Unintended Consequences of the North Dakota Oil Boom: Stress on the Local Counties

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Abstract

After the discovery of the Parshall Oil Field in 2006, the current North Dakota oil boom started to unfold. The fast growing oil and gas industries have created thousands of new jobs and a billion dollar budget surplus for the state government. Meanwhile, the boom challenges the oil producing counties that are struggling to maintain high quality social services to a rapidly increasing population. Our paper describes the main aspects of the interactions between oil sector employment, secondary employment, domestic immigration, and the fiscal policies of Dunn County and the State government through the use of a system dynamics model. We use the increased mileage of high impact roads in the County of Dunn as an example of pressures on the provision of infrastructure and it also serves as a proxy for the provision of social services in general. We stress the importance of fiscal policy to mitigate the impact of the oil boom. System dynamics can be used as a tool in planning and evaluating policies for the oil producing counties and we believe that the North Dakota oil boom model can serve as a starting point for further research on the topic.

Key words: Bakken, Boom towns, Fracking, Fiscal policy, Infrastructural demand, Oil sector employment, Service population, System dynamics.

Introduction

> *"I care about my hometown (...) I don't want to see it get out of control. I don't want to see it turn into a dirty oil town. That's a tough fight right now, to try and keep it a welcoming community and place where people want to move to. That's the goal, and the opportunity is right in front of us."*
>
> – Brent Sanford from McKenzie County in The Dickinson Press commenting the oil boom (Monke, 2014).

The fast growing oil and gas industries in North Dakota have created thousands of new jobs and a billion dollar budget surplus for the state government. At the same time, the boom challenges the oil producing counties. These counties struggle to keep providing high quality social services to a rapidly increasing population. We used a system dynamics model to explore the development of the booming oil producing counties.[1] This paper reports our findings with a focus on the unintended consequences of the North Dakota oil boom.

The first part of the paper introduces the oil boom and its causes. We also present our contribution, with an emphasis on the need for system dynamics work in the region. Thereafter the problematic behavior is presented. There are many ways to approach the oil boom and its consequences on the provision of social services in the affected counties. We use the decreased road quality in the County of Dunn as an example of counties unable to keep up with the increased pressure on social services. We further present the model and its features as our hypothesis of the structure of the problems that many of the oil producing counties face. This part is followed by an analysis, including policy suggestions.

Background

After the discovery of the Parshall Oil Field in 2006, the current North Dakota oil boom started to unfold. The recent development of horizontal hydraulic fracturing technologies has made the extraction of the previously inaccessible shale oil and shale gas possible. Because hydraulic fracturing ('fracking') is a relatively labor intensive technology, it multiplies the employment effect from the boom. Thousands of workers have immigrated to the oil producing counties of North Dakota, mainly to the Bakken area in the north-western part of the state. The boom is creating enough jobs to give North Dakota the lowest unemployment rate in the United States. There are however downsides to the recent development. Small towns in the oil producing area are struggling to cope with the rising population and the increasing demand for public infrastructure and social services.[2] The rising population and the oil and gas industry put pressure on the roads in the Bakken area: the roads are torn by the heavy trucks and by the cars of the thousands of employed people who have moved to the area to work. These issues encouraged us to build a model that explores the dynamics between the oil industry, the rising population, and the pressure it puts on the social systems.

[1] The model was the outcome of a first semester course of the European Master Programme in System Dynamics (2013/14). The course was given by Professor David Wheat.

[2] Examples of problems are sewage systems that are overloaded, overcrowded hospitals, and the inability of the police to keep up with an increasing number of crimes (Davies, 2012).

Previous research
Previous studies of the oil boom in North Dakota have used employment based modeling for estimations of population changes following the oil sector boom (Bangsund et al., 2012, Bangsund & Hodur 2013). To use physical measures of the oil extraction process such as rigs and wells along with different employment categories (as in Bangsund & Hodur, 2012) is intuitive and gives a basic understanding of the problem's underlying structure. It is nevertheless difficult to get an overall picture of the challenges that the local counties face without modeling the dynamic interactions between employment, immigration, and fiscal policy.

With a system dynamics model, policy makers can examine different scenarios in order to act in a timely and thoughtful manner. In our attempts to develop such a model, previous literature on rapid and unmanaged growth of boom towns has been useful (Ford, 1977; Jacquet, 2009; Leistritz et al., 1982). With the vast attention that has been given to the current North Dakota oil boom and our approach of linking together the oil extraction phases with employment, immigration, and taxation, we believe our model is well-timed and useful for policy makers. Comparing to other methods, the transparent method of modeling the physical structures, feedbacks and delays intrinsic in the system dynamics approach is advantageous in bringing clarity to the challenges that the decision makers in the region are faced with.

Problematic behavior

Our point of departure is the declining quality of social services provided by the oil producing counties of North Dakota. To define a reference mode has been challenging due to difficulties in finding an appropriate measurement. Figure 1 presents sketches of the problematic behavior and its underlying causes. The use of sketches as reference modes is consistent with accepted practice (Ford, 2010, p.50). After the Parshall Oil Field was discovered in 2006, the quality of social services has decreased significantly (Bohnenkamp et al., 2011; Davies, 2012). This development is shown in Figure 1a. Figure 1b displays the exponentially increasing service population, i.e. the people that demand social services. Consistent with this development, the miles of high impact road has increased exponentially, shown in Figure 1c[3]. Meanwhile, the counties' transportation budgets have remained fairly constant, which is displayed in the last sketch (Center for Governmental Research, 2013).

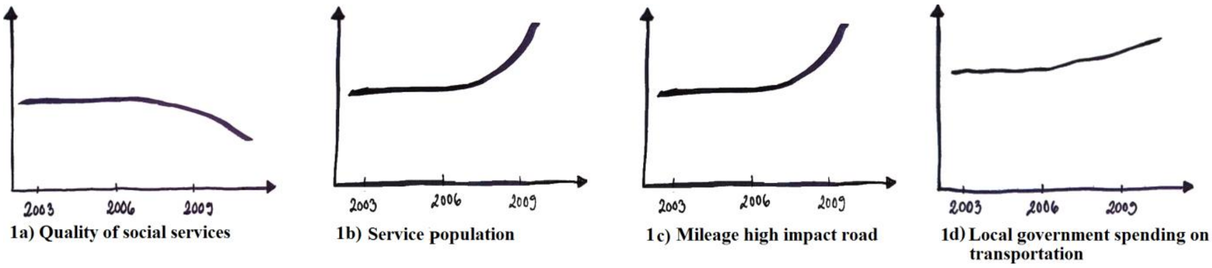

Figure 1: Sketches of the problematic behavior and its underlying causes.

