January 2018

WORKING PAPER SERIES

2018-ACF-01

Market Structure and Supply Shocks: Evidence from Mining Disasters

Hinnerk Gnutzmann
Leibniz University Hannover

Oskar Kowalewski
IÉSEG School of Management (LEM-CNRS - UMR 9221)

Piotr Spiewanowski
Institute of Economics, Polish Academy of Sciences

IÉSEG School of Management
Lille Catholic University
3, rue de la Digue
F-59000 Lille
www.ieseg.fr

Market Structure and Supply Shocks: Evidence from Mining Disasters

Hinnerk Gnutzmann[a], Oskar Kowalewski[b,c], Piotr Śpiewanowski[b,*]

[a] *Institute for Macroeconomics, Leibniz University Hannover*
[b] *Institute of Economics, Polish Academy of Sciences (INE PAN)*
[c] *IÉSEG School of Management and LEM CNRS (UMR 9221)*

Abstract

This paper provides new evidence on how imperfectly competitive markets with excess capacity mitigate the adverse impact of supply shocks on prices. We study the potash market, which is controlled by a syndicate that assigns output quotas in proportion to production capacity of its members. This sharing rule creates incentives for excess capacity investment. Hence, it insulates the market from the impact of extreme events. Using a novel data set of potash mine disasters, we show that permanent or long-term loss of up to 4% of global or 20% of country production capacity does not affect the production levels and the commodity prices.

Keywords: commodity prices, supply shocks, market structure, resilience, syndicates
JEL: Q31, L13, Q54, L72

1. Introduction

Disasters – both natural and man-made – are widely expected to become more prevalent due to climate change.[1] These disasters are likely to hit commodity supply, for example due to extreme weather events or conflict, especially when commodities are geographically concentrated (Merener, 2016). At the same time, when and where disaster may

*Corresponding author, piotr.spiewanowski@inepan.waw.pl

We are very grateful to Reinhard Ellwanger, Martin Gassebner, James Hamilton, Lutz Kilian, Udo Renk and participants of II. FINEXCA workshop, 2017 AERE and 2017 CEA and New Directions in Commodity Markets conferences for helpful comments. The authors gratefully acknowledge support from Narodowe Centrum Nauki (NCN) "Beethoven" grant (UMO 2014/15/G/HS4/03629) (Kowalewski and Śpiewanowski) and DFG "Beethoven" grant FINEXCA (Gnutzmann).

[1] See IPCC (2012); World Economic Forum (2017) and Levermann (2014).

strike is inherently difficult to predict; this makes it important to understand how disasters (i.e. *large, unanticipated supply shocks*) are transmitted in commodity markets, and whether market structure can mitigate their effects on supply. On the normative side, *resilience* of markets becomes an important criterion besides the price level, which has historically been emphasised in competition policy.

This paper studies a type of legal cartel that is influential in several commodity markets.[2] In a *syndicate*, a centralized marketing authority allocates a production quota to each firm based on its production capacity. We model how the presence of a syndicate affects firm and market responses to disasters. Building on Röller and Steen (2006), we show that syndicates create a strong incentive to invest in excess capacity. This can buffer against supply shocks – both at the firm and at the market level.

We then test this prediction empirically in the market for a key mineral, potash, which is subject to a syndicate, and where geology causes unpredictable and exogenous disasters. The potash industry is subject to exogenous supply shocks due to uncontrolled water inflow that can lead to the irreversible loss of an entire mine. This type of mining disaster has two important properties. First, it is essentially impossible to forecast and plausibly exogenous to mining practices. And second, it can have severe repercussions on global supply, destroying up to 4% of global capacity in a single incident. Since 1970, seven such catastrophic accidents have affected various firms in the potash industry, providing the exogenous variation for our study.

We find that syndicates are highly effective in mitigating disaster impacts in commodity markets. In the baseline estimates, which employ a difference-in-differences strategy comparing potash prices with other mineral fertilizers, we find no evidence of a statistically or economically significant price impact of mining disasters. This finding is very robust to alternative specifications and estimation methods. The results are driven by fast production recovery: throughout the sample period of more than 40 years, potash producers had sufficient spare capacity to make up for even large losses. In other words, the potash market provides evidence on how imperfect competition can insulate commodity consumers from exogenous supply shocks. Consequently, even large shocks do not cause any detectable price response.

Our study provides new evidence on the transmission of supply shocks in commod-

[2] Fink et al. (2017); Taylor and Moss (2013). Related theory (Harrington and Skrzypacz, 2011)

ity markets. Existing research has shown that supply shocks have a strong price impact in some commodities, such as frozen orange juice concentrate (Roll, 1984; Boudoukh et al., 2007); for other commodities, most notably oil, supply shocks have only small and transient price effects Kilian (2009). In the coffee market, a cartel-like agreement to allocate production quotas based on historical capacity was used (Igami, 2015); this does not create incentives to invest in excess capacity, hence the market remains vulnerable to shocks. Excess capacity due to syndicates, such as OPEC,[3] provides a possible microeconomic foundation for these diverging results.

Cost-passthrough is a related, but separate concern. One strand of the literature investigates how shocks to input prices (Hong and Li, 2017), exchange rates ((Auer and Schoenle, 2016; Amiti et al., 2014)) or taxes (Fabra and Reguant, 2014) are transmitted; it is well documented that increased market concentration reduces cost pass-through. In the passthrough literature, a shock is typically relatively small but affects multiple producers; thus, in the competitive framework, the supply curve is shifted horizontally. In contrast, a mining disaster has a large effect, but only on a single producer; hence, the supply curve shifts inwards due to the loss of capacity.

Our results show that, while syndicates certainly have downsides for social welfare due to higher commodity prices, their contribution to supply stability in the wake of disaster should be taken into account in a full welfare analysis, which is relevant to regulatory policy. Moreover, the results are important for policy as Rosenzweig et al. (2001) predict an increase in natural disasters and extreme weather events that will strongly affect the supply and demand in the agriculture market. Excess capacity equilibrium can be thus seen as an alternative to other commodity price stabilization schemes discussed in the literature, such as storage subsidies, government storage or price-band programmes ((Gouel, 2013; Wright and Williams, 1988)).

This paper is organised as follows. In section 2 we provide background on syndicates in commodity markets and the potash industry; we also present a novel dataset on potash mine disasters. Section 3 develops the theoretical predictions on disaster transmission in commodity syndicates. Section 4 outlines our data and methods for testing these

[3]Ghoddusi et al. (2017) argue that in OPEC, the production quota allocation is proportional to installed capacity (as in our model), but producers may later decide to violate their quota (in contrast to our setting, where the quota is enforced)

predictions, before section 5 presents the results. Finally, section 6 concludes.

2. Background

2.1. Syndicates in Commodity Markets

Commodity markets are often divided through explicit agreements, rather than conquered by competition. The history of such "syndicates" goes back at least to the 19th century (Bloch, 1932) and has covered commodities including oil, gas, coal, iron, and steel. Throughout, these syndicates share a common structure: first, a group of firms form an organization, the *syndicate*, which centralizes sales of the commodity. The syndicate observes market conditions and decides on the total quantity of the commodity to be sold to consumers. Second, the syndicate acts as an intermediary between consumers and the producer. Having determined total market supply, the syndicate purchases from its members in accordance with a *market sharing rule*: "the productive capacity was determined by expert technologists. The actual production was then fixed as a percentage of [capacity]" (Bloch, 1932). Thus, the market sharing rule is designed to equalize capacity utilization among syndicate members. Since production is constrained by the quota, the system is also known under the term "prorationing".

Syndicates are a particular type of cartel. First, syndicates are not only legal forms of cartels, but enjoy state backing. Syndicate production quotas may be legally enforceable, limiting cheating. Membership may be compulsory by law, ruling out defection. These factors strengthen the effectiveness of syndicates compared to illegal cartels. On the other hand, syndicates need to rely on explicit market sharing rules, which can be enforced in court. This limits the effectiveness of the syndicate, for example because it encourages gaming of the market sharing rule or constrains the ability of the syndicate to accommodate outsiders.

Throughout the history of commodity markets, syndicates and excess capacity have been closely linked. On the one hand, essentially any collusive agreement aims to increase prices by curtailing supply, thereby creating spare capacity. On the other hand, and peculiar to syndicates, larger capacity increases a syndicate member's share of the industry profits. Thus, syndicates create a purely rent–seeking rationale for capacity investment. A particularly stark manifestation of this phenomenon is the so–called "quota mine": a mine which is developed solely to increase a syndicate member's production quota and not for actual production.[4] To some observers, the levels of capacity investment may seem "absurd" (Bloch, 1932, p. 216), although as we shall see, this may be perfectly rational given the syndicate mechanism.

2.2. Potash Market

Potash is a generic name for various salts that contain potassium, a key plant nutrient, in a form that can be taken up by plants.[5] The other two macronutrients indispensable for crop production are phosphorus (P) and nitrogen (N). Generally, these three main fertilizer ingredients are complements. This is due to Liebig's law, which states that plant growth depends on the availability of the *most deficient* nutrient.[6] Nearly all demand for each of these elements comes from agriculture.[7]. Potash and phosphates (source of phosphorus) exhibit also similarities on the supply side as both products are mined and concentrated in few regions (albeit different ones), while nitrogen can be produced at any location supplied with hydrocarbons (typically natural gas).

The potash industry is organized into two syndicates and fringe players (al Rawashdeh and Maxwell, 2014). In North America, the association Canpotex controls export sales of Agrium, PotashCorp and Mosaic; each firm is assigned a quota in line with their productive capacity. In Eastern Europe, a syndicate – the Belarusian Potash Corporation – was used to control sales from Russian and Belarusian production. This syndicate collapsed in 2013, i.e. at the end of the sample period. The three largest exporters - Canada, Russia and Belarus - jointly produce over 30 mln tonnes of potash per year or 60% of world production.

Potash deposits are found deep underground and exploited in few areas with high

[4]For example, the German mining regulation of 1910 granted a time-limited permission to explore new deposits in the vicinity of existing mines. This led to a flurry of capacity investment purely to increase syndicate quotas (Moraht, 1921, p. 60)

[5]Over 90% of the world potash is produced as potassium chloride (KCl), also known as muriate of potash. Other forms include potassium sulphate, potassium magnesium sulphate and potassium nitrate. For aggregate statistics quantities of various potassium forms are frequently reported jointly as K_2O equivalent. However, in this paper, for consistency with price data all quantities are reported as KCl equivalent using standard conversion factors (1mt KCl = 0.61mt K_2O) (PotashCorp, 2014).

