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UNDERSTANDING CRUDE OIL TRANSPORT STRATEGIES IN NORTH AMERICA[1]

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On July 6, 2013, an oil-laden unit train derailed and exploded in Lac-Mégantic, Quebec, killing 47 people and levelling its downtown. Following a dramatic increase in crude oil shipments on US Class I railroads from just 9,500 carloads in 2008 to 234,000 in 2012 (AAR 2013), this accident shocked many and led to the significantly increased public scrutiny of crude oil by rail (CBR).

Simultaneously, there has been intense scrutiny of several proposed pipelines from the oil sands of northern Alberta to the west and east coasts of Canada as well as to the US Gulf of Mexico Coast (USGC). Pipeline opponents are concerned not only about negative potential environmental impacts from the pipelines themselves, such as a spill of diluted bitumen (a form of crude oil to be shipped), but also about the consequences of greenhouse gas (GHG) emissions caused by the energy-intensiveness of bitumen production and refining. Proponents counter that a denial of pipeline permits by the Canadian and US governments would lead to more CBR, which they argue would not only be less cost-effective, safe, and environmentally-friendly, but also ultimately lead to the same amount of GHG being emitted from the production and refining of oil sands bitumen (e.g. Krugel 2013). Therefore, much of the debate over proposed pipelines from the oil sands hinges on whether railroads could accommodate oil production increases economically and with comparable societal impacts.

The stakes are high: oil sands production could increase from 1.8 million barrels per day (Mb/d) in 2012 to 5.0 Mb/d in 2035, bringing along with it both positive and negative impacts for Canada and the US. Until these impacts are considered through political and regulatory processes in Canada and the US, railroads deciding whether to invest in capacity to transport bitumen are presented with considerable uncertainty.

To provide context for addressing this uncertainty, the first part of this paper qualitatively discusses the relative performance of railroads versus pipelines along economic, environmental, and safety dimensions, relates how this relative performance may affect oil sands development, and suggests how the impacts from the transportation system and oil sands production fit within the broader strategy of the Canadian and US governments. The second part of this paper quantitatively addresses the uncertainty faced by the railroads using a dynamic programming model, which determines the optimal investment capacity investment for the railroad industry as a whole to transport bitumen from the Alberta oil sands. The results from this model are then related back to the governmental positions discussed in the qualitative section.

The governments' perspectives: a qualitative approach

Three important impacts of oil sands production and its transportation system are: economic impacts (and relatedly energy security), GHG emissions/climate change impacts, and local environmental impacts. After describing each impact, the position of the Canadian and US governments related to these impacts will be explained. The federal governments of the US and Canada are the focus, because they hold authority over pipeline permit approval for interprovincial and international pipelines, though provinces and states have some jurisdiction over certain aspects of pipeline construction, such as pipeline "siting" in the US (Vann et al. 2012, CEAA 2012). The relative performance of railroads versus pipelines will then be described to understand how the each government could favor one mode over the other to accomplish its strategic objectives, and the consequences they would need to be aware of. Throughout this discussion, uncertainties of interest to both governments and the railroads are identified.

Canada would receive significant economic benefits from oil sands production growth. Assuming plausible growth, jobs in the oil sands could grow from 75,000 jobs (direct, indirect, and induced) in 2010 to 905,000 jobs in 2035, and over this period, the Government of Canada could expect to receive $311 billion in tax revenue (Honarvar et al. 2011). As a result, all major Canadian federal political parties support (at least some of) the capacity expansion necessary to support oil sands production growth, though the New Democratic Party opposes pipelines solely designed to export unprocessed crude oil (Canadian Press 2013, Barton 2013).

Production from the oil sands also impacts the economy of the US through its trade relationship with Canada, but the magnitude of the benefits is a more contentious issue in the US. The oil sands sector could contribute to the creation and preservation of 465,000 jobs (indirect and induced) in the US in 2035, up from 21,000 in 2010 (Honarvar et al. 2011), but only some of the benefits are specifically tied to Alberta oil ending up in the US. Because oil is globally traded, US refiners may be able to import comparably priced oil from abroad regardless, although this would not necessarily be from an ally of the US (Levi 2009). As a result, the economic impacts in the US of a particular energy transport project are more difficult to quantify, leaving room for political debate.