[3] As an indicator of the accuracy of our sketches on the pressures on roads, data suggests that vehicle miles travelled (VMT) within North Dakota increased more than 30% between 2008 and 2012 to over 10.09 billion miles (North Dakota Department of Transportation, 2013). The state now has the highest VMT per capita in the United States (U.S. Department of Transportation, 2013).

Hypothesis

The model presents our hypothesis for the problematic behavior in the form of a system dynamics model. That includes our hypothesis of the interactions between the oil sector employment, secondary employment, immigration, and the fiscal policies of Dunn County and the North Dakota state government.

The oil production processes of drilling, fracking, and extraction are driving the increase in employment. When oil wells have been prospected, they need to be prepared for production. The preparation phases of drilling and fracking are labor intensive and increase the demand for employment. The increased employment demand together with a stable labor supply makes the oil counties attractive for immigrants from other states (Forrester, 1969; Buch et al., 2013). This leads to both temporary and permanent domestic immigration and an increase in the service population (the term ‘service population’ includes all who access services in the region i.e. both the temporary and permanent residents).

An increased service population means increased demand for social services. The counties obtain tax revenues partly through the allocation from the state government. Two prominent sources of revenues for the state government are income taxes and oil revenue taxes, which both are highly affected by the oil boom. While both permanent and temporary residents increase the demand for social services such as roads usage, only the former pay income taxes to the state of North Dakota. Further, only a fraction of the increased state revenues from income taxes and oil revenue taxes are transferred to the oil producing counties (Headwaters Economics, 2012a; Williams & Shadunsky, 2013).

To further clarify the model’s structure, we now turn to our stock and flow structures and a causal loop diagram.

*Stock and flow structure*s

Below we present four simplified stock and flow structures representing parts of our model. Figures 2 and 3 show the driving forces behind the development of the oil sector employment. Figure 4 illustrates immigration and population concepts. Figure 5 displays a basic version of the tax system part of the model with a focus on the problematic stress on the road system.

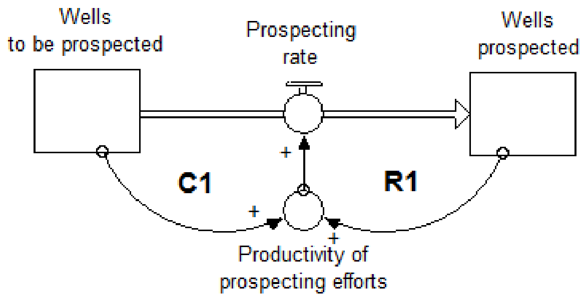

Figure 2: Stock and flow diagram of the ‘*depletion effect’* (C1) and the ‘*learning effect*’ (R1), simplified to display only the local feedback loops.

The number of wells that are being prospected is determined by two feedback loops representing the 'experience effect' and the 'depletion effect' (Figure 2). The 'experience effect' loop (R1 in Figure 2) is a reinforcing feedback loop. A reinforcing or positive feedback loop is "*a chain of cause-and-effect relationships that closes on itself to create self-reinforcing change*" (Meadows et al., 2004, p.25). In this paper, we use 'R' to indicate a reinforcing or positive feedback loop. The reinforcing 'experience effect' R1 loop postulates that prospecting experience, that is experience and knowledge of where and how to drill, increases for every new well that has been prospected. In Figure 2 this affects the productivity of prospecting efforts positively. This in turn increases the number of wells prospected.

The 'depletion effect' loop (C1 in Figure 2) is a counteracting feedback loop. A counteracting or negative feedback loop is a chain of cause-and-effect relationships that counteracts or balances a behavior over time. The counteracting 'depletion effect' loop C1 claims that oil well prospectors start with the sites that are most accessible before turning to less accessible places. Ceteris paribus, this lowers the productivity of prospecting efforts the more wells that have already been prospected. This 'depletion effect' hampers the prospecting process. Note that Figure 2 is simplified to display only local feedback loops.

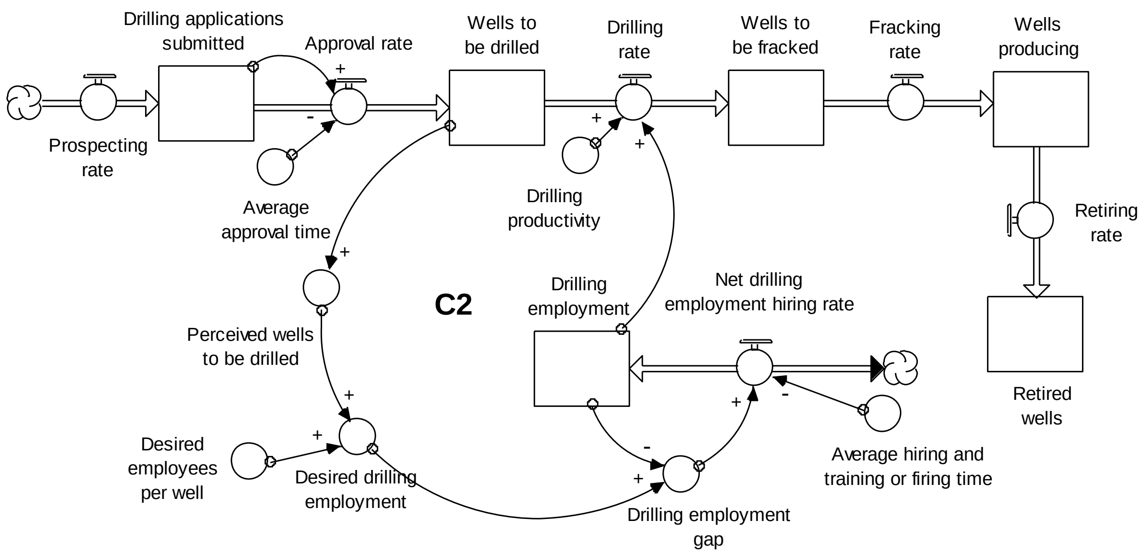

Figure 3: Stock and flow diagram showing the drilling part of the oil employment. Loops similar to C2 exist for all oil production phases.

