Empirical Analysis of Energy Pipeline Safety

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Abstract

This paper investigates the variables associated with safety performance of Canadian oil and gas pipelines. We construct a data set that including minor and major pipeline adverse events, environmental and safety regulations, pipeline throughput and physical characteristics for federally-regulated oil and gas pipelines in Canada. The results of show that the introduction of environmental abandonment fees is positively and significantly related to increases in the probability and number of pipeline minor incidents. Absolute liability for adverse pipeline events is associated with significant decreases in the probability and number of pipeline serious accidents. Absolute liability has reduced serious accidents more for oil pipelines than for natural gas pipelines.

Keywords: Environmental Regulation; Pipeline Safety
JEL Code: L95, L98, Q35.

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1 Introduction

In 2017, more than 95% of Canadian crude oil and natural gas was transported from Canada to world markets through pipelines. Industry participants, regulatory authorities and the public have argued that inadequate pipeline capacity depresses Canadian oil prices and reduces public revenue (NEB, 2016; Heyes et al., 2017; Aliakbari and Stedman, 2018; Walls and Zheng, 2020). Inadequate transportation infrastructure places the Canadian energy sector at a considerable disadvantage, and could lead pipelines to operate beyond capacity (Dachis, 2018). However, building new pipelines or expanding existing pipeline capacity in Canada is constrained. For example, Trans Canada Keystone XL pipeline, a major expansion of Canadian existing pipeline capacity, was blocked during the Obama administration. Although proponents argued that pipeline construction would bring local economic benefits, mounting concerns from the public emphasized the safety issues associated with possible oil spills.

Canada's National Energy Board (NEB) introduced a set of new policies to mitigate environmental impacts and improve pipeline safety for all oil and gas pipelines under its jurisdiction.[1] Since 2009, the NEB has been working to establish a pipeline abandonment fund for all pipelines under its jurisdiction. Each pipeline company is required to evaluate and report future costs of abandonment, including all costs associated with environmental risks during dismantling. A pipeline company then amortizes its abandonment fee and makes payments annually to a third party fund. Also, the most significant changes to the *Pipeline Safety Act*, which came into force in June 2016, allow the NEB to handle pipeline incidents or accidents by requiring pipeline companies to assume *absolute liability*. The concept of absolute liability makes companies operating oil and gas pipelines responsible for all costs and damages, regardless of the origin of the fault.

These new policies are intended to reduce the environmental impact and to improve the safety performance of Canadian oil and gas pipelines. Nevertheless, how effective the new regulations have been in improving pipeline safety outcomes remains open to question. The new regulations may impose significant financial costs on pipeline companies, which may or may not be passed on to their consumers. As a consequence, pipeline companies could reduce current expendi-

[1]The NEB regulates energy pipelines that cross provincial borders. Other pipelines are regulated by provincial l authorities.

tures by deferring maintenance and repair, increasing the risk of adverse pipeline events.[2] This paper provides the first quantitative evidence on the effectiveness of the new set of policies on decreasing energy pipeline safety risks in Canada. We find that abandonment fees are significantly and *positively* related to the occurrence and number of pipeline incidents. On average a 10% increase in the share of abandonment fees in sales revenue is associated with 1.63 more incidents per month. We also find that the imposition of absolute liability, since 2016, is associated with significant decreases in the probability and number of serious accidents. The number of accidents was reduced by 0.0270.028 per month since the establishment of absolute liability, approximately equivalent to eliminating a pipelines monthly accident occurrence. Moreover, implementing absolute liability is more effective in decreasing accident occurrences for Canadian oil pipelines than for natural gas pipelines. This may weaken the general success of establishing absolute liability since natural gas pipelines generate accidents more frequently than oil pipelines.

This article contributes to the literature on the impact of regulatory intensiveness of environmental hazards. One strand of this literature focuses on the effectiveness of regulatory enforcement in improving the safety performance of hazardous material transportation. Using a dataset of pipeline operators in the U.S. from 2006 to 2011, Stafford (2014) finds that federal inspections and civil penalties are *not* particularly effective at enhancing pipeline safety. Moreover, Stafford (2017) analyzes the role that US states play in enforcing federal natural gas pipeline regulations. Her results imply that states' assumed oversight has *not* significantly improved the safety performance of natural gas pipelines. Our paper contributes to this strand of literature by examining the impact of the stricter regulation on the safety performance of Canadian energy pipelines. The context of Canadian regulation is novel, and its extent is more stringent than U.S. federal compliance inspections and penalties. We show that more stringent regulation, such as imposing absolute liability, could lead to a reduction in serious pipeline accidents.

This paper also adds to the broader literature on the determinants of trans-

[2] The managerial incentives of pipeline companies could be distorted due to regulation. For example, Hausman and Muehlenbachs (2019) show that rate-of-return regulation led natural gas pipeline companies in the U.S. to pass through the cost of leaked natural gas to their consumers, spending too little on repairing leaks.

portation safety for hazardous materials (e.g., Restrepoa et al., 2009; Sosaa and Alvarez-Ramirezb, 2009; Gough et al., 2014; Strogen et al., 2016). Perhaps the most closely related paper is Mason (2018), which examines the relationship between increased crude oil shipments by rail and the incidents and accidents of railways in the U.S. His results indicate that there is a positive link between the accumulation of minor incidents and the frequency of serious incidents. As well, there is a positive relationship between increased crude-by-rail shipments and the occurrence of incidents. We contribute to this literature by investigating the determinants of pipeline safety in Canada. To do so, we construct a large dataset consisting of key variables associated with pipeline safety, including oil and gas throughput, regulatory structure, and physical characteristics. Consistent with the literature, we find that increased oil and gas throughput is *positively* associated with the occurrences of pipeline incidents. In addition, there is *positive* link between increased cumulative incidents and the occurrences of serious pipeline accidents.

2 Dataset Construction and Description

2.1 Pipeline Incidents and Accidents

We obtain information, from the Transportation Safety Board (TSB), on adverse events for all federally-regulated pipelines from 2006 to 2017. The TSB reports the date and location of each adverse event and whether it is associated with rupture, injury, death, evacuation, or environmental impact. Events are classified into two types: incidents and accidents. An incident represents an uncontrolled release of a commodity, with a minor effect on human lives and environment. Accidents result in substantial substance releases, human injuries and deaths, or significant environmental impact. We link the data on pipeline event occurrences to the NEB's database of each pipeline's monthly throughput and physical characteristics, including length, age, nominal pipeline size, building materials, and transporting products.

Fourteen pipelines under NEB jurisdiction are included in the sample (See Table 1 below). Eight pipelines carry natural gas, while the remainder transport oil, refined petroleum products, or condensate. These fourteen pipelines accounted for more than 85% of safety events from 2006 to 2017 as reported by TSB. Figure

1 plots the distribution of historical incidents and accidents along the Canadian pipeline system. Figure 2 shows the numbers of quarterly incidents and accidents over time for all pipelines.[3] The number of incidents has increased since 2009. In contrast, the number of accidents rose sharply from 2009 to mid-2010 but fell thereafter.