[6]However, the nutrients perform slightly different functions. Potash and phosphates are typically used in conjunction to improve crop quality (Yara, 2017, p. 8). Nitrogen application is somewhat less closely related to potash, as its main role is to drive yields rather than quality (op. cit.).

[7]80% of nitrogen demand and over 90% of potassium and phosphorus demand (PotashCorp, 2014).

capital intensity. Production in three main producing countries is distributed over just 22 mines in only four geographically distinct regions.[8] Due to this strong concentration, a single mine accident can have a systemic impact on the potash commodity market.

Since the beginnings of the potash trade in the 19th century, formal market sharing arrangements – rather than competition – have been an important feature of the market. Until 1945, when Germany was the world's largest potash producer, German potash sales were centralized through the *Kalisyndikat*; each syndicate member received a production quota proportional to its production capacity (Moraht, 1921, p. 59-60). After World War II, the USA became the potash market leader. American potash producers had formed the Potash Export Association, an export syndicate under the Webb-Pomerene Act in 1938. This was a single sales agency through which domestic producers were channelling all their exports in line with a fixed production quota for each member. In the 1960s, eight out of 11 major potash firms in the country, accounting for 85% of US exports, belonged to the organization. The cartel dissolved in the late 1960s due to a conflict of interests between firms active only in the USA and those that purchased mineral rights to the newly discovered ample deposits in Canada (Larson, 1970).

In 1970, the Canadian province of Saskatchewan – now the leading global producer – introduced a system of mandatory production quotas; again, quota was assigned in line with production capacity (see Ready (1971, pp. 594 - 596) for a review of the early market sharing formula). While the system underwent several reforms since then, the basic principle of the syndicate remains in place until today.[9] Until 2013, potash exports from Belarus and Russia (the second and third largest producers, respectively), were also managed through a syndicate ("Belarusian Potash Corp."). Just as in the previous cases, this syndicate also allocated production quotas in line with capacity (BelarusDigest, 2012).

Among today's syndicate members, excess capacity remains very large. For example, PotashCorp (2017) reports a "nameplate capacity" of 19.1 million tonnes of KCl; the firm's sales quota in its syndicate, Canpotex, is based on this capacity figure. This compares to an actual production of a mere 8.60 million tonnes in 2016, or 45% of nameplate

[8] 11 potash mines in Canada, 10 in Saskatchewan and one in New Brunswick, five Russian mines in the Perm region and six mines in Belarus in Salihorsk region, see USGS (2017).

[9] Production capacity is assessed by independent engineers and only a short sample production run is needed to validate the estimate (Canpotex, 2017). This methodology underscores that marginal capacity in a syndicate is often more important for dividing rents rather than actual production.

capacity. Global capacity utilisation rates, which also include competitive fringe producers, fluctuate between 60% and 75% as shown in the Appendix Figure A1. Persistent and large excess capacities are important features of industries with syndicates.

2.3. Potash Mine Accidents

Potash mines are at risk of catastrophic flooding or collapse, which can lead to the permanent loss of the mine. Most of the potash extraction is through conventional shaft mines, with the remainder extracted using solution[10] and brine mining from land–locked water bodies.[11] Figure 1 illustrates a case of mine collapse, typical for relatively shallow and thick salt deposits, such as potash deposits in Perm, Russia. Conventional potash deposits in other regions are usually located at greater depths. However, the geological structure and solubility of potash salts makes them prone to flooding caused by uncontrollable brine inflow from underground water sources. As a result, potash production is permanently exposed to a significant threat of mine closures. Indeed, over the last 50 years, the industry has experienced seven such accidents. The complete list of affected mines is presented in Table 1 with detailed account of each accident presented in Appendix A3.

A single mine loss can wipe out a significant share of global production capacity. As shown in Table 1 a typical potash mine disaster in the last 50 years led to a 1%-4% decrease in global production capacity, or 10%-20% of production capacity in the major producing countries such as Canada or Russia. For smaller producers, a mine disaster may result in a definite end of the industry in a country, as happened in Congo, where production has not been restored after a flooding of the country's single mine. Although in most of the described cases the capacity loss was irreversible, in two cases production was restored, though the mine restoration never took less than two years.

Potash mine disasters appear to occur at a constant rate over time, independent of market conditions. Some types of mining accidents are preventable, and hence accident occurrence depends on safety efforts. For example, market structure has been shown to affect accident occurrence of Chinese coal mines (Jia and Nie, 2017). For geological reasons, the occurrence of potash mine disasters is likely to be exogenous. Hence, we verify

[10] e.g. Belle Plaine and Patience Lake mines in Saskatchewan.
[11] e.g. Dead Sea, Salar de Atacama, Great Salt Lake.

FIGURE 1
Potash Mine Collapse: An Example

Note: The figure shows an aerial view of the sinkhole caused by the collapse of mine Solikamsk-2 in 2014. *Source:* Ilya Lipin, used with permission.

if the frequency distribution of accidents follows a Poisson distribution. This would be the case if accidents occur independently and at a constant rate per month. As Appendix Table A2 shows, there is essentially no evidence to reject the hypothesis that potash accidents follow a Poisson distribution based on a Chi-squared test. This test result gives us additional confidence that accidents are indeed exogenous with respect to commodity market conditions.

2.4. Syndicates in Other Markets

Oil and Gas Market. As Libecap (1989) details, crude oil prices were controlled through prorationing introduced in the 1930s until 1973. Indeed, the potash prorationing system is explicitly based on the scheme used in the oil industry. Under the scheme, the quantity of oil produced was adjusted in order to stabilize nominal prices. While there was some variation between states in how the regulation was administered, the case of Texas –

TABLE 1
Major potash mine accidents

Date	Country	Mine Name	Affected Capacity: Mine (MMT)	Share of Country Prod.	Share of Global Prod.
1970-08-27	Canada	Cominco	1.2	23.03%	4.19%
1977-06-15	Congo	Holle	0.5	100.00%	1.19%
1986-03-09	USSR	Berezniki-3	1.8	10.74%	3.86%
1987-01-01	Canada	Patience Lake	1.2	9.65%	2.32%
1997-10-30	Canada	Cassidy Lake	1.3	8.78%	3.14%
2006-10-29	Russia	Berezniki-1	1.4	14.92%	2.84%
2014-11-18	Russia	Solikamsk-2	2.3	19.11%	3.50%

Note: Mine Capacity in million metric tonnes of potash (KCl)
Source: Data collected by authors from various sources, see appendix A3 for details.

the largest oil producer state at the time – is instructive (pp. 850 - 852). Each month, the Texas Railroad Commission (TRC) determined the state production quota. Then the expected production of unregulated wells (which were unregulated due to their high marginal cost of production) was subtracted from the quota, and the remainder allocated among regulated wells. Lastly, the permitted production quota of each well was determined as a share of its capacity. As in the case of potash, this market sharing rule contributed to excess capacity. As (Libecap, 1989, p. 851) puts it, these rules "clearly promoted dense, deep drilling in Texas by firms to increase their monthly quota" .

While the prorationing system was operational, it succeeded in limiting the price impact of supply shocks. The oil prorationing system led to mostly stable prices and occasional large jumps (Hamilton, 2013). Each month, the TRC would set production quotas to be consistent with demand at last month's prices. As a result, prices were stable *unless* the market was subject to a large external shock. Hence, oil prices during the TRC period are "a fairly unique time series, changing only in response to specific identifiable events" (Hamilton, 2013). In other words, while prices were mostly stable from month to month, supply shocks took a large toll on prices. For instance, during the Suez Crisis of 1956, world oil production fell by ten percent and rationing was introduced in Europe, while the general US inflation pressures of the late 1960s led to a series of price hikes, but not continuous adjustment. Within a few months, excess capacity from the US was able to compensate for oil shortages in Europe (Alhajji, 2005).

The decline in US oil production went hand-in-hand with the end of the prorationing system. By 1972, the TRC rapidly increased production quotas; nevertheless, actual production declined due to the depletion of Texan oil fields. Hence, the world oil market transitioned from being centred in the Gulf of Mexico to the Persian gulf, albeit not at all "smoothly" (Hamilton, 2013, section IV). Clearly, a production rationing system not only contributes to creating excess capacity, but also relies on the existence of this very excess capacity to be able to control market prices.

Cement. Röller and Steen (2006) study how the market sharing rule of the Norwegian cement cartel affected excess production. This cartel, which operated legally from 1923 until its members merged into a cement monopolist in 1969, also used an explicit market sharing rule. First, a common sales office determines the total quantity of industry supply to the domestic market. Then each firm is allocated a fixed quota of its actual production for sale in the domestic market, so as to implement the desired domestic supply; the remainder is sold on the export market.[12] As Röller and Steen (2006) show, Norwegian cement producers thus had an excessive incentive to export – even at prices below marginal cost.

The cement cartel insulated the Norwegian cement market from local supply shocks; instead, prices moved in line with the world market. In practice, the cartel appears to have had a level effect on Norwegian cement prices: domestic cement prices were permanently above world market prices but the two series follow parallel trends (figure 4, op. cit.). This is to some extent remarkable, because significant marginal cost components – such as electricity and wages – are subject to country-specific shocks; apparently, the sharing rule of the Norwegian cement cartel rendered these shocks irrelevant to domestic prices.