When wells have been prospected, an application to drill, frack and produce is sent. This is represented by the flow 'prospecting rate' into the stock 'Drilling applications submitted' in the upper left of Figure 3. When applications have been approved the wells are to be drilled. The counteracting loop C2 suggests that the more wells that have been approved and that are to be drilled ('Wells to be drilled'), the more labor is needed. The number of desired drilling employment thereby increases which eventually leads to a hiring decision. When drilling employment consequently raises the drilling rate increases. An increase in the drilling rate reduces wells to be drilled - and the loop C2 is thus closed. Similar counteracting loops exist for wells to be prospected (in Figure 2), wells to be fracked and wells producing (in Figure 3).

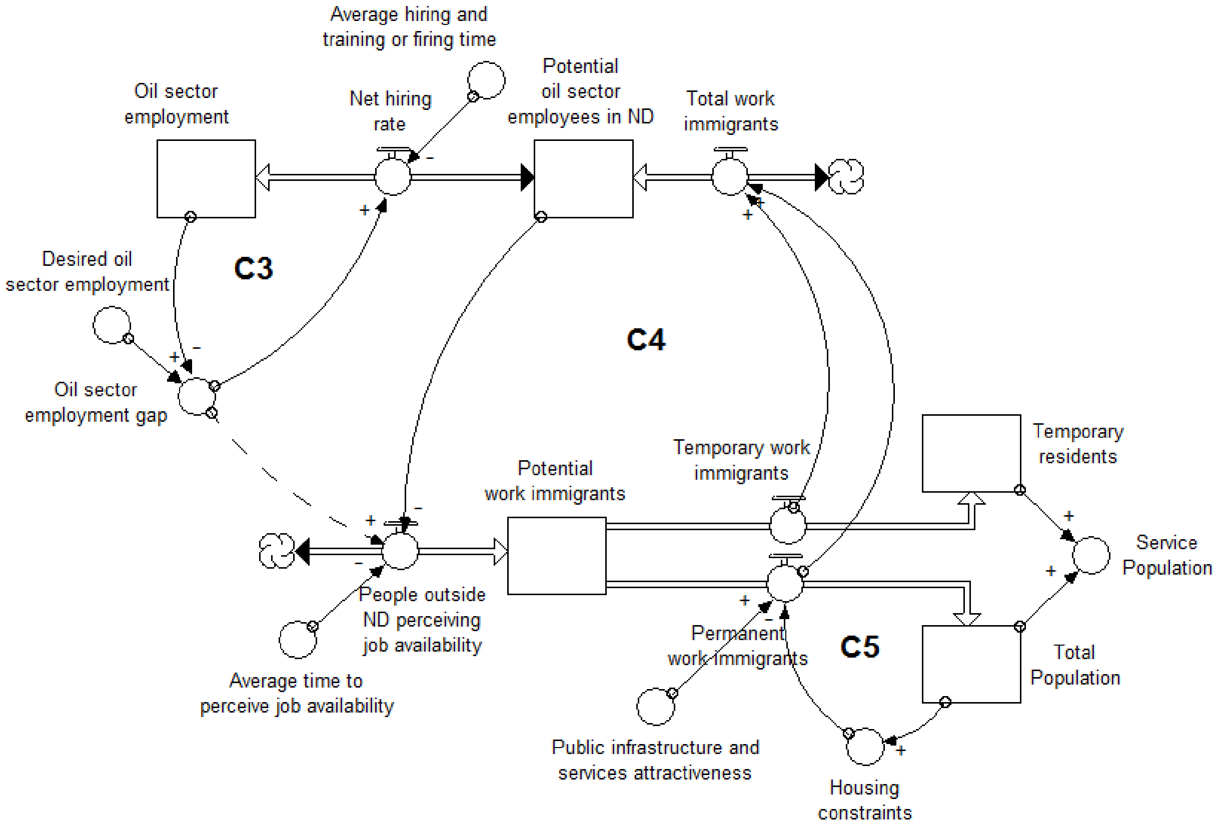

Figure 4: Stock and flow diagram showing immigration and service population concepts, simplified to include all the oil sector employment sectors (e.g. 'drilling employment' and 'oil field service employment').

In Figure 4 the counteracting loop C3 hypothesizes that when oil sector employment is lower than the desired level, the 'oil sector employment gap' is filled by people already living in the area, 'Potential oils sector employees in ND'. The gap however also increases the number of people outside North Dakota that perceive job availability (counteracting loop C4) and there is an incentive to immigrate. People outside the area will perceive the job availability and become potential immigrants to the oil sector. The potential immigrants that decide to immigrate to the area to look for work will be added to potential oil sector employees, which reduce the number of people perceiving job availability and then contribute to the closing of the C4 loop when hired.

We believe that the decision to move to the oil counties either permanently or temporary depends partly on the availability of housing and the quality of social services provided by the counties. In fact, the excess demand for housing has caused many people to live in their cars or trailers or in 'man camps' (Bangsund & Hodur, 2013). The counteracting loop C5 in Figure 4 shows that people that want to immigrate permanently are constrained to do so if they cannot find a house to live in. When people move in permanently, total population increases and the vacancy rate of houses decreases. Also, houses become more expensive. If there are not enough available affordable houses, fewer people will move in permanently. Furthermore, a lower quality of public infrastructure and services makes lives less pleasant and discourages people from moving in permanently, and even encourages residents that lived in the area before the boom to leave.

