rates for the State and Producer (i.e., those that result in their respective minimum Relative Regret values). A fair solution is a policy that is based on equivalent pain and gain for all stakeholders, as defined when the Equivalent Regret is zero. Any other policy can also be plotted on the playing field to see how fair it is to the stakeholders. This suggests that our approach could be valuable for policy negotiations and for developing stakeholder strategies.

Conclusions

Our simple model shows that an energy policy can be robust and flexible to account for an uncertain or unknowable future. Traditional forecasting techniques can fail in light of deep uncertainties. Regret analysis gives a clearer picture of the risks involved, likely conflicts and possible solutions. In the studies conducted, the Net tax policy (based on Equivalent Regret considerations) appeared to be both fair to the State and Producer and robust. More sophisticated techniques may be required to identify sound policies when there are numerous drivers and levers in the system.

Future Work

This research will be extended to study more realistic situations. For example, the SD model and regret analysis could be used to look at ways to encourage the development of untapped energy resources. It is possible that reduced taxes or other incentives might help. Another issue might be the impact of changes in the society (e.g., population growth) on the State's needs for both revenues and energy supplies.

Mechanical failure and climate change surprises could be included in the SD model. Multiple oil and/or gas fields (developed, undeveloped and undiscovered) could be included to study ways to encourage exploration and development. These techniques may also prove valuable for designing policies that smooth the transition to renewable energy resources.

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