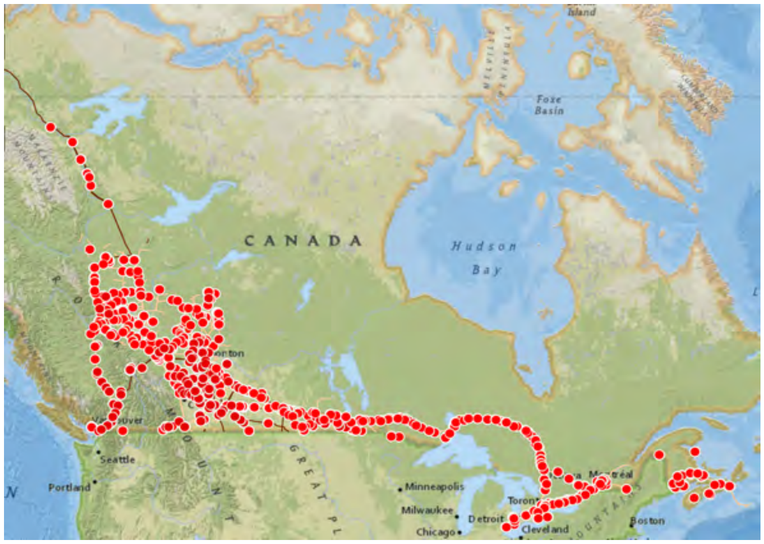
Table 2 indicates that the number of incidents and accidents per month are strongly right–skewed with a large number of zero observations. Therefore, we apply three types of non–linear models of count data in the analysis: Logit, Poisson, and negative binomial regression.[4]

Table 1: Pipelines in the Sample

Pipeline Name	Transported Substance
Alliance	Natural Gas
Kinder Morgan Cochin	Light Condensate
Emera Brunswick	Natural Gas
Enbridge Mainline	Crude Oil; Petroleum Refined Products
Foothills	Natural Gas
Keystone	Crude Oil
Maritimes & Northeast	Natural Gas
NOVA (NGTL)	Natural Gas
Enbridge Norman Wells	Crude Oil
TransCanada Mainline	Natural Gas
Trans Qubec & Maritimes (TQM)	Natural Gas
Trans Mountain	Crude Oil; Petroleum Refined Products
Trans-Northern	Petroleum Refined Products
Westcoast	Natural Gas

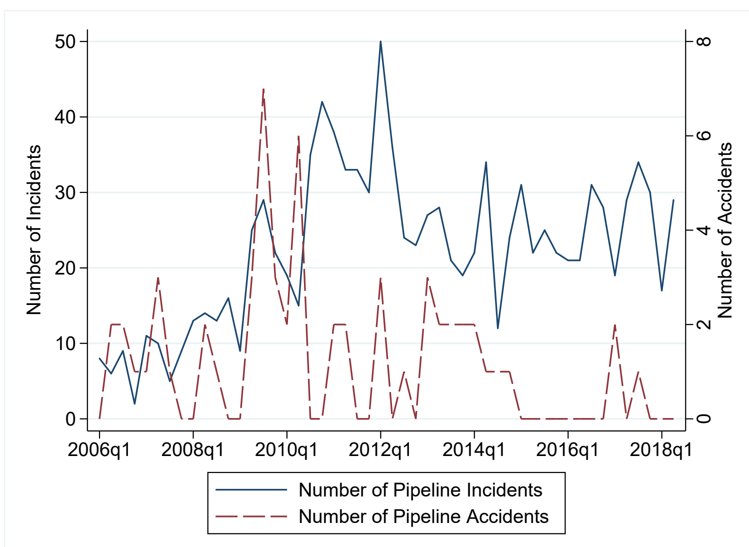
[3] We have converted monthly data to quarterly pipeline occurrences for the purpose of exposition in Figure 2.

[4] OLS is inappropriate in modeling pipeline events as the dependent variables are not normally distributed. We will discuss this further in Section 3.



Source: NEB

Figure 1: The Distribution of Historical Incidents and Accidents along the Canadian Pipeline System



Source: Authors' calculation

Figure 2: Number of Incidents and Accidents for All Pipelines in Canada

Table 2: Distribution of Number of Incidents and Accidents

Number of Incidents	Frequency	Percent(%)	Cumulative Percentage (%)
0	1,277	68.11	68.11
1	326	17.39	85.49
2	153	8.16	93.65
3	50	2.67	96.32
4	40	2.13	98.45
5	17	0.91	99.36
6	6	0.32	99.68
7	1	0.05	99.73
8	1	0.05	99.79
10	2	0.11	99.89
12	1	0.05	99.95
15	1	0.05	100
Skewness		3.63	
Kurtosis		26.03	

Number of Accidents	Frequency	Percent(%)	Cumulative Percentage (%)
0	1,822	97.17	97.17
1	48	2.56	99.73
2	4	0.21	99.95
3	1	0.05	100
Skewness		7.23	
Kurtosis		66.67	

2.2 Throughput and Other Characteristics

We obtain from the NEB monthly throughput for all pipelines listed in Table 1. There are two types of pipeline configurations in the sample: multiple key points and single key point.[5] Half of the pipelines in the sample consist of multiple key points. For a single-key-point pipeline, the observation of throughput is unique within a period (e.g. one month). As such, we directly link monthly average throughput to the number of pipeline events within a month for the single-key-point pipelines.

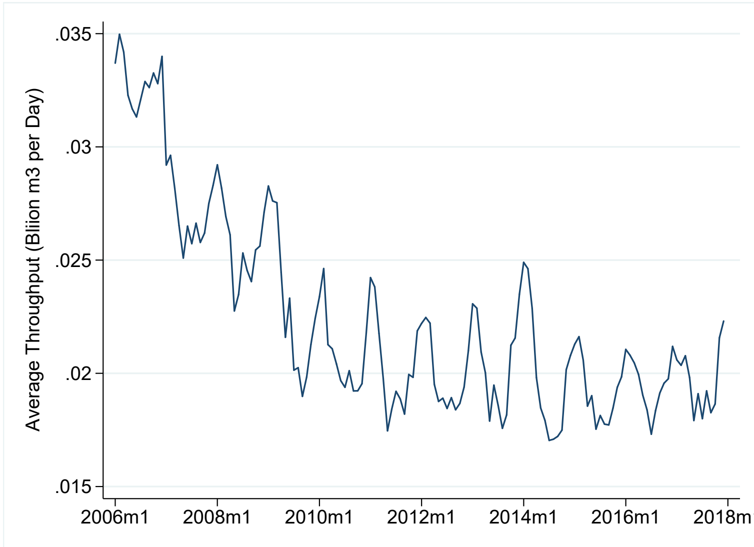
For multiple-key-point pipelines, throughput may vary across different key points. Also, throughput may further differ by the purpose of transportation within a key point. For example, for the key point of Sarnia, affiliated with the Trans Canada Mainline pipeline, NEB reports throughput by three types of shipping: intra-Canada, export, and import. This creates a difficulty in matching

[5] A key point of a pipeline refers to a main delivery or receiving point where key parameters of operation, such as pressure, throughput, and utilizing capacity, can be recorded.

a pipeline incident or accident uniquely to throughput for a specific period. In most cases, only one transportation type is in use for a key point in a given month. Therefore, we aggregate throughput for all types of transportation for a key point in a month. Next, we compute the distances between the location of an incident or accident and each key point for a pipeline.[6] A pipeline incident or accident is then paired with the nearest key point at the time of the event. This procedure allows each incident or accident to be matched with the nearest-key-point throughput, which reflects a pipeline's operational condition at the time of an adverse event occurrence.