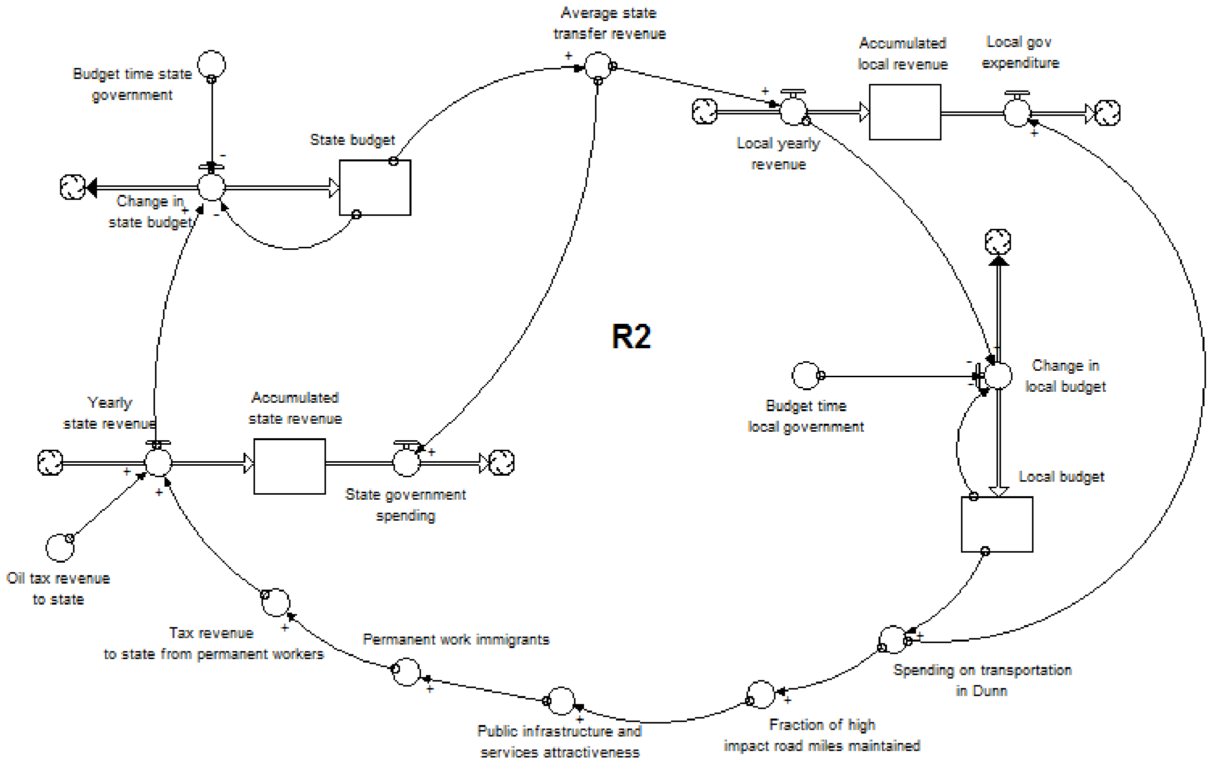

Figure 5: Simplified stock and flow diagram of the tax system.

Figure 5 shows the part of the model that represents the tax system in North Dakota. It is divided into two parts, the state government and the local government of Dunn County. Each part includes a main stock showing the accumulated tax revenue, with an inflow of tax revenue and an outflow of government spending. Key sources of tax revenues for the state government are the income tax paid by the permanent residents in North Dakota, and the tax income from the oil production. The state government and the local government are linked together through the 'Average State Transfer Revenue', which is the money transferred from state government funds to the local governments. This is generally one of the main income sources at the local level (Felix, 2011).

There are two stocks representing the budget at the state level and at the local level respectively. The 'Budget Time' converters are showing the time it takes for the decision makers to update their estimations of future tax revenues and make changes in the budget. The tax revenues collected preceding years will lay the foundation for a future budget. The budget time is assumed to be two years. Besides that two years is a reasonable average time to update perceived future budgets, policy makers in Dunn County, as for the policy makers in the state of North Dakota, work under a biennial budget system.

The reinforcing loop R2 presents that the more permanent workers living in North Dakota, the larger the income tax revenue. The larger the tax revenue, the bigger the budget for coming budget periods – and the larger the transfer to local governments. Increased transfers from the state generate larger budgets at the local level. When there is more available funding there is room for increased investments in social services and infrastructure – such as road maintenance. The 'Fraction of High Impact Road Miles Maintained' serves as an indicator for the quality of social services, and will have an impact on immigration. The better the quality of social services provided by the government, in this case the quality of the roads, the more attractive it is to immigrate to North Dakota (this link is also presented in Figure 4). If the attractiveness increases more workers will move in permanently, and will then contribute to the welfare of the state by paying income tax.

The declining quality of the roads in Dunn County is one of the unintended consequences of the oil boom. In 2006, very few of the road miles in the county where highly impacted from traffic. General road maintenance was on average only two or three operations per year. The annual cost of maintenance was estimated at around 1,500 US dollars per mile. When the oil industry started booming the trucks from the oil companies, in addition to the cars driven by the oil workers, started to damage the roads in the county. The highly impacted road miles increased rapidly, and weekly maintenance is now required to ensure high road quality. The cost to maintain high impact road miles is now estimated to be $24,000 annually (Center for Governmental Research, 2013).

Causal loop diagram

The model's most prominent variables and feedback loops are presented in the causal loop diagram below (Figure 6). This causal loop diagram also shows the links between the different sectors of the model.