[12]Röller and Steen (2006) use "capacity" and "production" interchangeably, because in their framework firms always produce to full capacity (see footnote 18)

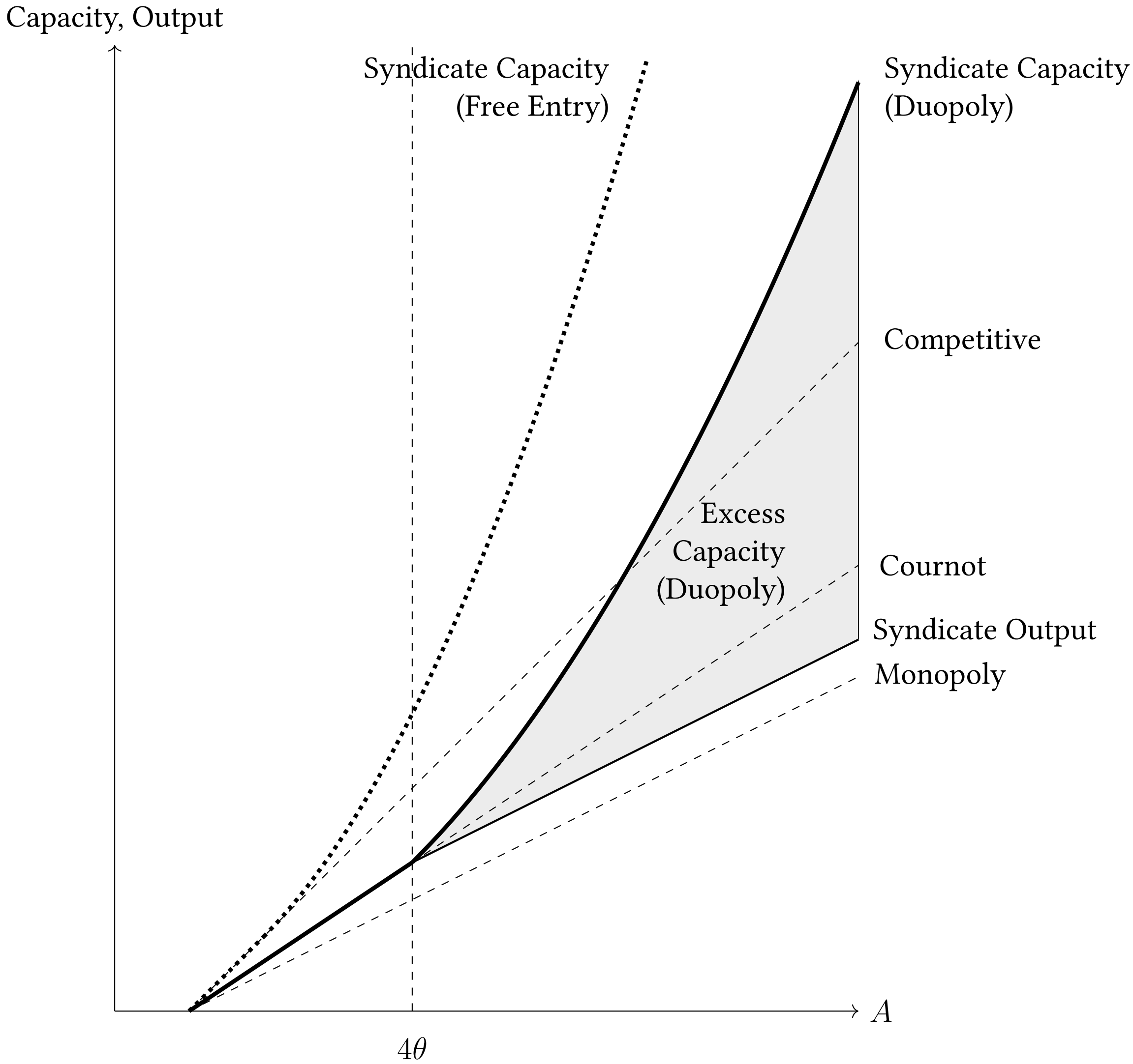
3. Syndicates and Supply Shock Transmission

To explore the relationship between syndicates, excess capacity and supply shocks, we turn to a two-stage model. In the first stage, firms simultaneously determine their level of capacity investment. In the second stage, the syndicate then observes market conditions and determines total supply to equal the monopoly quantity. The syndicate then purchases from each member in proportion to its capacity (i.e. production rationing or "prorationing") in the third stage. Participation in the syndicate is compulsory, but each firm can freely invest in capacity. Thus, the set–up closely mirrors the structure of syndicates actually observed in the market.

The model closely follows Röller and Steen (2006), with two important differences. First, the syndicate in our setting determines world market prices, rather than takes a world market price as given. Second, we allow for excess capacity in equilibrium, while in Röller and Steen (2006) firms export surplus production abroad. To obtain closed-form solutions for the model, we assume a linear demand function, $P = A - Q$ and constant marginal cost θ per unit of capacity investment; the detailed calculations are collected in Appendix A1. Our central interest is to understand how an *unanticipated* shock to capacity affects market outcomes.

The policy of the syndicate is to maximize industry profits, taking capacity levels as given. While the syndicate acts as an exclusive seller on the world market, its strategic problem differs from that of a monopolist. A monopolist jointly determines capacity investment and the quantity to produce based on expected demand, while the syndicate treats capacity investment as sunk; given the set-up, the syndicate acts as a revenue maximizer. In equilibrium, syndicate production is therefore always larger than under monopoly. The syndicate will never allow greater production than would arise under Cournot duopoly. In Cournot equilibrium, industry profits can always be improved by curtailing output, and – in general – reducing output is the policy that the syndicate would seek to implement. However, since the syndicate does not precisely implement the monopoly solution, there is a narrow parameter range where the syndicate cannot improve over the Cournot outcome. This occurs when industry profitability is low, because demand is weak compared to investment costs. This trade–off is illustrated in figure 2, where the thin solid line indicates equilibrium market production under a syndicate; as can be seen, for small values of A/θ, the market outcomes under the syndicate

FIGURE 2
Syndicate Market Sharing Rules and Excess Capacity



Source: Authors' calculations, see appendix A1.
Notes: Parameter A denotes the intercept of the demand curve, and θ the (constant) marginal cost of capacity.
The benchmark cases of perfect competition, Cournot duopoly and monopoly are indicated with dashed lines. In the benchmark cases, firms produce at full capacity; hence, capacity and output coincide.
The syndicate determines market output according to revenue maximization, taking industry capacity as given. Hence, syndicate output (thin solid) line does not depend on the number of firms in the industry. Syndicate members simultaneously choose capacity levels; industry capacity in the two firm–case is shown by the thick solid line. For $A \geq 4\theta$, excess capacity occurs in equilibrium. Under free entry, industry capacity is larger – it is set to dissipate industry profits – as the dotted line indicates.

coincide with those under Cournot. The figure also indicates that the syndicate always brings a smaller quantity to market than under perfect competition, where profits of the industry operating at full capacity would be zero.

The syndicate mechanism generally leads to excess capacity in equilibrium. Since the syndicate limits total production, prices remain well in excess of marginal cost; thus, firms would like to sell more. Under the rationing system, a firm will be allowed to increase its production somewhat – at the expense of other firms – when it increases capacity; thus, increases in capacity allow a firm to increase its share of the "industry pie". This effect is already potent in the case of two firms. The thick solid line in figure 2 shows that capacity under the prorationing system increases faster than demand when there is an oligopoly. But due to the syndicate policy, the quantity sold in the market increases only proportionally with demand. Thus, the stronger the demand, the larger the excess capacity in the industry – as highlighted by the shaded area in the figure.

The number of firms determines the level of capacity but not market prices in a syndicate. In the case where free entry is allowed, excess capacity is larger than under duopoly (dotted line in figure 2). On the one hand, free entry ensures that the marginal return to capacity investment must be zero. On the other hand, the syndicate limits total supply. This results in an equilibrium where prices exceed marginal cost, but industry profits are zero – they are dissipated through excess capacity. This pattern is clear from figure 2: excess capacity of 50% or more can be readily rationalized by the syndicate mechanism. Thus, since production at the firm affected by the disaster may not fall, the disaster may not have any effect on total output or market prices. Testing these two – admittedly stark – hypotheses is our objective in the remainder of the paper.

Firms may be able to absorb disasters through their excess capacity. When a disaster strikes, firms lose a part of their production capacity. However, the production quota is not re-assessed. Thus, as long as the shock does not destroy more capacity than was idle before the disaster, firm output is not affected. Moreover, the production of other firms is also not affected. In view of the large excess capacity created by syndicates, this is the usual case. Alternatively, for very severe shocks – which have a binding effect on production at the affected firm – one may see a fall in output at the affected firm and increase in output at other syndicate members. This effect, which is also present in a basic Cournot model in a stronger form, is only relevant for large shocks.

Large excess capacity under a syndicate mitigates the market impact of supply shocks.

Consider an unexpected shock to supply in the third period, i.e. after syndicate quotas have been determined. A potash mine collapse fits the pattern of such an unexpected shock particularly well, since the ex ante probability of collapse in a particular mine at a given time is very low. Due to excess capacity created by the syndicate market sharing rule, even substantial shocks to capacity need not have an impact on production *at the firm affected by the disaster*. In the baseline duopoly case, firm capacity utilization – the ratio of production to capacity – is given by $\frac{4\theta}{A}$. As discussed in section 2.1, syndicate member PotashCorp (for which data are available publicly) has a capacity utilization of 45%, which would be consistent with $A \approx 8\theta$. Hence, even a large mining disaster – erasing, say, 25% of capacity – would not have a binding effect on the firm's production plan. Thus our first testable hypothesis is:

Hypothesis 1. *Potash mining disasters do not reduce production at the affected firm or increase production at other firms.*

Under the hypothesis, the disaster does not impact production plans at any firm. Hence, market supply does not change and neither are prices affected. This is our second testable hypothesis:

Hypothesis 2. *Potash mining disasters do not affect potash prices.*

The presence of syndicates can have important consequences for the welfare analysis of mergers. Note that the syndicate objective does not depend on the number of firms; hence, entry or exit merely influences industry excess capacity, but not market supply. Reducing the number of firms makes the industry more profitable (reduction in excess capacity) but does not have an adverse price impact on consumers. Thus, given that a syndicate is in place, mergers are more likely to improve welfare than in a more competitive market.

4. Data and Methods

4.1. Data

Our data set contains prices and production quantities of potash and the other two main fertilizers, phosphate and nitrogen. For our sample, commodity prices are sourced from the World Bank's *Global Economic Monitor*; the series runs at monthly frequency from

January 1960 to June 2017, with prices quoted in nominal USD per ton of nutrient. Production data are available at annual frequency only, and are due to the *IFADATA* database of the International Fertilizer Association; they cover global production quantities, measured in thousand tonnes of nutrient, for the period from 1961 to 2014. In both cases, we use the full sample period available. Descriptive statistics are shown in Appendix Table A1(a).