For example, in the context of the Keystone XL (KXL) evaluation, President Obama has downplayed the economic benefits from the project, indicating that its construction would create only 2,000 construction jobs, lower than the estimate given in the Department of State's (DoS's) Draft Supplemental Environmental Impact Statement (DSEIS) of 3,900 person-years in direct construction jobs (*The New York Times* 2013, DoS 2013). By contrast, many in Congress support its construction partly because of these same economic impacts (Energy and Commerce Committee 2013). Therefore, even when considering the more easily defined construction benefits of the KXL, there is significant debate over value of the economic benefits received from a pipeline project.

Because of the difference in the economic benefits potentially received by the Canadian and US governments, there is also divergence in their goals. The Canadian government wants a cost-effective crude oil transport system with sufficient capacity: it prefers pipelines, which, as shown in **Table 1**, are generally a lower cost mode. The DoS finds that the total cost of shipping raw bitumen via rail is comparable to that of pipelines, particularly if the perspective of small shippers is considered because they are charged higher "uncommitted" rates (US DoS 2014). However, this understanding is primarily based on *estimates* at this point, because the use of unit trains from Alberta only began in October 2013 (Williams 2013), and specialized infrastructure would is needed to support the transport of raw bitumen.

Table 1: Logistics cost of bitumen shipping from Alberta to the USGC

	Rail	**Pipeline**
US DoS (2014)	Rawbit: \$17.76/bbl Railbit: \$21.69/bbl	Committed: \$16.14/bbl Uncommitted: \$25.30/bbl

Additionally, whether railroads would make the investments necessary to transport the expected 3 Mb/d in production growth is uncertain. The DoS (2014) finds that such growth would be consistent with the capacity expansion that took place to accommodate coal production from the Powder River Basin. However, Cairns (2013) opines that handling the 3 Mb/d growth is "probably a stretch too far" for the railroads. Because of these unresolved questions and their greater comfort with pipelines, Canada is in favor of pipelines, even if railroads could plausibly handle the traffic competitively.

By contrast, from the US perspective, the desirability of the two modes depends on the prioritization of its goals. Specifically, the production and refining of crude oil derived from oil sands bitumen results in higher GHG emissions as compared to other heavy crudes refined in the US by 2 to 13% (DoS 2014). If GHG emissions reductions are the priority, then denying pipeline permits may be preferable, because rail transport generally appears less economic, and its ultimate capacity is uncertain. Notably, analysis for the DoS (2014) finds one scenario in which a denial of the KXL would result in modestly less production from the oil sands.

However, if reducing GHG emissions were the priority, encouraging a GHG-reduction policy in Canada appears to be President Obama's preferred approach: "Canada at the *source* in those tar sands could potentially be doing more to mitigate carbon release" (The NY Times 2013, emphasis added). However, Prime Minister Stephen Harper downplays the issue: "[emissions from oil sands production are] almost nothing globally" (Fitzpatrick 2013). Although Canada has a GHG emissions reduction target for 2020, Canada does not have any federal policy for GHG emissions reductions from the oil sector. Combined with expected oil sands production growth, Canada is currently poised to *increase* carbon emissions from the baseline year (2005). Though the US is also not on track to meet the same GHG emissions-reduction goal as Canada, Canada's oil and gas sector is a critical component to meeting that goal, because it represents 23% of Canadian emissions in 2011 (Demerse and Partington 2013).

The resistance by Canada to implementing carbon constraints, particularly when the US president views them as a key priority also suggests that there is greater uncertainty over how the incremental cost of rail transport could impact oil sands production growth. One proposal by The Pembina Institute (an environmentally-inclined think tank) for a $150/tonne carbon tax would result in an effective cost of $2.87/barrel (Partington et al. 2013), which is well within the price differential between pipelines and rail. That the Canadian government has not put more modest proposals in place suggests that oil sands producers could be more cost sensitive than the DoS concludes.

The choice of transportation modes also affects the amount of GHG emissions. While pipelines are generally considered more energy efficient and produce fewer GHG emissions than unit trains, some research indicates that the opposite may be true. Because the power grid in the US Midwest relies on fossil fuels, unit trains may produce fewer GHG emissions than pipelines from Alberta to the USGC (Tarnoczi 2013). Because these results conflict with the information provided by the DoS (2014), more research is needed into the lifecycle impacts of the two modes; it should not necessarily be assumed that pipelines have lesser impacts in all cases.