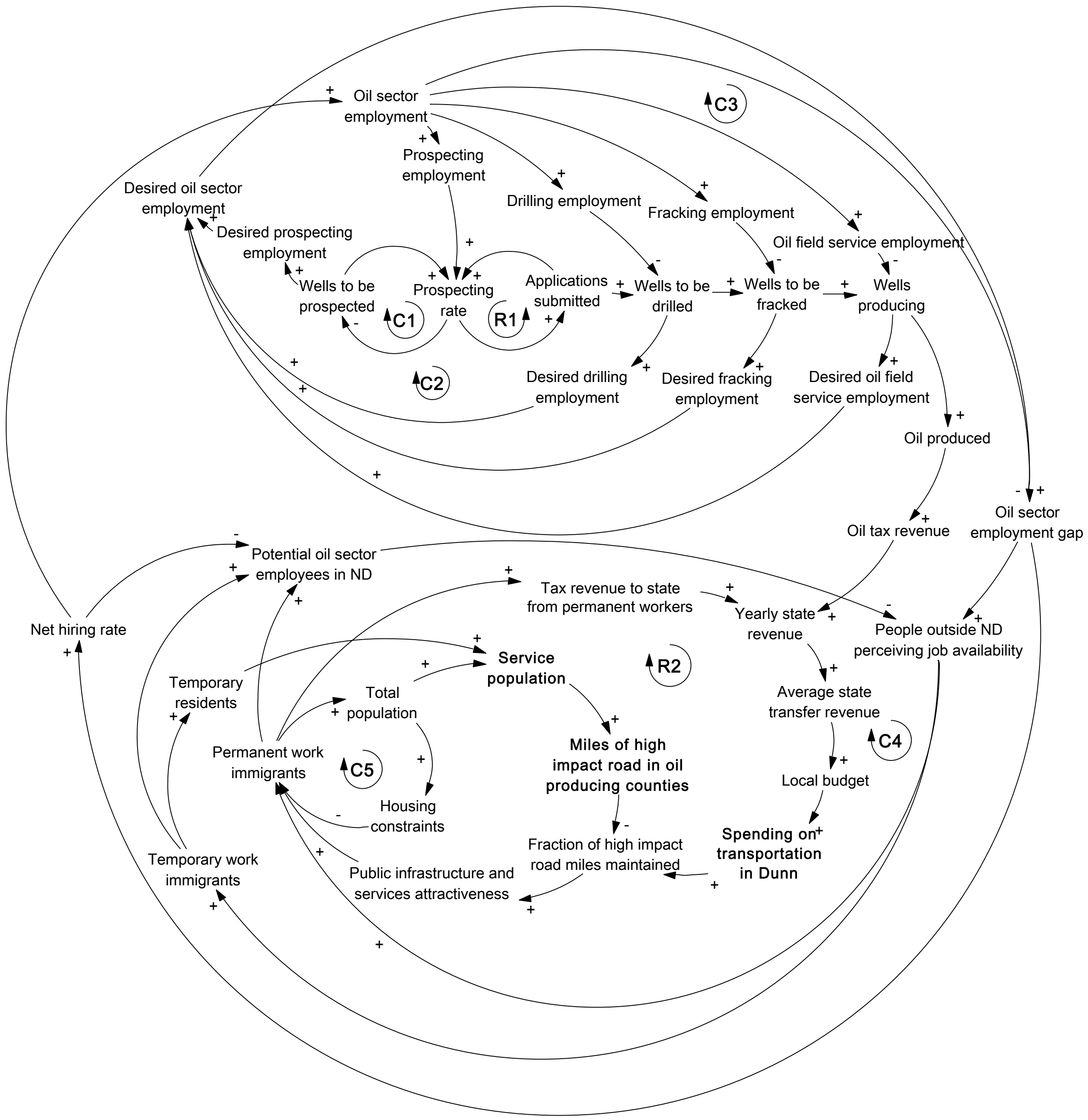

Figure 6: Causal loop diagram.

Analysis and simulation

Below, we present and analyze simulated graphs showing the behavior of the model. We show simulations of the population development and present simulations of the oil sector employment. Further, we present simulations of transportation spending in Dunn County.

The development of the population in the Bakken area is illustrated in Figure 7. Initially there was a low percentage of temporary residents and people were less constrained to move in. When more people immigrated permanently, the housing availability decreased and the area became overcrowded. Therefore, more people were constrained to move in permanently, and the percentage of temporary residents grew.

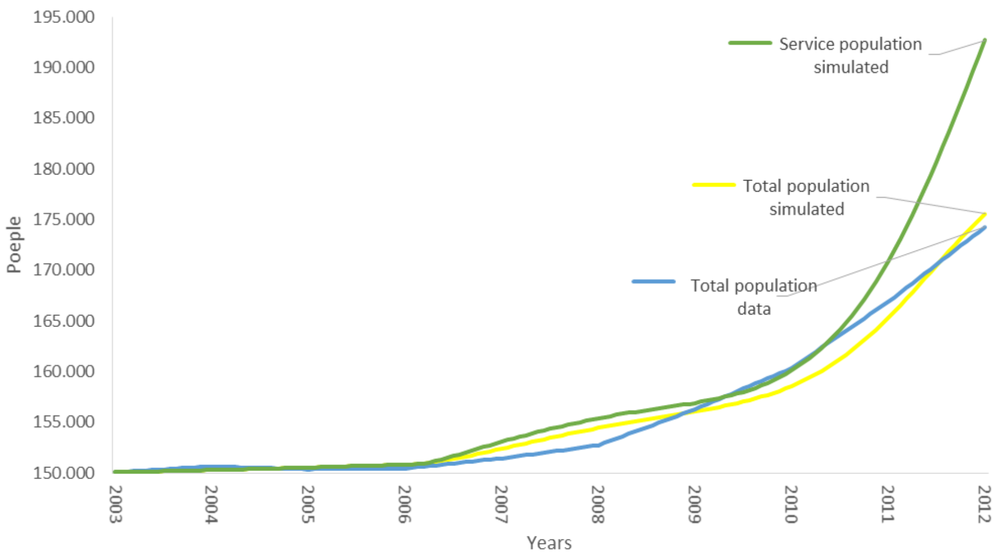

Figure 7: Population, Bakken area (2003-2012). Data source: (U.S. Census Bureau, 2011, 2013).

Figure 8 presents the simulated total employment in the oil sector and the corresponding data (U.S. Department of Labor, 2013). Because the employment part of the model is initialized in a dynamic equilibrium, the simulated employment is a straight line until 2006. In 2006, the discovery of the Parshall Oil Field offsets the processes as explained above.