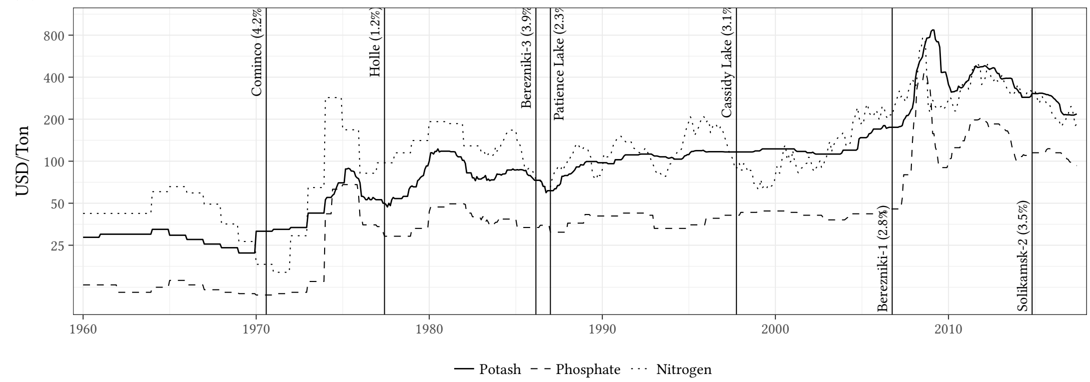
The history of fertilizer prices is closely related to other energy commodities. Figure 3(a) plots the price series in levels. Driven by rising Canadian production, potash prices exhibit a declining trend until the late 1960s. This trend is dramatically reversed in January 1970, when potash prices rose more than 40% in a single month as authorities in Saskatchewan, Canada, the largest potash producing region, introduced a *de facto* export cartel under the Potash Conservation Regulation. As we discuss below, the cartel implemented a "prorationing" system to control the price through production quotas; hence, prices never returned to their pre-1970s level. The 1973 oil crisis had a severe effect on nitrogen and phosphate prices (production of both is highly energy intensive), but also went hand in hand with potash price increases. This was followed by an era of stability in the potash market. For a quarter century, from 1980 until 2005, potash prices hovered around the nominal USD 100 level. While there was some price volatility in the 1980s – apparent in part (b) of the figure – the potash market in the 1990s could only be described as "remarkably stable". This is certainly true compared to oil, as crude prices ranged from more than USD 70 to less than USD 20 in the same period.[13] During this period, phosphate prices clearly followed a parallel trend to potash prices. For nitrogen prices, the most salient feature was greater volatility due to the volatility of natural gas prices, the main cost factor in nitrogen production. Visual inspection nevertheless suggests a common trend with potash. In 2007, prices of all fertilizers escalated: phosphate was most strongly affected, followed by potash. Prices fell after 2008, but by the end of the sample period still far exceeded historical levels. For example, potash prices have been above USD 200 per ton (twice the historical level) since 2007.[14]

[13]For the whole sample, the coefficient of variation in potash prices is lowest for potash returns (11.32), followed by phosphate (16.87) and nitrogen (17.67). More generally, it is an open question whether commodity prices are more volatile than those of manufactured goods (Arezki et al., 2013).

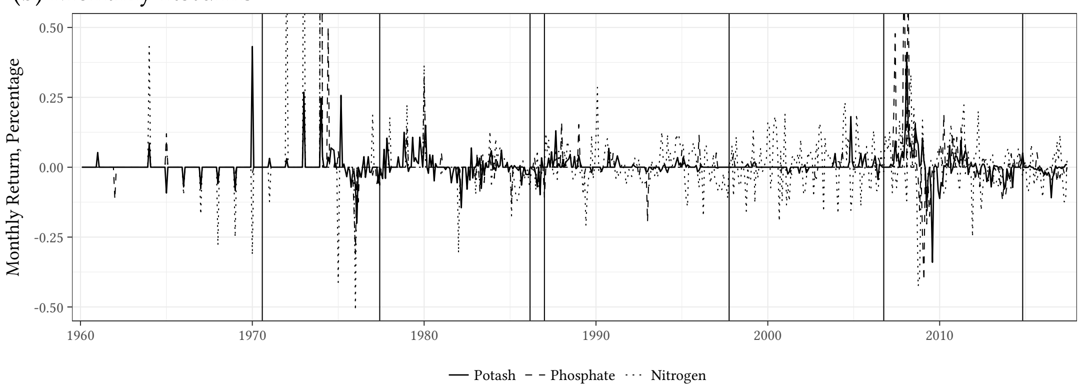
[14]For an engaging qualitative account of the potash market, see https://www.theglobeandmail.com/globe-investor/canpotex-and-potash-the-monopoly-behind-the-mineral/article1241076/?page=all.

FIGURE 3
Fertilizer Prices and Potash Mining Accidents

(a) Price Level



(b) Monthly Returns



Note: Vertical lines denote the timing of potash mine disasters; affected mine and share of global capacity lost is indicated in each case.
Source: Price series from the World Bank *Global Economic Monitor*, and authors' calculations. Potash mining accidents collected by authors.

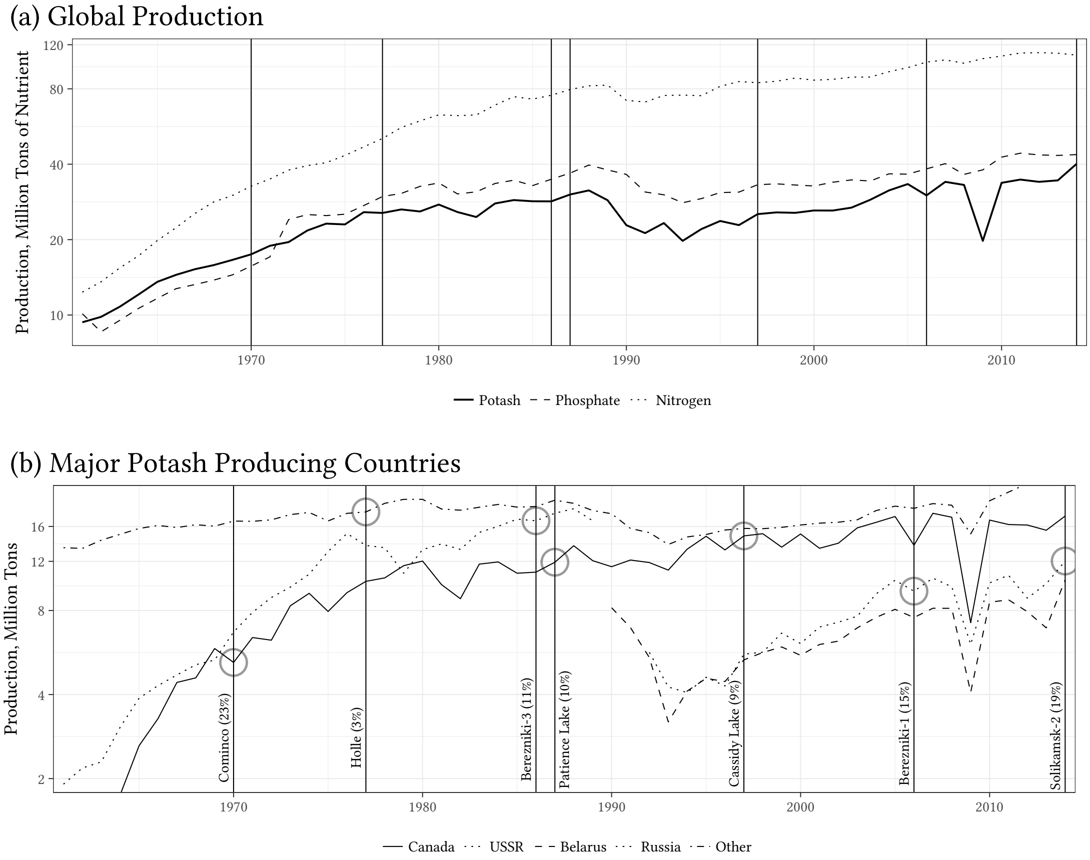
At first pass, the potash market appears to compensate for mine disasters without triggering a price impact. In figure 3, vertical bars indicate the timing of potash disasters. For each individual disaster, visual inspection suggests *no* contemporaneous price impact – prices remain essentially flat in the month the disaster occurs. Neither does there seem to be much of a delayed price impact: for six of the seven accidents, prices do not increase in the 12 months following the disaster. This resilience is remarkable given the scale of capacity losses. In fact, the data suggest the hypothesis that mine disasters have no price impact *at all*.

Fertilizer production has increased dramatically over the last five decades. As figure 4a shows, growth was especially rapid until the late 1980s. Then, falling fertilizer production and consumption in the Soviet Union leads to a period of output decline. From the mid-1990s onwards, production again continues to expand. A notable anomaly is the sharp fall in potash output in the year 2008, which coincides with the food price crisis; this is possibly related to a collusive agreement between the Canadian and Belarusian potash syndicates (Jenny, 2012).

Visual inspection of production data indicates that mine disasters did not impair production. In figure 4a, global nutrient production is shown; years with potash mining disasters are highlighted with vertical lines. Visual inspection suggests little, if any, impact of disasters on global production. At the country level, the disaster-driven capacity loss was between 10% and 25%, so even an untrained eye should be able see its impact on the production figures, if there was an impact. Yet, we can see nearly none of it (see figure 4b). The are some exceptions, but in those cases the reason of the production decreases can be easily explained. The Canadian Cominco mine was flooded in 1970. This year, however, coincides with the introduction of the prorationing system that led to production decrease across all mines in the country. In 1986, Soviet Union suffered from a mine collapse that was associated with a small decrease in potash production in that year. However, Soviet Union was not a member of an international syndicate at that time and all production facilities had a single owner (state), so the excess capacity enhancing prorationing mechanism did not apply. Finally, the 2006 Berezniki-1 flooding wiped out 15% of the Russian production capacity and the production level indeed decreased that year. However, we can see that the production decrease in Russia was significantly lower than in Canada, which did not suffer from exogenous events in that period. Furthermore, the disaster happened only in late October, so the mine was operating for most of the year. Hence, the production decline in Russia is unlikely to have been caused by the Berezniki-1 incident.

To test the hypothesis on lack of impact of potash mine disasters on prices and quantities, we now specify a formal econometric model of potash price shocks and producers' quantity adjustment.

FIGURE 4
Fertilizer Production and Potash Mining Accidents



Note: Vertical lines denote the timing of potash mine disasters; affected mine and share of global capacity lost is indicated in each case.
Source: Production data by the International Fertilizer Organization, in million metric ton, total per nutrient. Potash mining accidents collected by authors.

4.2. Estimation

Our goal is to estimate how mine disasters are transmitted to market prices and production quantities. We now specify difference-in-differences strategies to estimate first the price effect, and then turn to quantities.