The *local* environmental impacts from the bitumen production have not been a critical issue in the debate surrounding transportation capacity, unlike the issue over spills from pipelines and railcars. In terms of research, Crosby et al. (2013) finds "critical gaps in the current oversight, rules and regulations, contingency planning requirements, and response capacity to address the increasing transport of oil sands products," though there is no evidence that the transport of bitumen causes more spills (Barteau et al. 2013). Despite the concerns, the Canadian Government passed legislation in 2012 to give the federal cabinet final decision-making power over whether a project subject to environmental reviews proceeds, instead of the National Energy Board (NEB), the regulator of interprovincial and international pipelines in Canada, which aligns with their overall strategy of supporting pipeline development (Hoberg 2013). In the US, President Obama has emphasized concerns over GHG, but concerns over local environmental impacts are being litigated in state courts (Bernstein 2014).

Therefore, transport safety records merit examination. As tabulated in **Table 3**, railroads have a lower spill rate but a higher rate of injury as compared to pipelines. Although railroads have a lower spill rate per ton-mile than pipelines, they have a higher incident rate than pipelines. Therefore, on an environmental-impact basis, railroads perform modestly better than pipelines; yet public perception may still view railroads as less safe due to their higher incident rate. On a public safety basis, railroads have an injury rate 30 times higher than pipelines for the transport of petroleum products (though it is not clear from the cited report whether these accidents were solely related to the transport of the hazardous material) (Furchtgott-Roth 2013). As a result, the modal split between pipelines and railroads has safety implications, particularly from a public safety perspective.

More importantly, using historical data as a comparison has limitations, which is particularly of concern in the case of railroads, as they have not previously used unit trains to transport oil. This historical data does not include recent accidents involving crude oil, particularly the accident at Lac-Mégantic, in which approximately 38,000 barrels of oil was released (Beaudin 2013), almost double the amount of oil released (20,600 barrels) in the largest inland pipeline spill in the US (Reuters 2013). The chair of the Transportation Safety Board of Canada also emphasizes these concerns: "In this new environment, it is no longer enough for industry and government to cite previous safety records or a gradual, 20-year decline in the number of main-track derailments" (Tadros 2013). Therefore, public safety is an impact that needs to be mitigated if rail is to take a greater role in transporting crude oil, and new approaches to identifying hazards will be necessary to deal with such a major operational change.

Table 3: Historical safety record in transporting crude oil

Historical averages	Rail	Pipelines
Frequency (incident/billion ton-miles)	0.81–2.08	0.58–0.58
Typical Magnitude (barrels/incident)	16.4 – 65.7	266 – 269
Spill rate (barrels/million ton-miles)	2.2–3.5	6.3 - 11.3
Injuries* (incidents per billion ton-miles)	0.1925	0.0068
*Requiring hospitalization. Results only available from Furchtgott-Roth (2013). Sources: AAR (2013), Furchtgott-Roth (2013)		

Ultimately, whether President Obama, with the aim of reducing GHG emissions, justifies denying pipeline permits because it may constrain oil sands production is a value judgment in a political context. If he does so, he should also address the rail safety implications in his policies. However, because the performance of railroads is comparable to pipelines (though uncertain) along some dimensions economic and societal importance, the consequences of denying pipeline permits on GHG emissions, economic, and other environmental impacts are not as great as often presented in the political debate. As President Obama's deliberations unfold, as well as the evaluation process for pipelines in Canada, railroads are presented with considerable uncertainty, the implications of which on both the railroads, and by extension, governments, are now studied.

The railroads' perspective: a dynamic programming model

A dynamic program is used to determine if and when railroads would invest in capacity to transport crude oil from Alberta to the USGC (a representative destination). The problem horizon is 20 years starting in 2014. In total, there are five two-year periods and a final 10-year period. All values assumed in the analysis are given in **Table 9**.