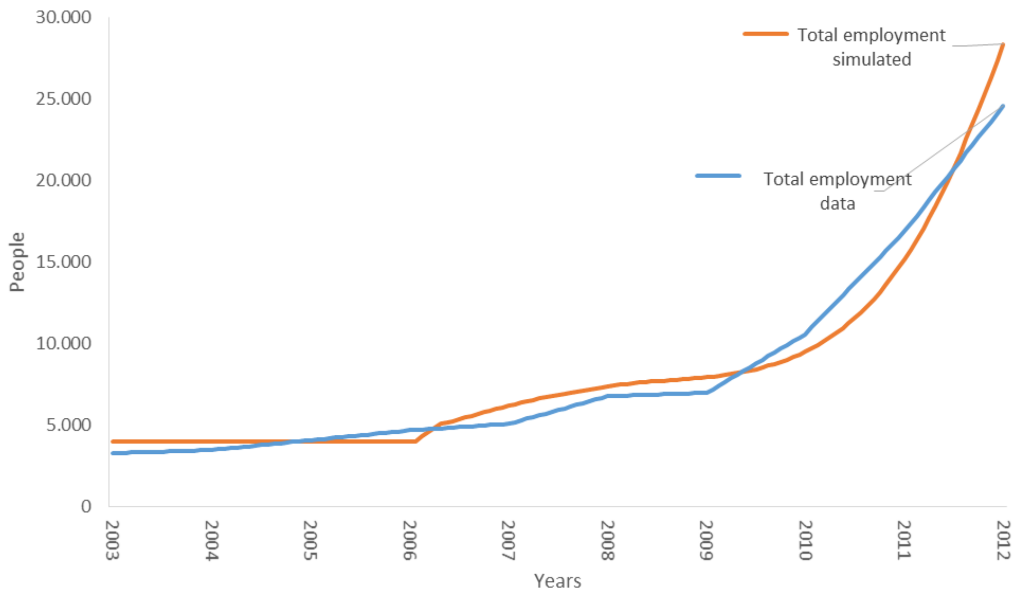

Figure 8: Total employment in oil sector (2003-2012). Data source: (U.S. Department of Labor, 2013).

We have used the model to create a future scenario of the oil sector employment based on the oil production processes of prospection, drilling, fracking and oil field service, presented in Figure 9. The goal of the modelling process has been to understand the structure of the development and not to predict precise future numbers. The “future” curves should therefore be interpreted as expected trends under a “business as usual” scenario.

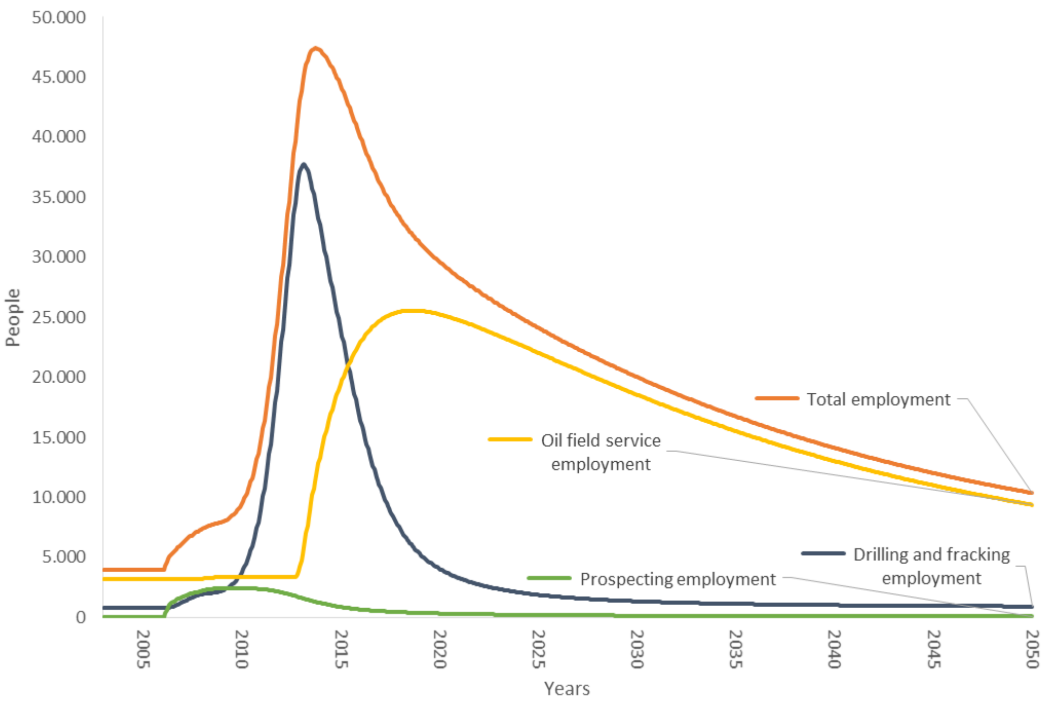

Figure 9: Simulated potential development of oil sector employment (2003-2050).

Figure 9 displays simulation results for future employment. Prospecting employment increases in the beginning as potential places for wells are found in the area. This leads to the substantial exponential increase in drilling and fracking employment. Further, as most wells have been drilled and fracked, the oil field service employment increases substantially. Since drilling and fracking are the most labor intensive phases of the process, total employment peaks around the same time as the drilling and fracking employment. It then decreases in a pattern of exponential decay, as the wells are being depleted.

Figure 10 presents that the desired spending on transportation is increasing as the oil boom starts to unfold. Both the data and the simulated spending on transportation slowly starts to increase, but are not reaching the level of the desired spending. At the time of the completion of the model, data on government spending was only available until fiscal year 2011. The simulation therefore runs only for the years 2003 to 2010.