Figure 3 plots average throughput across all pipelines from 2006 to 2017. The average throughput exhibits an apparent seasonal cycle: The average throughput usually increases during winter heating seasons. This implies that it is necessary to control the seasonal effect by using monthly dummies. We also include the other key characteristics of pipelines as control variables in the analysis. The set of control variables consists of pipeline age, length, nominal pipeline size (i.e. outside diameter), and a set of indicator variables for products transported and construction materials. All these variables are time-invariant except age, and they are assumed to be pre-determined. Summary statistics of these control variables are displayed in Table 4.

[6] We extract the values of longitude and latitude for all key points for multiple-key-point pipelines in our sample. We also obtain the longitude and latitude for each pipeline incident or accident from TSB. The distance between location of an incident or accident and a key point is calculated by the "Haversine" formula, which represents the shortest distance between two points over the Earth's surface.



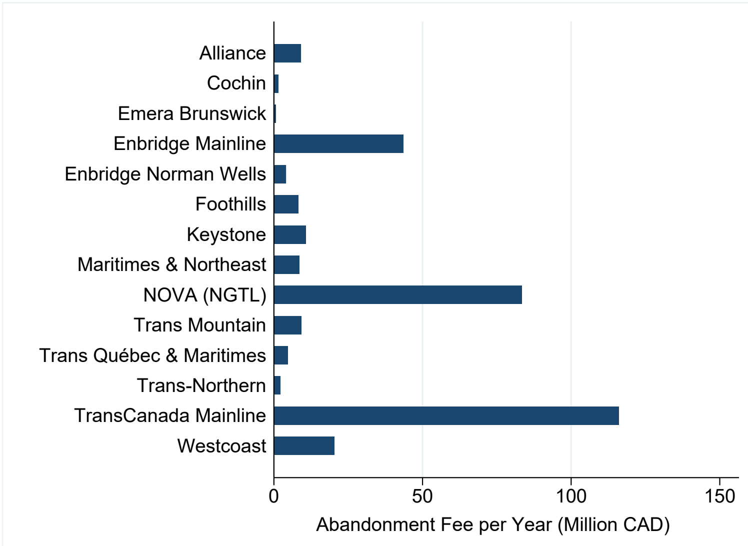
Source: Authors' Calculation

Figure 3: Average Throughput across Pipelines

2.3 Abandonment Fee and Absolute Liability

Since 2009, the NEB has been working to establish a pipeline abandonment fund for each pipeline it regulates. All NEB-regulated pipelines are required to set aside funds in a third-party trustee account to safely cease operation at the end of its life. Pipeline companies are required to submit abandonment cost estimates and their amortization schedules. The abandonment fee for a pipeline is then collected in annual installments until the pipeline is abandoned. When a company applies for abandonment, the NEB holds hearings to ensure that abandonments are carried out safely and that potential environmental, socio-economic, and financial impacts are properly addressed. Figure 4 shows the annual abandonment cost estimates for all pipeline companies in the sample. It ranges from the highest cost of $120 million per year for the Trans Canada Mainline (TCM) to the lowest cost estimate of $0.57 million per year for the Emera Brunswick Pipeline. The cost to safely abandon all NEB–regulated pipelines is more than $8.5 billion.[7]

[7]The total cost is computed by multiplying annually amortized abandonment fee with years of amortization for each pipeline and summing them over for all pipelines.



Source: NEB and Authors' calculation

Figure 4: Abandonment Fee per Year

Since June 2016, the *Pipeline Safety Act* (PSA) requires that pipeline companies hold enough financial resources to pay the cost associated with adverse outcomes of an incident or accident. Pipeline companies are liable for all losses and damages from an adverse event up to $1 billion, regardless of the origin of the fault. Pipeline companies must demonstrate to the regulatory authority that they have sufficient financial resources to cover absolute liabilities. Table 3 presents the class of absolute liability for all NEB-regulated pipelines. The absolute liability limits for an oil pipeline, carrying crude oil or petroleum refined products, is based on pipelines' average throughput in previous years. There are three oil pipelines falling into the highest $1 billion class: Enbridge Mainline, Trans Mountain, and Keystone. The remaining oil pipelines in our sample are subject to the second class ($300 million) of liability. In contrast, natural gas pipelines fall into different limit classes by risk values. NEB calculates the risk value of a natural gas pipeline by the square of the outside diameter (mm) multiplied by the maximum operational pressure (MPa) of a pipeline. Therefore, unlike oil pipelines, the class of absolute liability for a natural gas pipeline is based on physical characteristics.

The data consist of a monthly panel including fourteen NEB-regulated pipelines in Canada. The data span January 2006 to December 2017 and are an unbalanced panel as pipelines entered into service at different times. Table 4 presents summary statistics for the primary variables of interest. The average number of incidents per pipeline is 0.6 per month, and accidents only occur 0.03 times per pipeline per month. The annual abandonment fee is not negligible when compared to a pipeline company's sales revenue. The mean share of abandonment fee in a pipeline company's sales revenue is about 4.3%, and the largest share of abandonment fee reaches 8.7%.[8] The last three rows report pipeline physical characteristics, including age, size, and length. The physical characteristics vary substantially across pipelines.

Table 3: Absolute Liability for Energy Pipeline Regulated by NEB

Crude Oil and Petroleum Refined Products		
Class	Criteria	Absolute Liability Limit
class 1	throughput $\geq$ 250,000 bpd*	$1 billion
class 2	50,000 $\leq$ throughput $<$ 250,000 bpd	$300 million
class 3	throughput $<$ 50,000 bpd	$200 million

Natural Gas		
Class	Criteria	Absolute Liability Limit
class 1	risk value** $\geq$ 1000,000.	$200 million
class 2	15 000 $\leq$ risk value $<$ 1000,000	$50 million
class 3	risk value $<$ 15,000	$10 million

The Other Commodity		
Class	Criteria	Absolute Liability Limit
class 1	in a liquid state	$10 million
class 2	in a gaseous state	$5 million

*bpd denotes barrels per day

** risk value=the square of the outside diameter of a pipelines (mm) $\times$ the maximum operation pressure (MPa)

[8]The share of abandonment fee in sales revenue is zero before 2009 as NEB started applying abandonment fees in 2009. We focus on this variable because the impact of abandonment fee on firms' managerial decisions depends on the magnitude of abandonment fee relative to firms' sizes. We are only able to observe firms' annual sale revenues rather than operating costs in our data. Therefore, we normalized abandonment fees by sales revenue in terms of percentage. Alternatively, we can normalize abandonment fees by pipelines' operating capacities. This option produces similar estimated marginal effects of abandonment fees but make the estimates less significant. A possible explanation for this result is that the variations in capacity are much smaller than the variations in sale revenue.