The objective of railroads is to maximize profit, π, (in \$ million) over all periods. As provided in equation (1), profit in a given time period t is defined as the transportation rate per million barrels (R) minus the variable transportation cost per million barrels (VC) multiplied by the amount of crude oil shipped by rail in million barrels (FD_t) over the time period (i.e. (365×2) in the case of the first five time periods), minus the capital cost incurred ($CapCost_t$).

$$\pi = \sum_{t\in T} \pi_t = \sum_t (R - VC)(365\times 2)FD_t - \mathrm{CapCost_t} \qquad (1)$$

If such pipeline capacity were available to a destination, it is assumed that oil shippers would rather ship by pipeline. Therefore, as given in equation (2), fulfilled daily demand by rail (FD_t) is the minimum of the rail capacity (RC_t) that exists at the beginning of a given state, and the oil sands supply (OSS_t) that exceeds pipeline capacity (PLC_t). Oil sands supply and pipeline capacity are stochastic. All units are in millions of barrels per day (Mb/d).

$$FD_t = \min[\max[(OSS_t - PLC_t), 0], RC_t] \qquad (2)$$

The capital cost (in \$ million), given in equation (3), is the sum the infrastructure investment cost ($LCost_t$) and the locomotive purchase costs ($ICCost_t$). The factors used to convert rail capacity investment actions (dRC_t, in million barrels per day) into these respective costs are given in **Table 9**. This analysis assumes that the railroad companies are currently operating at their infrastructure and locomotive capacity limit, and thus transporting oil would require an immediate investment.

$$\mathrm{CapCost_t} = \mathrm{LCost_t} + \mathrm{ICCost_t} \qquad (3)$$

The dynamic programming problem value function (in \$ million) used in time periods 1 through 5 is given by equation (4). The value function represents the best possible present value of expected profits that the railroads could achieve, given current railroad capacity at time t and optimal capacity investments in all future periods. The expected value (i.e. $E[\dots]$) accounts for the future variability of pipeline capacity and oil sands supply. In essence, the value function at time period t (V_t) is expressed as a trade-off between immediate and discounted future rewards. The value function is calculated recursively starting with the last time period and working backwards.

$$V_t(RC_t, PLC_t, OSS_t) = \max_{dRC_t}\{(R - VC)FD_t - CapCost_t + (1 + dr)^{-2}(E[V_{t+1}(RC_{t+1}, PLC_{t+1}, OSS_{t+1})])\}, \forall t = 1, 2, 3, 4, 5 \quad (4)$$

Equation (4) is used for the first five time periods; the value function for the last 10-year time period (t = 6) is provided by equation (5). This equation assumes that the annual profit the railroads receive is an annuity throughout the time period and dependent on the railroad capacity, pipeline capacity, and the oil sand supply at the beginning of the period. The annuity is converted to a present value at the start of the period using a present value factor.

$$g(RC_t, PLC_t, OSS_t) = (R - VC)(FD_6)(365)\left(\frac{1-(1+dr)^{-10}}{dr}\right), t = 6 \quad (5)$$

The maximum possible railroad capacity (including infrastructure and locomotives) expansion (dRC_t) in one period was assumed to be 0.6 Mb/d in 0.2 Mb/d increments. This value was selected to correspond with the maximum possible oil sands expansion, but is also plausible based on experience from the Bakken-formation region, where rail traffic increased by about 0.4 Mb/d between 2012 and 2013 (AAR 2013). Assuming that this trend could continue, the capacity expansion would be 0.8 Mb/d over a two-year period.

Table 4 presents the oil sand supply probability mass function (PMF) used for all periods (i.e. the probability [P_t^{OSS}] of a possible growth in oil sands supply [ω_t^{OSS}] in any period), an approximation of the low, reference, and high oil sand production forecasts from the NEB (2013). It is assumed that oil sands supply in the subsequent time period cannot exceed the crude oil transportation capacity, as given by equation (6).

$$OSS_{t+1} = \min(OSS_t + \omega_t^{OSS},\ PLC_t + \omega_t^{PL} + RC_t + dRC_t) \quad (6)$$

Table 4: Probability mass function for oil sands supply.

$\boldsymbol{\omega_t^{OSS}}$	**0.0**	**0.2**	**0.4**	**0.6**	**(Mb/d)**
P_t^{OSS}	0.0	0.1	0.8	0.1	$\forall t \in T$

Possible pipeline expansion projects are listed in **Table 5**. The probabilities that these pipelines are approved or not approved are assigned using judgment based on (1) the discussion in the first section of this paper, and (2) the understanding of the decision-making authority of Canadian and US governments regarding pipelines. The selection of probabilities is also guided by a framework proposed by Hoberg (2013) used to characterize the political risks of pipeline approvals. Because the PMF relies on judgment, three scenarios, "low", "base" and "high" were considered.