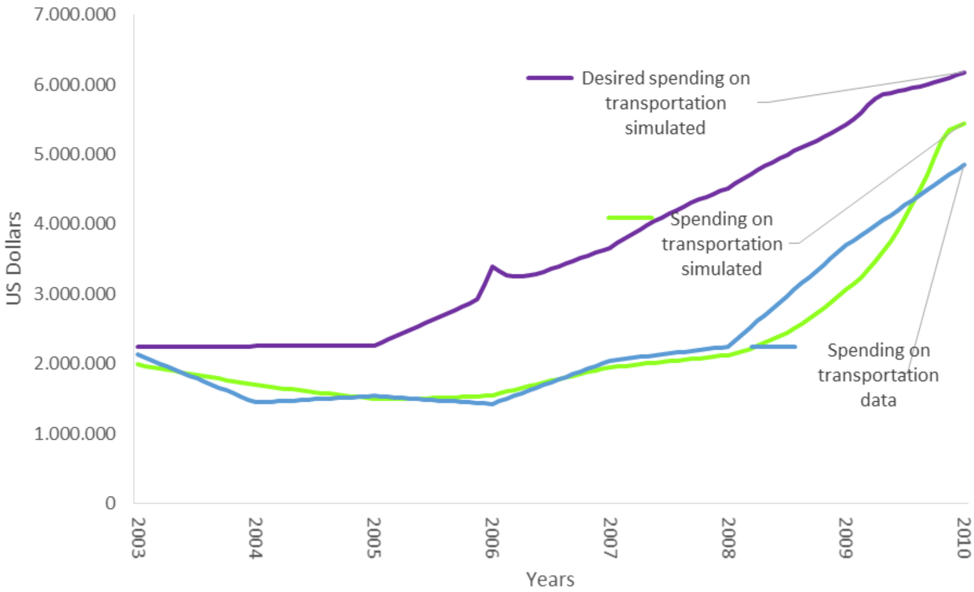

Figure 10: Simulated and actual spending on transportation Dunn County (2003-2010). Data sources: (Dunn County, 2012; Center for Governmental Research, 2013).

Policy suggestions

In this section policy suggestions are introduced to see how the counties can cope with the unintended consequences of the oil boom. The policies introduced focus on how to increase the tax revenue of the oil producing counties so that they are able to cope with the growing demand for social services.

An intuitive policy could be to increase the state's tax rate on oil. Higher effective tax rates would generate more state revenue which means more revenue transferred to local counties - even if the fractional transfer rates remains constant. Larger budgets at a local level allows for increased investments in infrastructure and social services – in the case of Dunn that would generate more available funding for the maintenance of the road system. It is in the state's power to change the tax rate and it would probably not be accompanied by much costs. A higher tax could perhaps negatively affect the oil production, but it is suggested that an increase in the tax rate on oil and gas will not affect prices or industry investment (Headwaters Economics, 2012b). Also, North Dakota's effective tax rate is on an average level in comparison to the neighboring energy-producing states, which implies that there is room for further increases.

Figure 11 displays the effect of a ceteris paribus increase in the tax rate on oil in our model on Dunn County´s local budget. Since the oil tax only makes up a fraction of the total tax revenues and only a fraction of the oil tax revenue is transferred to Dunn County, the effect of this policy is smaller at a local level than what it is at the state level.

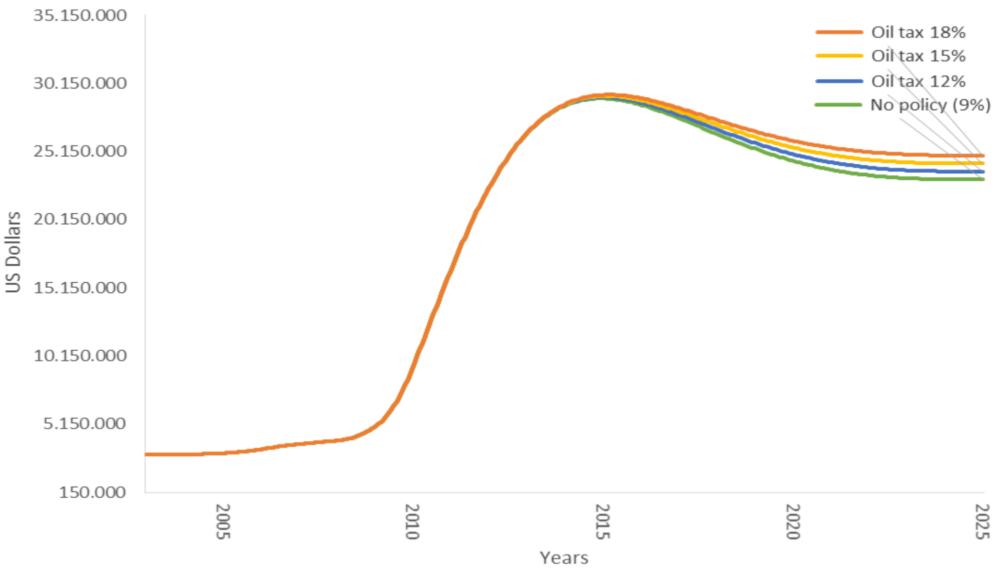

Figure 11: Tax policy parameter test showing the effect on 'local budget' (2003-2025).

Another policy suggestion is to change the fraction of the state's budget transferred to the oil boom affected counties. By changing the distribution formula the state would allocate more money to the local counties in the Bakken area, and thus make sure that they have enough resources to handle the pressures on the social systems. The local governments may do their best to lobby the state government to give them more funding, but the allocation of state revenue is at lasts in the hands of the state government. The state of North Dakota does however have a large budget surplus, and it appears that such a change is already starting to take place (Headwaters Economics, 2012b).

Conclusion

Technical improvements and the 'discovery' of the Parshall Oil Field have put North Dakota in the center of the U.S. oil industry, and turned it into the fastest growing oil-producing area in the country. The booming oil industry challenges the oil producing counties. As the oil boom continues to unfold, there are increasing concerns about the governments' abilities to meet the rising demand for social services and investments in infrastructure. It is crucial that these issues are addressed to ensure that the state adapts to the boom and that local communities do not suffer unduly from the developments.

The North Dakota oil boom model captures the ongoing trends in employment, immigration and the challenges that the oil producing counties face. We believe that the complexity of the challenges associated with the North Dakota oil boom with numerous feedbacks make system dynamics a useful tool when conducting research in this area.

Measuring social performance has been a challenge and using road maintenance as a proxy for the quality of social services might not be optimal. Road quality might be a blunt tool that does not say much about the overall performance of the social services. However, the model does provide a useful foundation for further research. For further research, we believe that adding wages and the housing market to the North Dakota oil boom model would enable additional policy analysis and guidance.