Table 4: Summary Statistics

Variable	Unit	No. of Obs	Mean	Std. Dev.	Min	Max
No. of Incidents	Natural Number	1,875	0.600	1.195	0	15
No. of Accidents	Natural Number	1,875	0.031	0.195	0	3
Pipeline Throughput	Billion Cubic Meters per Day	1,875	0.024	0.062	0	1.355
The Share of Abandonment Fee in Sales Revenue	%	1,113	4.29	2.022	0.494	8.704
Pipeline Age	Years	1,874	37.30	20.89	0	66.42
Nominal Pipeline Size (Outside Diameter)	Inches	1,875	14.566	13.406	0.375	36
Pipeline Length	Kilometers	1,875	817.92	672.977	6.461	2896

3 Empirical Analysis of Pipeline Incidents

3.1 Pipeline Incidents

Our first equation to analyze pipeline incidents is,

$$\begin{aligned} Incident_{it} =& \alpha + \beta_1 Throughput_{it} + \beta_2 Abandonment_{it} + \beta_3 Liability_t \\ &+ \mathbf{X_{it}}\theta + \varepsilon_{it}, \end{aligned} \tag{1}$$

where $Incident_{it}$ is the number of incidents for pipeline i at time t; $Throughput_{it}$ denotes the log of pipeline throughput for pipeline i at time t; $Abandonment_{it}$ represents the share of abandonment fee in pipeline i's sales revenue at time t; $Liability_t$ is an indicator variable that equals one after June 2016 and zero otherwise. The *liability* variable captures the effect of absolute liability established by the regulator since June 2016. $\mathbf{X}$ is a vector of control variables that consists of a pipeline's age, size, length, a set of indicator variables if a pipeline transports crude oil, condensate, or refined products, an indicator variable equal to one if a pipeline is built by using stainless steel and zero otherwise, and monthly dummies.[9] The parameters of interest are β_1, β_2, and β_3. They quantify the relationship between the number of incidents and pipeline throughput, amortized abandonment fees, and absolute liabilities. As the dependent variable is strongly right–skewed, equation (1) is estimated by two types of count data models: Poisson and negative binomial. We also replace the number of incidents by a binary variable that equals one if an incident occurs and zero otherwise; we then

[9]All the pipelines in the sample transport four substances: natural gas, crude oil, condensate, and petroleum refined products where natural gas is the reference group. Pipelines are constructed by using two types of materials: stainless steel or carbon steel.

re-estimate equation (1) as a Logit model.[10]

The estimated results of equation (1) in Table 5 indicate that the frequency of incidents significantly increases with throughput, abandonment fee, nominal pipeline size, the status of stainless steel pipelines, and the status of oil pipelines. The estimated variance parameter α is 0.816 and the null hypothesis that $\alpha = 0$ is rejected at the 1% significant level.[11] This implies the presence of over–dispersion for our count data. Therefore, we favor the negative binomial over the Poisson model when interpreting the results.

Table 6 presents the marginal effects for estimating equation (1). We mainly focus on the negative binomial model, since it provides consistent estimates in the presence of over-dispersion. The marginal effect of $ln(throughput_{it})$ in column (3) suggests that a 10% increase in throughput is associated with 1.62 additional pipeline incidents per month. A 10% increase in the share of abandonment fee in sales revenue is associated with 1.63 more incidents per month. However, the marginal effect of absolute liability is negative but *insignificant* across specifications. This indicates that the absolute liability established by NEB since 2016 has *not* had a statistically significant impact on incident occurrences.[12]

The estimated marginal effects of control variables are also informative. For example, pipeline age and length do *not* affect pipeline incidents at the 5% significance level. However, the number of pipeline incidents would significantly rise by 0.22 per month if pipelines' nominal sizes increase by 10 inches. Stainless steel pipelines generate 1.68 more incidents per month than carbon steel pipelines. Lastly, crude oil and petroleum refined product pipelines are 35% and 52.7% more likely to yield incidents than natural gas pipelines (see column (1) in Table

[10] We apply pooled Logit, Poisson and negative binomial models rather than fixed-effect count data models. We would lose numerous observations that are all zero with a panel (pipeline company) if applying a fixed-effect estimator. Nevertheless, by including pipeline age, length, size, and other physical characteristics as additional covariates, our specification is sufficient to control pipelines' idiosyncratic effects, both time-variant and time-invariant.

[11] Poisson regression can suffer from the over-dispersion of count data. We apply robust standard errors clustered on pipeline companies to mitigate this issue. This is a useful strategy for Poisson regression applied to over–dispersed data in practice (Cameron and Trivedi, 2005). Unlike the Poisson model, the negative binomial model explicitly accounts for over-dispersion in estimation. We report a variance parameter of the gamma distribution, α, in the estimation of negative binomial model, which collapses to Poisson if $\alpha \longrightarrow 0$. We consider the presence of over–dispersion if $\alpha > 0$. This is implemented by testing the null hypothesis $H_0 : \alpha = 0$ against $H_1 : \alpha > 0$.

[12] This finding could be due to the low statistical power since our sample ends by 2017, just more than one year after the imposition of absolute liability. However, this could also be due to heterogenous responses of pipeline companies. We investigate this in more detail below.

6).

Table 5: Analysis of Pipeline Incidents: Estimated Resulted of Equation (1)

	Dependent Variable: Pipeline Incident Counts		
	(1) Logit	(2) Poisson	(3) Negative Binomial
Log of Throughput	0.245**	0.272***	0.264***
	(0.118)	(0.093)	(0.084)
Abandonment Fee (%)	0.309***	0.264***	0.265***
	(0.093)	(0.083)	(0.075)
Absolute Liability	-0.081	0.229	0.150
	(0.375)	(0.348)	(0.343)
Controls:			
Pipeline Age (Years)	-0.006	-0.018	-0.018**
	(0.011)	(0.012)	(0.09)
Nominal Pipeline Size (Inches)	0.041***	0.034***	0.036***
	(0.013)	(0.009)	(0.010)
Pipeline Length (1000 KM)	-0.117	-0.148	-0.100
	(0.239)	(0.215)	(0.212)
Stainless Steel	3.374***	2.138***	2.390***
	(0.654)	(0.445)	(0.572)
Crude Oil	2.929**	2.570***	2.671***
	(1.224)	(0.863)	(0.874)
Condensate	-0.331	0.019	-0.113
	(1.076)	(0.917)	(0.802)
Petroleum Refined Products	4.512***	4.263***	4.480***
	(1.360)	(1.178)	(1.064)
Constant	0.655	0.359	0.616
	(0.745)	(0.607)	(0.691)
α			0.816
P–value of $H_0 : \alpha = 0$			0.000
Log Likelihood	-670.153	-1404.475	-1325.831
N	1484	1484	1484

Robust standard errors in parentheses clustered on pipelines.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Testing $H_0 : \alpha = 0$ is equal to testing the presence of over–dispersion of Poisson models.