Table 5: Possible pipeline capacity expansion in time periods 1 and 2.

Pipelines	**Capacity (b/d)**
Require US approval; decision expected in period 1	*1,180,000*
Enbridge Alberta Clipper (AC) (Phase 1)	120,000
Enbridge Alberta Clipper (AC) (Phase 2)	230,000
TransCanada Keystone XL (KXL)	830,000
Require Canadian approval; decision expected in period 2	*2,215,000*
Enbridge Northern Gateway (NG)	525,000
Kinder Morgan Trans Mountain Expansion (TMX)	590,000
TransCanada Energy East (EE)	1,100,000

The decisions in period 1 are subjected to the uncertainty of whether President Obama will approve approximately total 1.2 Mb/d of capacity from Canada to the US. Possible increments of pipeline capacity (ω_1^{PLC}) in period 1 and their associated probability (P_1^{PLC}) are given in **Table 6** for "low", "base", and "high" scenarios.

Table 6: PMF of pipeline capacity expansion, period 1.

$\boldsymbol{\omega_1^{PLC}}$	**0.0**	**1.2**	**(Mb/d)**
P_1^{PLC}	0.6	0.4	(low)
P_1^{PLC}	0.4	0.6	(base)
P_1^{PLC}	0.2	0.8	(high)

In time period 2, it is uncertain whether the Canadian government will approve up to 2.4 Mb/d of capacity. Possible increments of pipeline capacity in period 2 (ω_2^{PLC}) and their associated probability (P_2^{PLC}) are given in **Table 7** for "low", "base", and "high" scenarios.

A priori, the "base" scenario PMF seems reasonable given current knowledge. These probabilities were determined by assuming a probability of approval for each of the Canadian pipelines, listed in **Table 8**, and using a probability tree to determine the probability of each increment of capacity expansion being approved from zero to 2.4 Mb/d. While the current Conservative party government is supportive of pipeline projects, because the next federal election is upcoming in 2015, the results of the next election will ultimately impact the approval of specific pipelines proposed entirely within Canada. Therefore, it is plausible that no pipeline capacity is developed or that all the proposed capacity develops, with assigned probabilities of 0.14 and 0.21, respectively. It also seems reasonable that the most likely eventuality is that 1.2 Mb/d of pipeline per day develops, which this corresponds to the capacity of the EE pipeline *or* the sum of the NG and TMX pipelines. The "low" and "high" scenario PMFs also seem like reasonable bookends of possible distributions. Therefore, even though the PMFs rely on judgment, the range provided reflects currently available information.

Table 7: PMF of pipeline capacity expansion, period 2.

$\boldsymbol{\omega_2^{PLC}}$	**0.0**	**0.6**	**1.2**	**1.8**	**2.4**	**(Mb/d)**
P_2^{PLC}	0.378	0.132	0.342	0.088	0.060	(low)
P_2^{PLC}	0.140	0.120	0.350	0.180	0.210	(base)
P_2^{PLC}	0.030	0.044	0.246	0.176	0.504	(high)

Table 8: Probabilities assigned to Canadian pipeline expansion.

	Approval probability			**Comments**
	Low	**Base**	**High**	
NG	0.3	0.5	0.7	This pipeline involves construction of a new right-of-way (ROW) through rugged terrain, and there is significant local and First Nations opposition to it.
TMX	Given NG approved:			This pipeline uses existing ROW and the permitting decision will follow the NG; therefore, there is likely correlation between the two decisions.
	0.5	0.7	0.9	
	Given NG denied:			
	0.1	0.3	0.5	
EE	0.4	0.6	0.8	This pipeline will use an existing natural gas pipeline for much of the route, and there appears to be fairly broad support for this proposal. However, the proposal is the least well scrutinized to date.

Results and discussion

Figure 1 contains the optimal policy matrices – the mapping between the state in period t and the best capacity investment action to take – calculated for the "base" assumptions. The matrices for time periods 1 (2014), 2 (2016), and 3 (2018) are stacked vertically, and for pipeline capacities of 0.0 and 1.2 Mb/d are arranged horizontally. Within each policy matrix, the rows correspond with the railroad capacity (RC) and the columns correspond with the oil sands supply that exists that exists at the beginning of the corresponding time period. The cells contain the optimal railroad capacity investment.