Prices. All prices are non-stationary in levels and stationary in returns, as the test results in Table A1(b) show. We therefore specify our model in terms of monthly commodity returns rather than levels. Let r_t^i denote the return in month t of a fertilizer i, indexed as K for potassium (from Latin *kalium*), P for phosphates and N for nitrogen. This return of the three commodities can be modeled as

$$r_t^i = \alpha_t + \sum_{l=0}^{L_1} \phi_l^i \text{shockSize}_{t-l} + \sum_{l=1}^{L_2} \rho_l r_{t-l}^i + \epsilon_t^i \tag{1}$$

where the time-fixed effect α_t measures the effect of general fertilizer market conditions. The coefficient ϕ_l^i measures the impact of a mining disaster on commodity i after l lags. The total number of lags considered is L_1, while we allow autocorrelation in returns up to L_2. Our primary measure of shockSize$_t$ is the mining capacity lost as a fraction of global production, with range $[0, 1]$. This approach follows the "quantitative dummy" specification of Hamilton (2003). For robustness, we also conduct regressions with an accident dummy alone; this does not affect the results of the analysis.[15] Lastly, we allow for lagged values of the commodity return to capture the time structure of shock propagation, momentum etc. The error term is denoted ϵ_t.

For potassium fertilizers, we would expect that mine disasters either leave prices unchanged, or cause a price increase if the shock is sufficiently large ($\phi_l^K \geq 0$). Since the other fertilizers, especially phosphate, are complements to potash, an adverse potash supply shock may lower demand for these commodities if the disaster causes a price increase. Thus, we would expect $\phi_l^i \leq 0$ for phosphate and nitrogen.

The model can be estimated by OLS, although this is likely to be inefficient. Since mining accidents are truly exogenous, they should not be correlated with the time-fixed effect. Thus, this variable can be dropped without triggering bias. The downside of this approach is that the share of variance explained will be small, leading to large standard errors for our coefficients of interest ϕ_l^K. Furthermore, in a small sample, we run the risk of observing a realization of the true data generating process in which accidents coincide with fertilizer demand shocks. To capture the dynamics of commodity returns, we may need to include several lags of the return series.

To circumvent those problems, we turn to a difference-in-differences (D-i-D) strategy. Consider taking differences of the return of potash with, say, phosphate. This transfor-

[15] Regression tables are available in the online appendix.

mation can eliminate the effect of the common price trend at the cost of bringing additional noise from the phosphate specific shocks ϵ_t^P as shown in equation 2. An OLS regression of a suitable modified version of model 1 compares the difference in return when an accident occurs to the difference in return in periods without an accident; in fact, for the case of two commodities, this OLS regression is numerically equivalent to a panel model with commodity and time fixed effects.

$$\tilde{r}_t^K = r_t^K - r_t^P = \sum_{l=0}^{l=L_1} \underbrace{\tilde{\phi}_t^K}_{(\phi_l^K - \phi_l^P)} \text{shockSize}_{t-l} + \sum_{l=1}^{l=L_2} \rho_l \tilde{r}_{t-l}^K + \epsilon_t^K - \epsilon_t^P \tag{2}$$

Furthermore, since the fertilizers are complements, estimates of the accident effect may be biased upwards (if $\phi^P < 0$, then $\tilde{\phi}_t^K > \phi^K$). Although this is an arguable drawback of the model, we will turn it into our advantage. Following the exploratory analysis above, our central interest is to develop a powerful test of the hypothesis that accidents have *no* impact on fertilizer prices. Due to the positive bias, we run an increased risk of rejecting the null hypothesis – no impact – when it is in fact correct (type I error). On the other hand, if standard tests fail to reject the null hypothesis, the estimated p-value will underestimate the level of confidence of the result.

Given the similarities with potash briefly outlined in section 2.3, phosphate is the most natural candidate for a "counterfactual" used to eliminate the common fertilizer demand in equation 2. Another possibility is a linear combination of other fertilizer prices, e.g. an average of phosphate rock and nitrogen (urea) prices. Both options will be used in the empirical section below.

Quantities. To assess the impact of mining disasters on production, we use a similar strategy as for prices. Here, the frequency is only annual, however there is variation by country. Thus, the basic estimation model we use has country- and time-fixed effects, plus dummies for the accident as in the price equation:

$$q_{ct} = \alpha_t + \theta_c + \sum_{l=0}^{l=L_1} \phi_l^i \text{shockSize}_{t-l} + \epsilon_{ct} \tag{3}$$

where q_{ct} represents potash production in country c in year t, θ_c now denotes the country fixed effect, and α_t denotes the time-fixed effect and ϕ_i the shock impacts as above.

5. Results

This section tests the hypothesis stated in the previous section. First, we verify that potash production quantities were unaffected by disasters in line with hypothesis 1. Even on the country level, where countries experienced up to 25% of capacity loss, we find no impact of mine disasters on quantities produced in the period following the accident. We then turn to the price response following hypothesis 2; as expected, disasters likewise trigger no price response.

5.1. Quantities

To support the graphical evidence presented in section 4.1, we formally test the impact of mine disasters on potash production in a given country with a series of panel regressions. The results are summarised in Table 2. Columns (1) and (2) show the impact of the disasters defined as a binary dummy (1) or a quantitative dummy (2) on the global production. No negative impact of the disasters can be detected and the model has very low predictive power. Columns (3) - (6) show the results of panel estimation with country and year fixed effects. To construct the panel, we separate the major producing countries (Canada, Soviet Union which later splits into Russia and Belarus) and aggregate the reminder of the world production into a single "rest of the world" entity. In a number of specifications allowing for linear and log-linear relations between exogenous changes in production capacity, we find robust evidence that potash mine disasters do not impede production in the affected country. None of the examined measures of lost production capacity has a significant negative impact on output in the affected countries. Some regression coefficients have even a positive sign (albeit insignificant).

5.2. Prices

Various OLS and D-i-D regression specifications robustly show lack of impact of potash mine disasters in potash prices as summarised in Table 3. In the basic OLS model of column (1), each individual coefficient on the supply shock is insignificant; however, the model clearly suffers from autocorrelated residuals as shown by a highly significant Durbin-Watson h-statistic. In column (2), lags of the return series are added.[16] This

[16]See Appendix A2 and Appendix Table A1(c).

TABLE 2
Regression Results: Impact of Mine Disasters on Annual Production

	Global:		Country:			
Dependent Variable:	Output	log(Output)	Output		log(Output)	
	(1)	(2)	(3)	(4)	(5)	(6)
Disaster	0.493		0.661		0.101	
	(1.343)		(1.021)		(0.155)	
lag(Disaster)	1.141		0.563		−0.022	
	(1.435)		(1.042)		(0.158)	
Global Loss		0.005				
		(0.016)				
lag(Global Loss)		0.012				
		(0.018)				
Capacity				0.529		
				(0.692)		
lag(Capacity)				0.164		
				(0.735)		
Local Loss						0.003
						(0.010)
lag(Local Loss)						−0.011
						(0.010)
Constant	0.387	0.022				
	(0.512)	(0.020)				
Country FE	NO	NO	YES	YES	YES	YES
Year FE	NO	NO	YES	YES	YES	YES
Observations	53	53	184	184	184	181
R^2	0.016	0.011	0.887	0.887	0.799	0.811
Note:						*p<0.1; **p<0.05; ***p<0.01

Output represent annual potash production in MMT. *Disaster* is a dummy variable that takes value one in the year of the disaster for the affected country and zero otherwise. *Global loss capacity* and *local loss* variables are quantitative dummies defined as the share of the affected mine in global production, mine capacity in MMT and the share of the affected mine in the country level production capacity respectively in the year and country of the event and zero otherwise.

solves the autocorrelation problem, but does not affect the earlier conclusion: The effect of supply shocks on prices is still jointly insignificant. This conclusion carries through the D-i-D estimates, both with phosphate rock monthly returns (columns (3) and (4)) and the mean fertilizer return used as counterfactuals as shown in columns (5) and (6).

All odd numbered columns include only pure quantitative dummy effect, i.e. the sup-

TABLE 3
Regression Results: Monthly Commodity Returns

Dependent Variable	OLS		Difference-in-Differences			
	%Δ Potash		%Δ(Potash-Phosphate)		%Δ(Potash-Mean Fertilizer)	
	(1)	(2)	(3)	(4)	(5)	(6)
Potash Shock Size:						
Lag 0	0.133	0.293	0.722	0.786	0.851	0.848
	(0.540)	(0.512)	(1.189)	(1.174)	(1.435)	(1.436)
Lag 1	−0.137	−0.063	0.028	0.060	−0.303	−0.310
	(0.540)	(0.513)	(1.189)	(1.175)	(1.435)	(1.436)
Lag 2	−0.196	−0.116	0.029	0.120	−0.370	−0.368
	(0.540)	(0.512)	(1.189)	(1.175)	(1.435)	(1.436)
Lag 3	0.097	0.179	−0.156	−0.220	0.250	0.254
	(0.536)	(0.509)	(1.180)	(1.166)	(1.425)	(1.426)
Lag 4	−0.339	−0.350	−0.164	−0.157	0.092	0.090
	(0.536)	(0.509)	(1.180)	(1.166)	(1.425)	(1.426)
Lag 5	0.122	0.229	0.159	0.039	0.172	0.171
	(0.536)	(0.509)	(1.180)	(1.166)	(1.425)	(1.426)
Lag 6	−0.039	−0.024	0.136	0.140	0.443	0.442
	(0.536)	(0.509)	(1.180)	(1.166)	(1.425)	(1.426)
Lag 7	−0.539	−0.519	−1.140	−1.114	−0.874	−0.878
	(0.536)	(0.509)	(1.180)	(1.166)	(1.425)	(1.426)
Lag 8	0.856	1.012**	−0.925	−0.904	0.441	0.448
	(0.536)	(0.509)	(1.180)	(1.167)	(1.425)	(1.426)
Lag 9	−0.021	−0.182	0.154	0.116	0.354	0.350
	(0.536)	(0.510)	(1.180)	(1.167)	(1.425)	(1.426)
Lag 10	0.047	0.033	0.482	0.518	0.389	0.386
	(0.540)	(0.514)	(1.189)	(1.176)	(1.435)	(1.436)
Lag 11	−0.100	−0.119	−0.030	0.042	−0.430	−0.433
	(0.540)	(0.514)	(1.189)	(1.176)	(1.435)	(1.436)
Lag 12	0.009	−0.083	−0.384	−0.212	−0.120	−0.117
	(0.540)	(0.513)	(1.189)	(1.176)	(1.435)	(1.436)
Lagged Dependent Variable:						
Lag 1		0.216***		0.005		0.008
		(0.039)		(0.039)		(0.039)
Lag 2		0.059		−0.047		
		(0.039)		(0.039)		
Lag 3		0.082**		0.098**		
		(0.039)		(0.038)		
Lag 4		0.129***		0.001		
		(0.039)		(0.039)		
Lag 5				0.148***		
				(0.039)		
Constant	0.004**	0.002	−0.002	−0.002	−0.004	−0.004
	(0.002)	(0.002)	(0.004)	(0.004)	(0.005)	(0.005)
Diagnostic Tests (p values):						
F-Test: All $\phi_i = 0$	0.99	0.93	1.00	1.00	1.00	1.00
Breusch-Pagan	1.00	1.00	1.00	1.00	1.00	1.00
Durbin-Watson	0.00	0.58	0.47	0.49	0.42	0.50
Goodness of Fit:						
Observations	677	677	677	677	677	677
R^2	0.007	0.111	0.004	0.035	0.002	0.002
F Statistic	0.340	4.856***	0.182	1.323	0.108	0.103

Note: $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$
Source:

ply size shock variable with its 12 lags on the right hand side of the equation. The even numbered columns are augmented with autoregressive components and the number of lags selected is guided by the standard information criteria and supplemented with robustness tests as described in Appendix A2. Inclusion of the lagged dependent variable helps to remove autocorrelation in residuals and increases the models' goodness of fit, but does not affect the main conclusion on the lack of impact of exogenous supply shocks on potash prices.