Abandonment fees are normalized by sales revenue in terms of percentages.

Absolute Liability is an indicator variable for observations after June 2016.

Stainless Steel is an indicator variable if a pipeline was built with stainless instead of carbon steel.

Crude Oil, Condensate, and Petroleum Refined Products represent the indicator variables if a pipeline carries one of these substances.

Table 6: Analysis of Pipeline Incidents: Marginal Effects by Estimating Equation (1)

	Dependent Variable: Pipeline Incident Counts		
	(1) Logit	(2) Poisson	(3) Negative Binomial
Log of Throughput	0.036**	0.162**	0.162**
	(0.017)	(0.064)	(0.064)
Abandonment Fee (%)	0.045***	0.158***	0.163***
	(0.013)	(0.049)	(0.048)
Absolute Liability	-0.012	0.137	0.092
	(0.055)	(0.207)	(0.209)
Controls:			
Pipeline Age (Years)	-0.001	-0.011	-0.011*
	(0.002)	(0.007)	(0.006)
Nominal Pipeline Size (Inches)	0.006***	0.021***	0.022***
	(0.002)	(0.006)	(0.007)
Pipeline Length (1000 KM)	-0.017	-0.089	-0.062
	(0.034)	(0.124)	(0.127)
Stainless Steel	0.505***	1.418***	1.682**
	(0.051)	(0.479)	(0.762)
Crude Oil	0.350***	4.963	5.513
	(0.097)	(4.351)	(4.990)
Condensate	-0.034	0.008	-0.044
	(0.112)	(0.384)	(0.296)
Petroleum Refined Products	0.527***	28.787	35.771
	(0.074)	(32.742)	(37.264)

Robust standard errors in parentheses clustered on pipelines.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.
Marginal effects are calculated from estimation results displayed in Table 5.
Abandonment fees are normalized by sales revenue in terms of percentages.
Absolute Liability is an indicator variable for observations after June 2016.
Stainless Steel is an indicator variable if a pipeline was built with stainless instead of carbon steel.
Crude Oil, Condensate, and Petroleum Refined Products represent the indicator variables if a pipeline carries one of these substances.

3.2 Heterogenous Responses to Absolute Liabilities for Pipeline Incidents

The preceding analysis shows that the establishment of absolute liability did *not* have a significant impact on the occurrence and number of pipeline incidents. A possible explanation for this result is that the NEB places heterogeneous absolute liability standards on different types of pipelines (see Table 3). This may yield a mixed and ambiguous result when using a single indicator variable, $Liability_t$, to capture the whole effect of absolute liabilities. To account for heterogenous absolute liabilities, the second estimable equation (2) is,

$$\begin{aligned} Incident_{it} =& \alpha + \beta_1 Throughput_{it} + \beta_2 Abandonment_{it} + \beta_3 High_i + \beta_4 Low_i \\ &+ \beta_5 NG_i + \beta_6 Liability_t \times High_i + \beta_7 Liability_t \times Low_i \\ &+ \beta_8 Liability_t \times NG_i + \mathbf{X_{it}}\theta + \varepsilon_{it}, \end{aligned} \tag{2}$$

where $High_i$ is an indicator variable for Enbridge Mainline, Trans mountain, and Keystone pipelines that fall into the Class 1 absolute liability (\$1 billion); Low_t denotes another indicator variable for the other oil pipelines in the sample, which are subject to the Class 2 absolute liability (\$300 million); NG_i represents natural gas pipelines.[13] The interaction terms, $Liability_t \times High_i$, $Liability_t \times Low_i$, and $Liability_t \times NG_i$, absorb the heterogeneous effects of absolute liability on Class 1 oil, Class 2 oil, and natural gas pipelines respectively; $\mathbf{X_{it}}$ is a vector of control variables including pipeline age, size, length, constructing materials, and monthly dummies.

The estimated marginal effects of equation (2) are presented in Table 7.[14] The coefficients of $High_i$ and Low_i for the Logit model are positive and statistically significant at the 1% level. This suggests that oil pipelines subject to the highest and lower liabilities were 37% and 42% more likely to generate incidents than a condensate pipeline before the establishment of absolute liability. Nevertheless, the coefficients of $Liability_t \times High_i$, $Liability_t \times Low_i$, and $Liability_t \times NG_i$ are all *insignificant* across all model specifications. Overall, this confirms that the effects of absolute liability on incident occurrences for all types of pipelines are ambiguous. Hence, we may rule out the possibility that pipeline companies respond to absolute liability heterogeneously.

[13] We treat pipelines carrying crude oil or petroleum refined products as "oil pipelines". We consider pipelines carrying condensate as the reference group which falls into the category of "the Other Commodity" in Table 3.

[14] Table A1 in Appendix presents the direct estimated coefficients of equation (2).

Table 7: Allowing Heterogenous Responses to Absolute Liability: Estimated Marginal Effects of Analyzing Incident Occurrence and Numbers by Equation (2)

	Dependent Variable: Pipeline Incident Counts		
	(1)	(2)	(3)
	Logit	Poisson	Negative Binomial
Log of Throughput	0.042**	0.172**	0.185**
	(0.020)	(0.075)	(0.081)
Abandonment Fee (%)	0.040***	0.136***	0.138***
	(0.013)	(0.045)	(0.043)
$High_i$	0.369***	5.651	7.218
	(0.077)	(5.119)	(7.235)
Low_i	0.422***	9.108	13.436
	(0.078)	(9.090)	(14.416)
NG_i	-0.017	-0.231	-0.197
	(0.125)	(0.673)	(0.520)
$Liability_t \times High_i$	-0.104	-0.641	-0.702
	(0.094)	(0.487)	(0.501)
$Liability_t \times Low_i$	0.064	0.546	0.582
	(0.119)	(0.381)	(0.395)
$Liability_t \times NG_i$	-0.009	0.202	0.127
	(0.073)	(0.230)	(0.239)
Controls:			
Pipeline Age (Years)	0.000	-0.007	-0.008
	(0.002)	(0.008)	(0.007)
Nominal Pipeline Size (Inches)	0.005**	0.017**	0.018**
	(0.002)	(0.007)	(0.008)
Pipeline Length (1000 Km)	-0.036	-0.142	-0.120
	(0.038)	(0.158)	(0.148)
Stainless Steel	0.494***	1.131***	1.410**
	(0.057)	(0.375)	(0.701)

Robust standard errors in parentheses clustered on pipelines.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Marginal effects are calculated from estimation results displayed in Table A1 of the Appendix.

Abandonment fees are normalized to sales revenue in terms of percentages.

Stainless Steel is an indicator variable if a pipeline was built with stainless instead of carbon steel.

Crude Oil, Condensate, and Refined Products represent the indicator variables if a pipeline carries one of these substances.

$High_i$ denotes the indicator variable for oil pipelines falling into the Class 1 liability.

Low_i denotes the indicator variable for oil pipelines falling into the Class 2 liability.

$Liability_t \times High_i$ is an interaction term for oil pipelines in the Class 1 liability since the establishment of absolutes liability.

$Liability_t \times Low_i$ is an interaction term for oil pipelines in the Class 2 liability since the establishment of absolutes liability.