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Appendix A: Validation test

Structure behavior test

In order to discover the endogenous dynamics of the model we will cut an important feedback loop. In this test we will eliminate effects of the oil employment part of the model because this part of the model is the source of dynamics for the other two parts of the model, the population dynamics part and the tax system part. We hypothesized that the boom in the desired oil sector employment triggered the boom in population and consequently the rise of desired spending on transportation in Dunn to keep up with the increased demand for maintaining the roads. In Figure 12 we can see the behavior of three important variables with the feedback loop of the oil employment sector operating. The behavior of all three variables can be described as increasing and the variables 'total population' and 'desired employment' show signs of exponential growth.

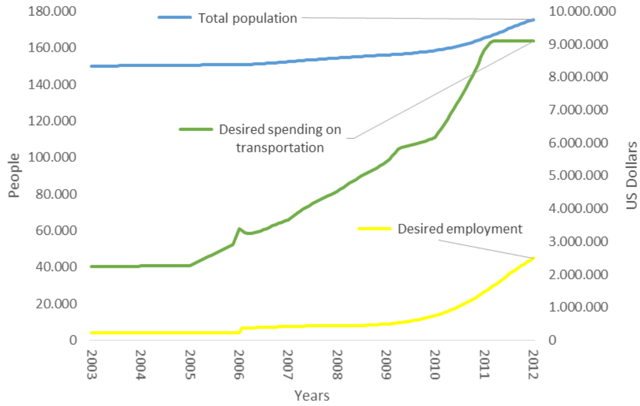

Figure 12: Simulated variables *before* cutting the loop (2003-2012).

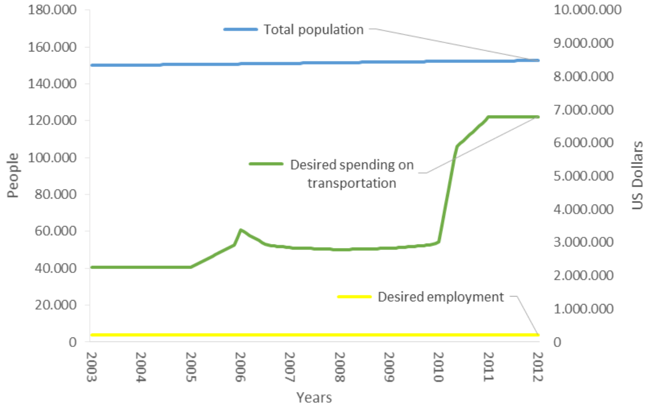

Figure 13: Simulated variables *after* cutting the loop (2003-2012).

By setting the setting the 'desired employment' to remain constant at its initial value, feedback loops of the oil employment part of the model are cut. The behavior of the model after eliminating the feedback loops is shown in Figure 13. Instead of increasing behavior, it can now be described as relatively constant.[4] As hypothesized, we can conclude that the founding of the Parshall Oil Field and the employment boom that followed, triggers the dynamics of other parts of the model.

[4] The desired spending on transportation does not show constant behavior after the loop is cut. This is because the desired spending on transportation depends partly on exogenous data on vehicle miles travelled per capita.

Appendix B: Model interface

The model is supplemented by an interface layer (see Figure 14). The interface allows the user to interact with the model, read background information, run simulations under different assumptions, and view the outputs. To explain and communicate the model we also use the storytelling function of *iThink*.[5] This feature allows us to break the model down into smaller parts and present it step by step, as can be seen in Figure 14, number 4.

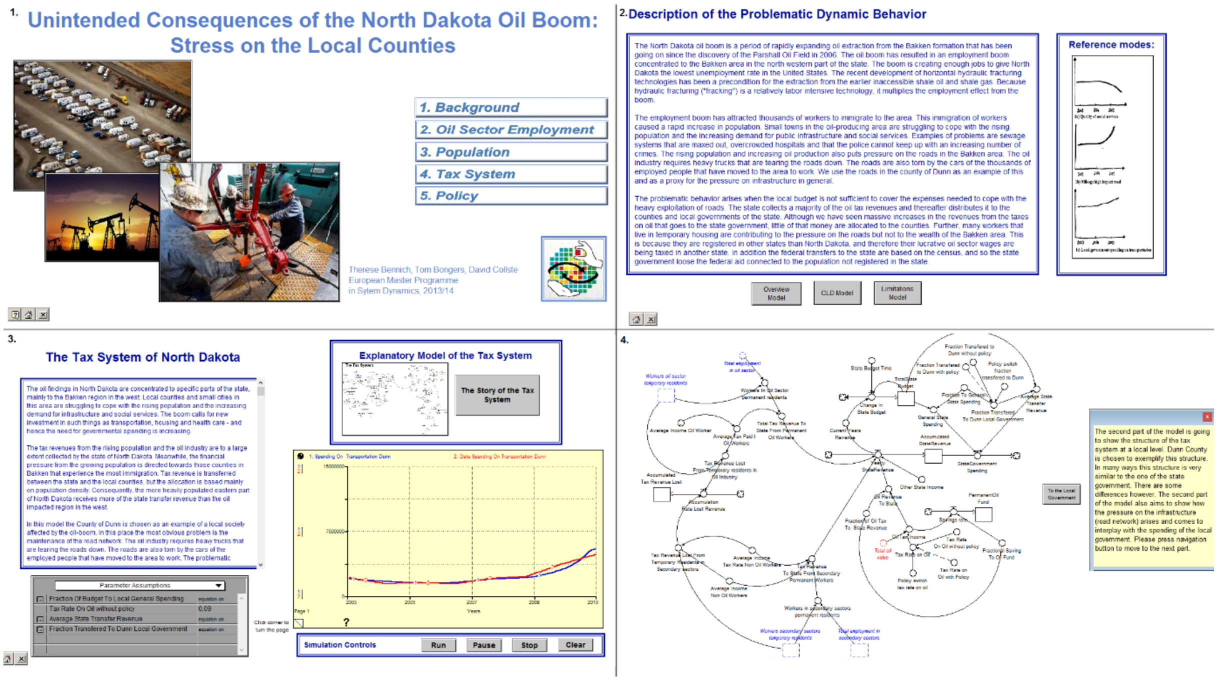

Figure 14: Screenshots of the model's interface.

[5] Software used: *iThink* v10.0: http://www.iseesystems.com/Softwares/Business/ithinkSoftware.aspx