Analysing the different D-i-D models, we can see that when compared to other fertilizers, we observe relative increase of potash price in the month of the accident, by 0.7% to 0.8% for each percentage point of the capacity lost. This trend, however, is overturned in the subsequent months. Regression coefficients on lagged values of the quantitative dummy variable do not show a clear pattern either between the lags or between the models strengthening the conclusion of no impact suggested by low values of the test on joint significance of the shock variables (F-test).

6. Conclusions

For a variety of reasons, risks of disasters – both natural and man-made – are on the rise; this makes it urgent to understand how institutions can promote (or hinder) the resilience of markets to such events. This paper studied a particular type of cartel, the syndicate, which allocates market shares in proportion to the productive capacity of each member. A well-understood consequence of this market sharing rule is excess capacity. While this feature clearly comes at a cost in excess of the standard monopoly deadweight loss, it can – in theory – lead to remarkable resilience to extreme events.

Potash production is plagued by mine disasters, and organized through syndicates. This makes it an ideal commodity to test how syndicated commodity markets respond to large disasters. Over the last decades, mine collapses have caused the loss of up to 4% of global or 20% of country level production capacity per incident. Due to excess capacity driven by the market structure, those events have had no impact not only on price but even country-level output rates.[17]

[17]The same cannot be said about the valuation of the affected firms. Uralkali's stock prices plummeted by nearly 30% on the day the Solikamsk-2 mine collapsed. No other firm owning a collapsed mine was listed at a stock exchange at the time of a disaster.

References

Agrium (2015). Agrium factbook 2014-2015. Available online: https://www.agrium.com/system/files/2014-2015_factbook.pdf.

al Rawashdeh, R. and Maxwell, P. (2014). Analysing the world potash industry. *Resources Policy*, 41:143–151.

Alhajji, A. F. (2005). The oil weapon: past, present, and future. *Oil & gas journal*, 103(17):22–22. Available online: http://www.ogj.com/articles/print/volume-103/issue-17/general-interest/the-oil-weapon-past-present-and-future.html.

Amiti, M., Itskhoki, O., and Konings, J. (2014). Importers, exporters, and exchange rate disconnect. *The American Economic Review*, 104(7):1942–1978.

Andreichuk, V., Eraso, A., and Dominguez, M. (2000). A large sinkhole in the verchnekamsky potash basin in the urals. *Mine water and the Environment*, 19(1):2–18.

Arezki, R., Lederman, D., and Zhao, H. (2013). The relative volatility of commodity prices: a reappraisal. *American Journal of Agricultural Economics*, 96(3):939–951.

Auer, R. A. and Schoenle, R. S. (2016). Market structure and exchange rate pass-through. *Journal of International Economics*, 98:60–77.

BelarusDigest (2012). Soyuzkali is hustled to the finish line. Published 18 September 2012. Available online: https://belarusdigest.com/story/soyuzkali-is-hustled-to-the-finish-line/.

Bloch, K. (1932). On German Cartels. *The Journal of Business*, 5(3):213–222.

Boudoukh, J., Richardson, M., Shen, Y. J., and Whitelaw, R. F. (2007). Do asset prices reflect fundamentals? Freshly squeezed evidence from the OJ market. *Journal of Financial Economics*, 83(2):397–412.

Canpotex (2017). Canpotex board approves new methodology for determining mine expansion productive capacity increases. Available online: http://investors.mosaicco.com/Cache/1001218617.PDF?Y=&O=PDF&D=&FID=1001218617&T=&IID=4097833.

Clark, J. F. and Decalo, S. (2012). *Historical Dictionary of Republic of the Congo*. Scarecrow Press.

Eilertsen, D. E. (1970). Potash. *Minerals Yearbook (USGS)*.

Fabra, N. and Reguant, M. (2014). Pass-through of emissions costs in electricity markets. *The American Economic Review*, 104(9):2872–2899.

Fink, N., Schmidt-Dengler, P., Stahl, K., and Zulehner, C. (2017). Registered cartels in austria: An overview. *European Journal of Law and Economics*, 44(3):385–422.

Garrett, D. E. (2012). *Potash: deposits, processing, properties and uses*. Springer Science & Business Media.

Ghoddusi, H., Nili, M., and Rastad, M. (2017). On quota violations of opec members. *Energy Economics*, 68:410–422.

Gouel, C. (2013). Optimal food price stabilisation policy. *European Economic Review*, 57:118–134.

Hamilton, J. D. (2003). What is an oil shock? *Journal of econometrics*, 113(2):363–398.

Hamilton, J. D. (2013). Historical oil shocks. In Parker, R. E. and Whaples, R. M., editors, *Routledge handbook of major events in economic history*, chapter 21, pages 239–265. Routledge.

Harrington, J. E. and Skrzypacz, A. (2011). Private monitoring and communication in cartels: Explaining recent collusive practices. *The American Economic Review*, 101(6):2425–2449.

Hong, G. H. and Li, N. (2017). Market structure and cost pass-through in retail. *Review of Economics and Statistics*, 99(1):151–166.

Igami, M. (2015). Market power in international commodity trade: The case of coffee. *The Journal of Industrial Economics*, 63(2):225–248.

IGWG (1997). *Overview of Trends in Canadian Mineral Exploration*. Natural Resources Canada, Minerals & Metals Sector.

IPCC (2012). *Managing the risks of extreme events and disasters to advance climate change adaptation: special report of the intergovernmental panel on climate change.* Cambridge University Press.

Jenny, F. (2012). Export cartels in primary products: The potash case in perspective. *Trade, Competition, and the Pricing of Commodities*, page 99.

Jensen, R. G., Shabad, T., and Wright, A. W. (1983). *Soviet natural resources in the world economy.* University of Chicago Press.

Jia, R. and Nie, H. (2017). Decentralization, collusion, and coal mine deaths. *Review of Economics and Statistics*, 99(1):105–118.

Kilian, L. (2008). Exogenous oil supply shocks: how big are they and how much do they matter for the us economy? *The Review of Economics and Statistics*, 90(2):216–240.

Kilian, L. (2009). Not all oil price shocks are alike: Disentangling demand and supply shocks in the crude oil market. *American Economic Review*, 99(3):1053–69.

Kramer, A. E. (2012). A russian city always on the watch against being sucked into the earth. *New York Times*, 2012-04-11. Available online: http://www.nytimes.com/2012/04/11/world/europe/russian-city-on-watch-against-being-sucked-into-the-earth.html.

Larson, D. A. (1970). An economic analysis of the webb-pomerene act. *The Journal of Law and Economics*, 13(2):461–500.

Levermann, A. (2014). Make supply chains climate-smart. *Nature*, 506(7486):27.

Libecap, G. D. (1989). The political economy of crude oil cartelization in the united states, 1933–1972. *The Journal of Economic History*, 49(4):833–855.

Merener, N. (2016). Concentrated Production and Conditional Heavy Tails in Commodity Returns. *Journal of Futures Markets*, 36(1):46–65.

Moraht, R. (1921). Die entwicklung des internationalen wettbewerbs auf dem kalimarkt. *Weltwirtschaftliches Archiv*, 17:51–67.

PotashCorp (2014). Overview of potashcorp and its industry. Available online: www.potashcorp.com/overview/upload/pdf/PotashCorp_Industry_Overview.pdf.

PotashCorp (2017). Production & capacity - potash. Available online: http://www.potashcorp.com/irc/potash/production-capacity-potash.

Prugger, F. F. (1979). The flooding of the cominco potash mine and its rehabilitation. In *Proc. 5th Symp. on Salt, Hamburg*, pages 333–340.

Rahm, M. R. (2006). 2006/07 potash outlook. Technical report, Mosaic. Available online: www.firt.org/sites/default/files/Rahm_Potash_Outlook_presentation.pdf.

Ready, W. F. (1971). The saskatchewan potash prorationing scheme. *Alta. L. Rev.*, 9:592.

Roll, R. (1984). Orange juice and weather. *The American Economic Review*, 74(5):861–880.

Röller, L.-H. and Steen, F. (2006). On the workings of a cartel: Evidence from the norwegian cement industry. *The American economic review*, 96(1):321–338.

Rosenzweig, C., Iglesias, A., Yang, X., Epstein, P. R., and Chivian, E. (2001). Climate change and extreme weather events; implications for food production, plant diseases, and pests. *Global change & human health*, 2(2):90–104.

Searls, J. P. (1987). Potash. *Minerals Yearbook (USGS).*

Singleton, R. H. (1977). Potash. *Minerals Yearbook (USGS).*

Taylor, C. R. and Moss, D. L. (2013). The fertilizer oligopoly: The case for global antitrust enforcement. *The American Antitrust Institute, USA.*

USGS (2017). *Minerals Yearbook - 2014 (Volume III. – Area Reports: International).* USGS.

Waltham, T., Bell, F. G., and Culshaw, M. (2007). *Sinkholes and subsidence: karst and cavernous rocks in engineering and construction.* Springer Science & Business Media.

Warren, J. (2015). Solikamsk sinkhole and potash ore. Available online: http://www.saltworkconsultants.com/blog/solikamsk-2-collapse-and-depth-to-ore-zones.

Webb, T. (2009). *New Brunswick Potash: A Review of Developments and Potential Exploration Alternatives.* New Brunswick, Minerals, Policy and Planning.