$Liability_t \times NG_i$ is an interaction term for natural gas pipelines since the establishment of absolutes liability.

4 Empirical Analysis of Pipeline Accidents

4.1 Modelling Accidents as a Function of Past Incidents

Sosaa and Alvarez-Ramirezb (2009) argue that a hazardous-material-pipeline accident may not be independent of previous events. Therefore, modeling pipeline accidents should account for the statistical dependence of a current accident on the counts of previous events. Mason (2018) shows that increases in the number of minor incidents of crude-by-rail transportation in past months exerts a statistically significant effect on the probability of a severe incident. In line with these studies, we analyze the occurrence of pipeline accidents in Canada by a Logit framework using the following equation,

$$Pr(Accident_{it}) = \alpha + \beta \sum_{j=t-q}^{t-1} Incident_{ij} + \varepsilon_{it}, \quad (3)$$

where the dependent variable is the probability of an accident for pipeline i at month t; $\sum_{j=t-q}^{t-1} Incident_{ij}$ denotes accumulated incident counts of pipeline i for the past q months. We present the marginal effects of estimating equation (3) in Table 8 for $q = 3, 6, 9, 12$.[15] Column (1) shows that the probability of pipeline accidents would increase by 2.6% if an additional pipeline incident occurred in the past three months. Column (2)–(4) show that the impact of past incidents declines when more distant past months are included.

Table 9 shows estimated marginal effects by replacing the number of incidents by accidents in equation (1).[16] For each specification (i.e., Logit, Poisson, and negative binomial), we present two sets of results by both including and excluding the cumulative incidents for the past three months as an additional covariate. The marginal effects for *Abandonment Fee* in Table 9 are insignificant, indicating that imposing abandonment fees are *not* significantly associated with changes in pipeline accidents. In contrast, the marginal effects for *Absolute Liability* are negative and significant. For example, the marginal effects of *Absolute Liability* for the Logit model (columns (1) and (2) in Table 9) represent that, on average, the probability of accidents decreased by 2.8%–2.9% per month since the establish-

[15] Table A2 in the Appendix presents the direct estimates of equation (3).

[16] Table A3 in the Appendix presents the direct estimates of equation (1), where the dependent variable is the number of accidents.

ment of absolute liability. Columns (5) and (6) for the negative binomial models show that on average the number of accidents was reduced by 0.027–0.028 per month since the establishment of absolute liability. Considering that the average number of accidents per month per pipeline is 0.031 (the second row of Table 4), the magnitude of reduction is *not* negligible. To put this into perspective, our estimates of the effect of absolute liability on accidents are roughly equivalent to entirely eliminating a pipeline's monthly accident occurrence.

Table 8: Marginal Effects of Logit Analysis of Accident Occurrence by Equation (3)

	Dependent Variable: Occurrence of Accidents			
	(1)	(2)	(3)	(4)
No. of incidents for past 3 months	0.026***			
	(0.006)			
No. of incidents for past 6 months		0.023***		
		(0.004)		
No. of incidents for past 9 months			0.018***	
			(0.002)	
No. of incidents for past 12 months				0.016***
				(0.001)

Robust standard errors in parentheses clustered on pipelines.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Marginal effects are calculated from estimation results displayed in Table A2 of the Appendix.

Table 9: Marginal Effects of Analyzing Accident Occurrence and Numbers

	Dependent Variable: Pipeline Accident Counts					
	Logit		Poisson		Negative Binomial	
	(1)	(2)	(3)	(4)	(5)	(6)
Number of Incidents for Past Three Months	0.019***		0.020***		0.020***	
	(0.006)		(0.007)		(0.006)	
Log of Throughput	-0.006	-0.005	-0.006	-0.004	-0.006	-0.004
	(0.010)	(0.011)	(0.010)	(0.010)	(0.010)	(0.010)
Abandonment Fee (%)	-0.001	-0.002	-0.002	-0.001	-0.002	-0.001
	(0.002)	(0.003)	(0.002)	(0.003)	(0.002)	(0.003)
Absolute Liability	-0.028***	-0.029***	-0.027***	-0.028***	-0.027***	-0.028***
	(0.004)	(0.005)	(0.004)	(0.004)	(0.004)	(0.003)
Controls:						
Pipeline Age (Years)	0.002**	0.002**	0.002**	0.002**	0.002**	0.002**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Nominal Pipeline Size (Inches)	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Pipeline Length (1000 KM)	0.003	0.004	0.002	0.004	0.002	0.004
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
Stainless Steel	0.025**	0.026**	0.024***	0.024***	0.024***	0.024***
	(0.010)	(0.010)	(0.009)	(0.009)	(0.009)	(0.009)
Crude Oil	-0.047	-0.042	-0.049	-0.037	-0.049	-0.037
	(0.087)	(0.085)	(0.101)	(0.083)	(0.101)	(0.083)
Condensate			-0.059	-0.048	-0.059	-0.048
			(0.098)	(0.078)	(0.098)	(0.078)
Petroleum Refined Products	-0.054	-0.049	-0.056	-0.044	-0.056	-0.044
	(0.089)	(0.086)	(0.103)	(0.084)	(0.103)	(0.084)

Robust standard errors in parentheses clustered on pipelines.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.
Marginal effects are calculated from estimation results displayed in Table A3 of the Appendix.
Abandonment fees are normalized to sales revenue in terms of percentages.
Absolute Liability is an indicator variable for observations after June 2016.
Stainless Steel is an indicator variable if a pipeline was built with stainless instead of carbon steel.
Crude Oil, Condensate, and Petroleum Refined Products represent the indicator variables for pipelines carrying one of these substances.

4.2 Heterogenous Responses to Absolute Liabilities for Pipeline Accidents

The marginal effects presented in Table 9 demonstrate that establishing absolute liability is associated with a significant reduction of pipeline accidents in Canada. Since the regulator places absolute liability on pipelines using different standards, it is instructive to examine the heterogenous responses of pipelines (in terms of accident occurrences) subject to different liability classes. We thus stratify the effect of absolute liability on pipeline accidents by liability classes. Similar to equation (2), the estimable equation for heterogenous responses in terms of accidents is,

$$\begin{aligned} Accident_{it} =& \alpha + \beta_1 Throughput_{it} + \beta_2 Abandonment_{it} + \beta_3 High_i + \beta_4 Low_i \\ & + \beta_5 NG_i + \beta_6 Liability_t \times High_i + \beta_7 Liability_t \times Low_i \\ & + \beta_8 Liability_t \times NG_i + \mathbf{X_{it}}\theta + \varepsilon_{it}, \end{aligned} \tag{4}$$

where $High_i$ is the indicator variable for oil pipelines classified into the Class 1 absolute liability (i.e., Enbridge Mainline, Trans-mountain, and Keystone pipelines); Low_t denotes the other oil pipelines subject to the Class 2 absolute liability; NG_i represents natural gas pipelines. Comparable to equation (2), the interaction terms, $Liability_t \times High_i$, $Liability_t \times Low_i$, and $Liability_t \times NG_i$, capture the heterogeneous effects of absolute liability on pipeline accidents.