		Pipeline Capacity = 0.0							Pipeline Capacity = 1.2						
	RC \ OSS	**0.0**	**0.2**	**0.4**	**0.6**	**0.8**	**1.0**	**1.2**	**0.0**	**0.2**	**0.4**	**0.6**	**0.8**	**1.0**	**1.2**
t = 1	**0.0**	0.0													
t = 2	**0.0**	0.0							0.0	0.0	0.0	0.0			
	0.2	0.0	0.0						0.0	0.0	0.0	0.0			
	0.4	0.0	0.0	0.0					0.0	0.0	0.0	0.0			
	0.6	0.0	0.0	0.0	0.0				0.0	0.0	0.0	0.0			
t = 3	**0.0**	**0.6**							0.0	0.0	0.0	0.0	**0.2**	**0.4**	**0.6**
	0.2	**0.4**	**0.6**						0.0	0.0	0.0	0.0	0.0	**0.2**	**0.4**
	0.4	**0.2**	**0.4**	**0.6**					0.0	0.0	0.0	0.0	0.0	0.0	**0.2**
	0.6	0.0	**0.2**	**0.4**	**0.6**				0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.8	0.0	0.0	**0.2**	**0.4**	**0.6**			0.0	0.0	0.0	0.0	0.0	0.0	0.0
	1.0	0.0	0.0	0.0	**0.2**	**0.4**	**0.6**		0.0	0.0	0.0	0.0	0.0	0.0	0.0
	1.2	0.0	0.0	0.0	0.0	**0.2**	**0.4**	**0.6**	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Figure 1: Policy matrices for the "base" scenario (Mb/d).

Assuming that railroads are operating at capacity, the results imply that they should not invest in capacity in 2014 (t = 1), nor in 2016 (t = 2), even if the KXL and AC are *not* approved. Railroads should only invest in capacity in 2018 (t = 3) if pipelines are nearing capacity, which implies that in the absence of uncertainty, the market is lucrative for railroads. Of course, there are going to be some specific geographic markets not served by pipelines in which rail transport is desirable regardless of whether pipelines are approved, which the model does not account for. However, on the whole, the base results suggest railroads should be cautious in terms of making any long-term capacity investments in competition with pipelines.

Figure 2 compares the policy matrices for the “low” (left) and “high” (high) scenarios. Only under a scenario in which there are *low* probabilities of pipeline approvals should railroads begin investing in capacity in periods t = 1 and t = 2. The results suggest that 0.4 Mb/d of capacity could be invested now (in 2014), and an additional up to 0.4 Mb/d could be invested in 2016, depending on oil sands supply growth; if growth were large in period 1, then more railroad capacity could built in period 2.

		Low likelihood of pipeline appr. Pipeline Capacity = 0.0							High likelihood of pipeline appr. Pipeline Capacity = 0.0						
	RC \ OSS	**0.0**	**0.2**	**0.4**	**0.6**	**0.8**	**1.0**	**1.2**	**0.0**	**0.2**	**0.4**	**0.6**	**0.8**	**1.0**	**1.2**
t = 1	**0.0**	**0.4**							0.0						
t = 2	**0.0**	**0.4**							0.0						
	0.2	**0.2**	**0.4**						0.0	0.0					
	0.4	0.0	**0.2**	**0.4**					0.0	0.0	0.0				
	0.6	0.0	0.0	**0.2**	**0.4**				0.0	0.0	0.0	0.0			
t = 3	**0.0**	**0.6**							**0.6**						
	0.2	**0.4**	**0.6**						**0.4**	**0.6**					
	0.4	**0.2**	**0.4**	**0.6**					**0.2**	**0.4**	**0.6**				
	0.6	0.0	**0.2**	**0.4**	**0.6**				0.0	**0.2**	**0.4**	**0.6**			
	0.8	0.0	0.0	**0.2**	**0.4**	**0.6**			0.0	0.0	**0.2**	**0.4**	**0.6**		
	1.0	0.0	0.0	0.0	**0.2**	**0.4**	**0.6**		0.0	0.0	0.0	**0.2**	**0.4**	**0.6**	
	1.2	0.0	0.0	0.0	0.0	**0.2**	**0.4**	**0.6**	0.0	0.0	0.0	0.0	**0.2**	**0.4**	**0.6**

Figure 2: Policy matrices for “low” and “high” scenarios (Mb/d).