World Economic Forum (2017). Global risk report. Available online: http://www3.weforum.org/docs/GRR17_Report_web.pdf.

Wright, B. D. and Williams, J. C. (1988). The incidence of market-stabilising price support schemes. *The Economic Journal*, 98(393):1183–1198.

Yara (2017). Fertilizer industry handbook 2017. Available online: http://yara.com/doc/245620_Fertilizer_Industry_Handbook_2017_with_notes.pdf.

Appendices

A1. Model of Syndicates and Excess Capacity

To explore the relationship between production rationing and commodity market volatility, we turn to a simple model closely related to Röller and Steen (2006). This model proceeds in two stages: first, firms invest in production capacity. In the second stage, the institutional "market sharing rule"' determines the quota that each firm is allowed to sell on the market.

In the first stage, each firm $i \in \{1, \ldots N\}$ invests in capacity; its capacity level is denoted c_i. There is a constant marginal cost θ for each unit of capacity, which is sunk in this period. In the second stage, the syndicate decides on the total quantity Q to be sold in the market, and allocates market shares $s_i(c_1, \ldots, c_n)$ to each firm proportional to their productive capacity. Then market outcomes unfold, where the marginal cost of production is normalized to zero up to each firm's capacity level and infinite thereafter.

This model differs from Röller and Steen (2006) in two important ways. First, in the present model, the syndicate determines global supply and hence also market prices, while in Röller and Steen (2006), the syndicate takes the world market price as given and determines only domestic supply levels. Second, there is no excess capacity in Röller and Steen (2006) – capacity that exceeds domestic demand is sold in export markets; in our model, the syndicate effectively controls global supply, so excess capacity is idle.

Market Outcomes: We assume a linear demand function, $D(Q) = A - Q$. To ensure that output is non-negative, assume that the intercept A is sufficiently large, i.e. $A > \theta$ throughout. Thus, taking into account the sharing rule and investment costs, the profit of firm is given by

$$\pi_i(c_1, \ldots, c_n; Q) = s_i Q(A - Q) - \theta c_i. \tag{4}$$

Syndicate Stage: The objective of the syndicate is to maximize industry profits by setting the total market output Q. The level of capacity is taken as given. Hence, the syndicate maximization problem is is

$$\max_{Q} \; (\underbrace{\sum_i^N s_i}_{1})Q(A-Q) - \sum_i^N \theta c_i \tag{5}$$

$$\frac{d}{dQ} = A - 2Q \tag{6}$$

$$Q^* = \min\left(\frac{A}{2}, \sum_i c_i\right) \tag{7}$$

Since investment costs are sunk in the syndicate stage, the syndicate does not take these into account when setting the market quota. Thus, the syndicate acts as a monopolist with a zero marginal cost.

Investment Stage with Two Firms: The problem of each firm is

$$\max_{c_i} s_i(c_1, c_2)Q^*(A-Q^*) - \theta c_i \tag{8}$$

Consider first the case that the syndicate constraint binds, i.e. $\sum c_i \geq \frac{A}{2}$. Then $s_i = c_i/(c_1+c_2)$. The first order condition for firm 1 is given by:

$$Q^*(A-Q^*)\frac{c_2}{(c_1+c_2)^2} - \theta = 0 \rightarrow c_1 = \pm\frac{\sqrt{Q^*(A-Q^*)c_2\theta} - c_2\theta}{\theta} \tag{9}$$

Disregarding the negative root the mutual best responses are given by:

$$c^*_{DUO} = \frac{Q^*(A-Q^*)}{4\theta} \tag{10}$$

which, given the optimal quantity Q* set by the syndicate yields the equilibrium investment level $c^*_{DUO} = \frac{A^2}{16\theta}$. This implies industry capacity $C^*_{DUO} = \frac{A^2}{8\theta}$; due to the market sharing rule, the quantity actually sold on the market is $Q^*_{DUO} = \frac{A}{2}$.

Note that the mutual best responses imply that the industry capacity costs are proportional to industry revenues. Consequently, the results are not changed if the order of the game is reversed, i.e. the syndicate sets the production level in stage one and the firms invest in capacity in stage two.[18]

In this equilibrium, capacity utilization – the ratio of production to capacity – is thus given by $\frac{4\theta}{A}$.

Since the solution was obtained under the assumption that the syndicate constraint binds, it remains to check when this is in fact the case: $2c^*_{DUO} \geq \frac{A}{2} \rightarrow A \geq 4\theta$.

Alternatively, suppose the syndicate does not bind. Then, $s_i = c_i$ and the problem reduces to a Cournot duopoly, and each firm produces at full capacity. We have the well–known equilibrium investment and output levels $c^* = \frac{A-\theta}{3}$. We have $Q^*_{CO} = C^*_{CO} = \frac{2(A-\theta)}{3}$. To verify that under this solution the constraint does not bind,

$$2c^* < \frac{A}{2} \rightarrow A < 4\theta \tag{11}$$

Thus, for the duopoly case, the syndicate constraint binds when $A \geq 4\theta$, leading to excess capacity in equilibrium. Otherwise, the syndicate does not bind and the Cournot outcome obtains.

Investment Stage with Free Entry: Suppose now there is free entry. Then the marginal firm must be indifferent about changing capacity and we have the equilibrium condition

$$0 = s_i(c_1, \ldots, c_n)Q^*(A - Q^*) - \theta c_i \tag{12}$$

Suppose first the syndicate constraint is binding. Then we must have $s_i = c_i / C^*_{FE}$, where $C^*_{FE} = \sum_j c_j$ denotes total industry capacity under free entry. Cancel out the common term c_i and get

$$\frac{Q^*(A - Q^*)}{C^*_{FE}} - \theta = 0 \rightarrow C^*_{FE} = \frac{A^2}{4\theta} \tag{13}$$

To verify that the syndicate constraint is binding, check $\frac{A^2}{4\theta} \geq \frac{A}{2} \rightarrow A \geq 2\theta$. Due to the

[18] Given the mutual best responses from equation 10, the industry capacity cost set in stage two equals $2 * \theta * \frac{Q^*(A-Q^*)}{4\theta}$. Thus, syndicates optimisation in stage one is defined as:

$$\max_Q Q\,(A - Q) - 2 * \theta * \frac{Q\,(A - Q)}{4\theta}$$

which is solved by $Q^* = A/2$, as in the case where the firms move first.

syndicate policy, the quantity actually sold on the market is only equal to $Q^*_{FE} = \frac{A}{2}$, i.e. the same level as under duopoly. Hence, all the new capacity created under free entry actually remains idle in equilibrium.

Now suppose the syndicate constraint is not binding under free entry. Then all output is sold and the price should equal the marginal cost of capacity, as under perfect competition. We must have $A - Q = \theta$ or $Q = A - \theta$. To verify when the assumption does not bind holds:

$$Q = A - \theta < \frac{A}{2} \rightarrow A < 2\theta \tag{14}$$

Benchmark Cases: Under perfect competition, each firm will invest in capacity until the marginal cost equals the market price. Thus, we must have $Q^c = A - \theta$ supplied to market at price c. Note that, provided demand is strong enough compared to marginal cost of capacity, the equilibrium capacity under prorationing duopoly can even exceed the level under perfect competition.[19]

Likewise, under monopoly, the standard first order condition holds and we have $Q^m = \frac{A-\theta}{2}$ supplied to the market, there is no excess capacity and the monopoly price is similarly well-known: $P^m = \frac{A+\theta}{2}$.

We know that under Cournot duopoly, we have $Q^m = \frac{2}{3}(A - \theta)$ supplied to the market.

Summary of Industry Capacity:

$$\begin{aligned}
C^*_{PC} &= A - \theta \\
C^*_{M} &= \frac{1}{2}(A - \theta) \\
C^*_{CO} &= \frac{2}{3}(A - \theta) \\
C^*_{DUO} &= \begin{cases} \frac{2(A-\theta)}{3} & \text{if } \theta \leq A < 4\theta \\ \frac{A^2}{8\theta} & \text{if } A \geq 4\theta \end{cases} \\
C^*_{FE} &= \begin{cases} A - \theta & \text{if } \theta \leq A < 2\theta \\ \frac{A^2}{4\theta} & \text{if } A \geq 2\theta \end{cases}
\end{aligned}$$

[19] This occurs if $A \geq (2^(3/2) + 4)\theta$.

Supply Response to an Unanticipated Shock: We now consider the response of firm supply and market price to an unanticipated supply shock. Note first that in the baseline cases – monopoly, Cournot and perfect competition – each firm builds up capacity in line with expected demand. Thus, there is no spare capacity and any unanticipated supply shock in the second period must reduce market output one-by-one.

Under a syndicate, there is in general excess capacity in equilibrium. A supply shock in the market outcomes period – which, by construction, cannot affect the syndicate production quotas announced in period 2 – may thus lead to *no supply response* at all if it is less than level of spare capacity.

Consider the duopoly case where $A \geq 4\theta$ (so there is excess capacity in equilibrium). Then the share of capacity utilized is given by:

$$s^*_{DUO} = \frac{q^*_{DUO}}{c^*_{DUO}} = \frac{\frac{A}{4}}{\frac{A^2}{16\theta}} = \frac{4\theta}{A}. \tag{15}$$

Thus, as demand increases relative to the cost of capacity, the share of capacity utilization rapidly drops. Thus, for natural resource industries – where rents due to resource scarcity can cause prices to far exceed the marginal cost of capacity investment – the incentive to build spare capacity can be substantial.

A2. Lag Selection

There is some autocorrelation in the fertilizer returns series, although it is less severe than for other commodities. For potash, the first order autocorrelation is estimated at 0.25, and declines afterwards (all autocorrelation functions are available in the online appendix. In the case of phosphate, the ACF is much lower at 0.10, although there is a peak in the autocorrelation at lag 5. For both commodities, there are some significant negative autocorrelations at long lags (more than 12 months). In the case of nitrogen, autocorrelation is insignificant at lags except 12. For nitrogen, the autocorrelation is readily understood: it is driven by seasonality in the form of a significant positive price shock in the month of January. This is driven by natural gas prices, which have the same autocorrelation structure. With the mineral fertilizers, no clear economic explanation for the autocorrelation structure is available and the pattern does not clearly follow a standard process.

Our choice of lag structure is thus guided by the standard information criteria and supplemented with robustness tests. As panel C of Table A1 shows, both the Hennan-Quinn (HQ) and Schwarz Criterion (SC) recommend a lag length of 4 months for the potash return series. For the difference between potash and mean return of other fertilizers, both criteria select a single lag. For the potash return difference with respect to phosphates, the HQ selects five lags while SC picks only a single lag; for this case, we select the larger number of lags and then "test down". These findings suggest that our differencing strategy is successful in removing autocorrelation from the return series.