The estimated marginal effects of equation (4) are presented in Table 10.[17] Our interpretation of marginal effects focus on columns (3) of Table 10, since the null hypothesis of $\alpha = 0$ (the absence of overdispersion) is rejected. The estimated coefficient of $Liability_t \times High_i$ suggests that oil pipelines bearing the highest liability have reduced accidents by 0.33 per month since the establishment of absolute liability. Similarly, oil pipelines subject to the lower liability have decreased accidents by 0.36 per month, slightly more than the highest liability oil pipelines. However, natural gas pipelines' accidents have only declined by 0.051 per month since the establishment of absolute liability.

To summarize, imposing absolute liability is more effective in decreasing accident occurrences for Canadian oil pipelines than natural gas pipelines. This result may weaken the general success of establishing absolute liability: Natural gas pipelines generate accidents more frequently than oil pipelines do.[18]

[17] The direct estimated results of equation (4) is presented in Tables A4 of Appendix. The coefficients of $High_i$ Low_i, NG_i, $Liability_t \times High_i$, and $Liability_t \times Low_i$ are not estimable in the Logit model because of the collinearity issues. We do not include the number of past incidents as an additional covariate because the estimation of Poisson and negative binomial cannot converge if we do so.

[18] The average numbers of accidents per month for oil and natural gas pipelines over the sample period are 0.021 and 0.039 respectively.

Table 10: Allowing Heterogenous Responses to Absolute Liabilities: Marginal Effects of Analyzing Accident Occurrence and Numbers

	Dependent Variable: Pipeline Accident Counts		
	Logit	Poisson	Negative Binomial
	(1)	(2)	(3)
Log of Throughput	0.0048	0.0047	0.0047
	(0.0106)	(0.0103)	(0.0103)
Abandonment Fee (%)	-0.0003	-0.0003	-0.0003
	(0.0032)	(0.0028)	(0.0028)
$High_i$		0.0244	0.0244
		(0.0434)	(0.0423)
Low_i		0.2614	0.2615
		(0.8757)	(0.8730)
NGi		0.0221**	0.0221*
		(0.0097)	(0.0102)
$Liability_t \times High_i$		-0.3322***	-0.3330***
		(0.1094)	(0.1167)
$Liability_t \times Low_i$		-0.3628***	-0.3633***
		(0.1196)	(0.1275)
$Liability_t \times NG_i$	-0.0546**	-0.0514*	-0.0514*
	(0.0252)	(0.0291)	(0.0297)
Controls:			
Pipeline Age (Years)	0.0010	0.0009	0.0009
	(0.0006)	(0.0007)	(0.0008)
Nominal Pipeline Size (Inches)	0.0001	0.0001	0.0001
	(0.0006)	(0.0006)	(0.0006)
Pipeline Length	0.0109**	0.0099*	0.0099*
	(0.0046)	(0.0056)	(0.0055)
Stainless Steel	0.0424*	0.0410	0.0410
	(0.0219)	(0.0288)	(0.0285)

Robust standard errors in parentheses clustered on pipelines.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.
Marginal effects are calculated from estimation results displayed in Table A4 of the Appendix.
Abandonment fees are normalized to sales revenue in terms of percentages.
Stainless Steel is an indicator variable if a pipeline was built with stainless instead of carbon steel;
$High_i$ denotes the indicator variable for the oil pipelines in the Class 1 liability;
Low_i denotes the indicator variable for the oil pipelines in the Class 2 liability;
$Liability_t \times High_i$ is an interaction term for oil pipelines in the Class 1 liability since the establishment of absolutes liability.
$Liability_t \times Low_i$ is an interaction term for oil pipelines in the Class 2 liability since the establishment of absolutes liability.
$Liability_t \times NG_i$ is an interaction term for natural gas pipelines since the establishment of absolutes liability.

5 Conclusion

This paper examines the effect of stricter environmental regulation on the safety performance of Canadian energy pipelines. Specifically, we focus on two newly established regulations: paying amortized abandonment fees in advance and the establishment of absolute liability. We construct a comprehensive monthly dataset that includes pipeline incidents and accidents, throughput, regulatory intensiveness, and pipeline physical characteristics for fourteen federally-regulated pipelines in Canada. We estimate the effect of regulatory intensiveness on pipeline incidents and accidents. Our results show that imposing abandonment fee is positively and significantly related to the increases in the probability and number of pipeline incidents. However, we do *not* find compelling evidence that the imposition of absolute liability is significantly associated with the reduction in the probability and number of incidents.

Using a similar framework, we find that the imposition of absolute liability is associated with the significant decreases in the probability and number of serious pipeline accidents. The effect of absolute liability on accidents are roughly equivalent to entirely eliminating a pipelines monthly accident occurrence. Absolute liability is more effective in reducing accident occurrence for Canadian oil pipelines than natural gas pipelines, although natural gas pipelines produce accidents more frequently than oil pipelines.

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Appendix

Table A1: Allowing Heterogenous Responses to Absolute Liability: Estimated Results of Analyzing Incident Occurrence and Numbers by Equation (2)

	Dependent Variable: Pipeline Incident Counts		
	(1)	(2)	(3)
	Logit	Poisson	Negative Binomial
Log of Throughput	0.284**	0.287***	0.299***
	(0.128)	(0.107)	(0.105)
Abandonment Fee (%)	0.273***	0.227***	0.224***
	(0.086)	(0.073)	(0.065)
$High_i$	3.110***	2.285***	2.570***
	(0.927)	(0.594)	(0.756)
Low_i	3.576***	2.723***	3.155***
	(0.880)	(0.755)	(0.831)
NG_i	-0.161	-0.448	-0.399
	(1.168)	(1.082)	(0.889)
$Liability_t \times High_i$	-0.712	-1.071	-1.136*
	(0.636)	(0.730)	(0.657)
$Liability_t \times Low_i$	0.436	0.913	0.941*
	(0.796)	(0.581)	(0.570)
$Liability_t \times NG_i$	-0.060	0.337	0.205
	(0.495)	(0.387)	(0.390)
Controls:			
Pipeline Age (Years)	0.000	-0.012	-0.013
	(0.012)	(0.012)	(0.010)
Nominal Pipeline Size (Inches)	0.032**	0.029***	0.030***
	(0.015)	(0.010)	(0.011)
Pipeline Length	-0.246	-0.238	-0.194
	(0.263)	(0.275)	(0.249)
Stainless Steel	3.183***	1.869***	2.175***
	(0.653)	(0.464)	(0.599)
Constant	-7.166***	-5.438***	-5.907***
	(0.963)	(0.789)	(0.822)
$ln(\alpha)$			-0.184
P–value of $H_0 : \alpha = 0$			0.000
Log Likelihood	-675.826	-1407.229	-1329.648
N	1484	1484	1484

Robust standard errors in parentheses clustered on pipelines.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.
Abandonment fees are normalized to sales revenue in terms of percentages.
Stainless Steel is an indicator variable if a pipeline was built with stainless instead of carbon steel.
Crude Oil, Condensate, and Refined Products represent the indicator variables if a pipeline carries one of these substances.
$High_i$ denotes the indicator variable for the oil pipelines in the Class 1 liability.
Low_i denotes the indicator variable for the oil pipelines in the Class 2 liability.
$Liability_t \times High_i$ is an interaction term for oil pipelines in the Class 1 liability since the establishment of absolutes liability.
$Liability_t \times Low_i$ is an interaction term for oil pipelines in the Class 2 liability since the establishment of absolutes liability.
$Liability_t \times NG_i$ is an interaction term for natural gas pipelines since the establishment of absolutes liability.