There is also sensitivity to capital costs. If capital costs were lower than the assumed values by 25%, then it is optimal for railroads to invest 0.4 Mb/d in time period 1, presumably because there would be time to recoup the capital costs before any pipelines are built. If the capital costs were in fact 50% lower than predicted, then a similar policy to what applies in the “low” probability case would apply.

Collectively, this analysis reveals that in the short term (until uncertainty over pipeline permit approvals is resolved), railroads should be cautious about making significant investment decisions for routes where they would be in direct competition with pipelines, unless capacity investments are relatively inexpensive. The risk that the pipelines could be approved dominates the fact that the market would be lucrative for the railroads in the absence of uncertainty. However, if railroads have low-cost capacity expansions available to them, then it is optimal for them to start transporting oil now, as there is more certainty that they can recoup lower capital costs.

For governments, these results suggest that any hesitation by the railroads in transporting crude oil is partly as a result of the uncertainty over pipeline approval. From the perspective of President Obama, this uncertainty may be desirable in terms of slowing down possible production expansion in the oil sands, thus decreasing GHG emissions. It also maintains pressure on the Canadian government to implement its own federal policy to manage GHG emissions in the oil and gas sector. From the Canadian perspective, they wish to remove this uncertainty by approving proposed pipelines as soon as possible.

Table 9: Parameter values used in the dynamic programming model.

Parameter	**Value**
Car cycle time, CCT	21 days[a]
Rate, R	$ 10.88/barrels [b]
Variable Cost, VC	1/1.8 of rate [c]
Cars per train, CPT	100 cars
Car capacity, CC	525 barrels/car [d]
Tank car gross weight, TCGW	286,000 lb/car
Horsepower per locomotive, HPPL	4400 hp
Horsepower per trailing ton, HPT	0.6 hp/ton
Average length of haul, ALoH	2485 miles [e]
Infrastructure capacity unit cost, CI	$1.8 million/ train/day/100 miles[f]
Locomotive unit cost, CL	$2 million/ locomotive [g]
Trains per unit of capacity, NT	$1/(CC \times CPT)$
Locomotives per train, LPT	$[(CPT)(TCGW)(HPT)/HPPL]$
Total locomotive costs, $LCost_t$	$(CL)(CCT)(NT)(LPT)(dRC_t)$
Total infrastructure capacity cost, $ICCost_t$	$(CI)(ALoH/100)(NT)(dRC_t)(2)$
Discount rate, dr	11% [h]

[a]The travel time from Alberta to the USGC is 8-10 days by rail (Carey 2013); [b]US DoS (2014), p. 2.2-30; [c]The maximum rate that a railroad can charge without review by the Surface Transportation Board (STB); [d]Cairns (2013); [d]The rail distance from Lloydminster, SK to Port Arthur, TX (US DoS 2014); [f]Lai and Barkan (2009) calculate the approximate cost of capacity using sidings for a typical 100-mile long subdivision; [g]Hagerty and Linebaugh (2012); [h]STB's cost of capital for railroads in 2012 (Progressive Railroading 2013).

Conclusions

This paper finds that a more holistic study of the performance of railroads and pipelines for crude oil transport provides a deeper understanding of possible strategies. In the short term, railroads should be cautious about investing in capacity until pipeline permit decisions are made. President Obama could thus maintain uncertainty over pipeline approvals to reduce GHG emissions and to pressure the Canadian government to implement an oil and gas sector GHG-reductions policy. The current Canadian government strategy is to mitigate this uncertainty through the approval of pipelines, though uncertainty over their approval will likely remain until after the federal election in 2015.

In the long term, if pipeline permits are denied, the dynamic programming model suggests that capacity investments are lucrative for railroads. If, as a result, governments rely more on rail transportation, the mitigation of public safety impacts would need to be prioritized. However, because the performance of railroads is comparable (though uncertain) to pipelines along some dimensions economic and societal importance, the consequences of denying pipelines on GHG emissions, economic, and other environmental impacts are not as great as often presented in the political debate. Therefore, greater emphasis should be on efforts to improve the overall system, such as implementing appropriate safety or climate policies, rather than debating the merits of a particular mode.

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[1] Regular paper