Table A2: Logit Analysis of Pipeline Accidents by Estimating Equation (3)

	(1)	(2)	(3)	(4)
No. of incidents for past 3 months	0.949***			
	(0.199)			
No. of incidents for past 6 months		0.873***		
		(0.161)		
No. of incidents for past 9 months			0.679***	
			(0.124)	
No. of incidents for past 12 months				0.604***
				(0.098)
Constant	-3.693***	-3.909***	-3.956***	-4.028***
	(0.378)	(0.365)	(0.357)	(0.343)
Log Likelihood	-232.062	-212.340	-205.495	-198.239
N	1833	1791	1749	1707

Robust standard errors in parentheses clustered on pipelines.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table A3: Estimated Results of Analyzing Accident Occurrence and Numbers

	Dependent Variable: Pipeline Accident Counts					
	Logit		Poisson		Negative Binomial	
	(1)	(2)	(3)	(4)	(5)	(6)
Number of Incidents for Past Three Months	0.835***		0.831***		0.831***	
	(0.224)		(0.235)		(0.235)	
Log of Throughput	-0.268	-0.216	-0.243	-0.168	-0.243	-0.168
	(0.454)	(0.483)	(0.411)	(0.438)	(0.411)	(0.438)
Abandonment Fee (%)	-0.065	-0.067	-0.063	-0.062	-0.063	-0.062
	(0.100)	(0.130)	(0.099)	(0.121)	(0.099)	(0.121)
Absolute Liability	-2.322**	-2.531**	-2.258***	-2.456***	-2.258***	-2.455***
	(0.909)	(0.991)	(0.873)	(0.940)	(0.873)	(0.940)
Controls:						
Pipeline Age (Years)	0.076**	0.078**	0.074**	0.073**	0.074**	0.073**
	(0.037)	(0.036)	(0.033)	(0.032)	(0.033)	(0.032)
Nominal Pipeline Size (Inches)	-0.031	-0.033	-0.030	-0.029	-0.030	-0.029
	(0.028)	(0.030)	(0.026)	(0.028)	(0.026)	(0.028)
Pipeline Length (Thousand KM)	0.113	0.185	0.064	0.179	0.064	0.179
	(0.209)	(0.234)	(0.198)	(0.213)	(0.198)	(0.213)
Stainless Steel	1.451**	1.498**	1.374**	1.409**	1.374**	1.409**
	(0.610)	(0.624)	(0.568)	(0.569)	(0.568)	(0.569)
Crude oil	-1.903	-1.771	-1.742	-1.478	-1.741	-1.478
	(2.183)	(2.353)	(1.952)	(2.101)	(1.952)	(2.101)
Condensate			-19.587***	-16.837***	-18.189***	-18.010***
			(2.803)	(3.184)	(2.803)	(3.184)
Petroleum Refined Products	-3.142	-2.980	-2.952	-2.575	-2.951	-2.575
	(3.404)	(3.669)	(3.112)	(3.357)	(3.112)	(3.357)
Constant	-4.806	-5.246	-19.802***	-20.571***	-21.282***	-21.777***
	(3.464)	(3.916)	(3.514)	(3.959)	(3.515)	(3.952)
$ln(\alpha)$					-33.403	-33.390
P–value of testing $H_0 : \alpha = 0$					0.000	0.000
Log Likelihood	-131.158	-135.211	-125.572	-129.779	-125.572	-129.779
N	1403	1436	1448	1484	1448	1484

Robust standard errors in parentheses clustered on pipelines.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Testing $H_0 : \alpha = 0$ is equal to testing the presence of over–dispersion of Poisson models.

Abandonment fees are normalized to sales revenue in terms of percentages.

Absolute Liability is an indicator variable for observations after June 2016.

Stainless Steel is an indicator variable if a pipeline was built with stainless instead of carbon steel.

Crude Oil, Condensate, and Petroleum Refined Products represent the indicator variables for pipeline carrying one of these substances.

Table A4: Allowing Heterogenous Responses to Absolute Liability: Estimated Results of Analyzing Accident Occurrence and Numbers

	Dependent Variable: Pipeline Accident Counts		
	Logit	Poisson	Negative Binomial
	(1)	(2)	(3)
Log of Throughput	0.200	0.200	0.200
	(0.445)	(0.430)	(0.430)
Abandonment Fee (%)	-0.012	-0.012	-0.012
	(0.134)	(0.119)	(0.119)
$Liability_t \times High_i$		-14.085***	-14.120***
		(0.868)	(0.868)
$Liability_t \times Low_i$		-15.381***	-15.408***
		(0.811)	(0.812)
$Liability_t \times NG_i$	-2.298**	-2.178**	-2.179**
	(0.983)	(0.961)	(0.961)
$High_i$	0.043	15.674***	15.665***
	(2.138)	(1.501)	(1.506)
Low_i	2.446	18.046***	18.038***
	(3.736)	(1.887)	(1.936)
NG_i		15.575***	15.566***
		(3.189)	(3.201)
Controls:			
Pipeline Age (Years)	0.042	0.040	0.040
	(0.028)	(0.027)	(0.027)
Nominal Pipeline Size (Inches)	0.005	0.006	0.006
	(0.025)	(0.025)	(0.025)
Pipeline Length (1000 KM)	0.460**	0.421**	0.421**
	(0.203)	(0.194)	(0.194)
Stainless Steel	2.284**	2.228**	2.229**
	(0.981)	(0.974)	(0.975)
Constant	-23.609***	-40.061***	-40.112***
	(4.942)	(2.123)	(2.072)
$ln(\alpha)$			-33.390
Pvalue of testing $H_0 : \alpha = 0$			0.001
Log likelihood	-126.977	-128.775	-128.775
N	1330	1484	1484

Robust standard errors in parentheses clustered on pipelines.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Abandonment fees are normalized to sales revenue in terms of percentages.

Stainless Steel is an indicator variable if a pipeline was built with stainless instead of carbon steel.

Crude Oil, Condensate, and Refined Products represent the indictor variables if a pipeline carries one of these substances.

$High_i$ denotes the indicator variable for the oil pipelines in the Class 1 liability.

Low_i denotes the indicator variable for the oil pipelines in the Class 2 liability.

$Liability_t \times High_i$ is an interaction term for oil pipelines in the Class 1 liability since the establishment of absolutes liability.

$Liability_t \times Low_i$ is an interaction term for oil pipelines in the Class 2 liability since the establishment of absolutes liability.

$Liability_t \times NG_i$ is an interaction term for natural gas pipelines since the establishment of absolutes liability.