A3. Detailed Review of Potash Disasters

Cominco (1970): Cominco Ltd. was a Canadian milling company with operations throughout the world. It was a major producer of lead, zinc, silver and fertilizers. In July 1965, the company started preparation for developing of its first potash mine in Vanscoy with 1.2MMT annual capacity around 40 km southwest of Saskatoon in the province of Saskatchewan in Canada (Eilertsen, 1970).

The production started in in January 1969. However, on August 27, 1970, a major water inflow occurred. During routine grouting of the concrete lining of one of the shafts, a major water source was intersected 600m underground. Water and sand under very high pressure entered the mine bringing mining operations to an abrupt halt. Thanks to complex engineering works and injection of a couple of hundred tonnes of cement, the hole through which the brine was flowing to the mine was plugged 2 weeks after the inflow occurred.

On September 22, dewatering of the mine started and over 500 000 m^3 of brine was pumped out from the mine over the subsequent 9 months. After equipment rehabilitation, the mine restarted its operations in September 1972, two years after the inflow occurred (Prugger, 1979).

The fertilizer division of Cominco Ltd. was later separated and in 1995 changed its name to Agrium, Incorporated. The Vanscoy mine continues its operations to this day and after a number of extensions the nameplate capacity for the mine is over 3 MMT (Agrium, 2015).

Holle Mine (1977): Potash Company of Congo was established in 1964 to extract potash resources in the Kouilou region in Republic of the Congo. The Holle mine started operations in 1969 and by 1970, CPC has become the single most important company in the country with nearly 15% share in Congolese exports (Clark and Decalo, 2012). The mine, with installations capable of operating at 0.5MMT a year, due to more complex than expected geology of the deposit was producing approximately 0.35MMT a year and the company was hardly breaking even.

In June 1977, while attempting to extend the mine, a fault was encountered that exposed a dolomite aquifer that overlay the potash deposits (Singleton, 1977). Deliveries of potash continued after the flooding until the accumulated producers' stocks of 0.1MMT were used and the company and the mine closed later that year.

In 2008, following unprecedented potash price growth, plans to explore Congolese potash deposits rejuvenated with inception of Holle Potash Corp, a greenfield potash mining firm that acquired mineral exploration rights for potash deposits in the neighbourhood of the former mine. Those plans did not materialize as the company did not even succeed to conduct feasibility studies for the project. However, in the meantime, two other companies Plymouth Minerals and Elemental Minerals also acquired mineral rights to potash deposits in the region.

Berezniki-3 (1986): The Berezniki-3 mine was located in Verkhnekamskoye field in Perm Territory of Soviet Union, world's second largest in terms of potash ore reserves. Potash mining in the regions started as early as in 1934, when the First Potash Mining Complex was launched in Solikamsk, later followed by another mine in Solikamsk and four mines in Berezniki. The Third Potash Mining Complex (Berezniki-3) started potassium chloride production in 1973 and was then the world's largest producer of potash according to official website of Uralkali, the current owner of the deposits.

On January 11, 1986, a jet of brine developed in one section of the mine. The leakage was closely monitored from January 11 until March 8, when the inflow of water sharply increased. On March 9, all miners were safely brought to the surface, though the mining equipment had to be left underground (Andreichuk et al., 2000). Brine leakage into the mine, at a depth of 400m, caused massive dissolution of the 90m of salt overlying the mined potash. Consequently, seven months later, in October 1986 cavity migration reached the surface with the instantaneous appearance of a sinkhole and 40 x 80m across (Waltham et al., 2007).

The impact of the accident on Russian potash exports, however, was limited as infrastructure bottlenecks in Soviet Union did not allow to transport to export hubs (Jensen et al., 1983, p. 272) all of its capacity. Furthermore, it was decided to supply potash ore from Berezniki-4 mine, which was then under construction.

Patience Lake (1987): Patience Lake mine, the oldest potash mine in Saskatchewan, was operated by the Potash Company of America, an American potash producer set up in New Mexico in the 1930s. The company was acquired by Potash Corporation of Saskatchewan in 1993.

The mine started its operations in 1958 but already after 11 months it was flooded and closed for 6 months (Garrett, 2012, p. 315). In 1975, the mine again experienced heavy brine inflow, but extensive grouting operations significantly reduced the leakage and the mine continued its operation without major problems for the subsequent decade. However, in 1986, the small flow into the mine started to grow and on January 1, 1987 it reached such a level that the flood outstripped pump capacity. It appeared hopeless to stop the leakage and the mine was abandoned.

Soon afterwards a process of controlled flooding started in order to restart the production as a solution mine. It was not a novel technology, as similar methods had already been used in an abandoned potash mine in Moab, Utah in 1970. The transformation of the Patience Lake mine to a solution mine was, however, associated with a significant decrease in production capacity. At the end of the first two production seasons in 1992 production rates of 300 000 t KCl/yr were achieved, down from 1.15 million tonnes KCl/yr mine capacity reported in 1984.

It has to be noted that at the same time another mine in a region, Esterhazy K2 mine (owned by IMC) was operating at 75% capacity while a leak from an aquifer was slowly plugged in (Searls, 1987).

Cassidy Lake (1997): Following the success of the government-sponsored drilling program exploring for potash salts in New Brunswick two mines opened in 1980s. Patience Lake mine developed by Denison Mines Ltd started its operations in 1985. Due to financial difficulties of the parent company, in 1991, the mine was sold to a consortium of Entreprise Minière et Chimique (EMC) of France and Kali und Salz A.G. (K+S) of Germany (which had already acquired a minority stake in the operations a couple of years earlier) to operate under name Potash Company of Canada Limited (Potacan) (Webb, 2009).

However, after 12 years of operations, the mine developed a serious leak in mid-June 1997. The company immediately embarked on a grouting strategy that officials hoped would be successful in reducing the inflow to a manageable level. Unfortunately, the program failed to produce the desired results and on October 30, 1997, the company announced that it would be closing the Cassidy Lake mine (IGWG, 1997).

After the closure Potacan sold the flooded mine and its compaction facility and other related infrastructure to Potash Corporation of Saskatchewan.

Berezniki-1 (2006): After the collapse of the Soviet Union, potash production was split between three companies, Belaruskali operating in Belarus, and two Russian firms extracting potash from Verkhnekamskoye field in Perm Territory - Uralkali operating Berezniki-1, -2 and -4 mines and Silvinit operating mines Solikamsk-1 and -2. The two firms merged in 2011 and continue to operate under Uralkali brand.

Berezniki-1 mine has history dating back to 1930, when the decision to built the mine was taken, though due to economic reasons and the outburst of the World War II the mine construction did not start before 1949. In 2005, the last year of full operation the mine produced 1.38 million tonnes KCl (Rahm, 2006). Problems for the mine started when on October 19, 2006, a flood occurred following a break in a section of an old part of the mine, which caused an inflow of brine. For 10 days efforts were being made to safe the mine, however, an increase in the brine flow forced the company to cease operations on October 29.

The mine closure was not the only consequence of the flooding for the company and the local community, as in the subsequent years a number of sinkholes occurred in the area. In October 2008 one of the sinkholes, called “the Grandfather” by the local population extended about 400 meters long, 300 meters wide and 100 meters deep and swallowed the main railroad line causing disruptions for potash shipments also forcing the local authorities to evacuate 2000 people from nearby apartment blocks (Kramer, 2012).

Solikamsk-2 (2014): Solikamsk-2 mine started its operations in 1980. 15 years later and 7 years after mining was completed in the area, a collapse sinkhole formed atop the mine. The collapse on January 5th, 1995 resulted in a 4.7 magnitude seismic event on the

Richter scale (Warren, 2015), though the event did not affect the mine's output. Since then, the accident area has been subject to detailed comprehensive monitoring.

On 18 November 2014, Uralkali detected higher levels of brine inflow in the Solikamsk-2 mine and all employees were evacuated from the mine. Later that day, a sinkhole with a diameter of approximately 30 meters-40 meters was discovered. The sinkhole is mainly associated with the area where the rocks and inter-bed pillars collapsed in 1995. In the following months, the brine inflow started to increase and the company decided to remove the underground equipment that was not being used to mitigate the consequences of the collapse and water inflow in February 2015. The mitigation activities included monitoring, installation of a dewatering system and backfilling to prevent further adverse effects of the accident. Later that year the company announced that it was confident it could continue mining the Solikamsk-2 mine from the existing infrastructure for another 6 to 7 years. In 2016, the mine was operating at 50% of its initial capacity. According to company statements, the full capacity was to be restored in 2022 upon construction of a new shaft.

TABLE A1
Supplementary Tables

(a) Descriptive Statistics

Variable	Obs.	Mean	Std. Deviation
Potash Returns	689	0.0039	0.0438
Phosphate Returns	689	0.0060	0.1006
Nitrogen Returns	689	0.0091	0.1610
Potash Price	690	133.6301	137.4831
Phosphate Price	690	53.2612	57.8836
Nitrogen Price	690	145.9995	110.6682
Potash Production	54	24.5584	6.9677
Phosphate Production	54	29.5914	9.9605
Nitrogen Production	54	67.6447	29.6135

(b) Unit Root Tests

Variable	Philips-Perron	KPSS
Potash Returns	-21.03^{***}	0.06
Phosphate Returns	-24.14^{***}	0.04
Nitrogen Returns	-24.82^{***}	0.05
Potash Price	-3.14^{*}	0.68^{***}
Phosphate Price	-4.38^{***}	0.52^{***}
Nitrogen Price	-4.15^{***}	0.55^{***}
Potash Production	-2.93	0.18^{**}
Phosphate Production	-1.75	0.24^{***}
Nitrogen Production	-1.67	0.26^{***}

(c) Lag Selection

Variable	AIC(n)	HQ(n)	SC(n)	FPE(n)
Phosphate Returns	5	5	5	5
Potash Returns	6	4	4	6
Nitrogen Returns	1	1	1	1
D-i-D (Phosphate)	5	5	1	5
D-i-D (Fertilizers)	1	1	1	1

Source: World Bank, IFADATA and authors' calculations.
All price data are presented in nominal USD. Production data presented in million metric tonnes (MMT),

TABLE A2
Poisson Test

Accidents per month, sample mean: $\hat{\lambda} = 0.01002$

Frequency Distribution of Potash Mining Accidents, by month

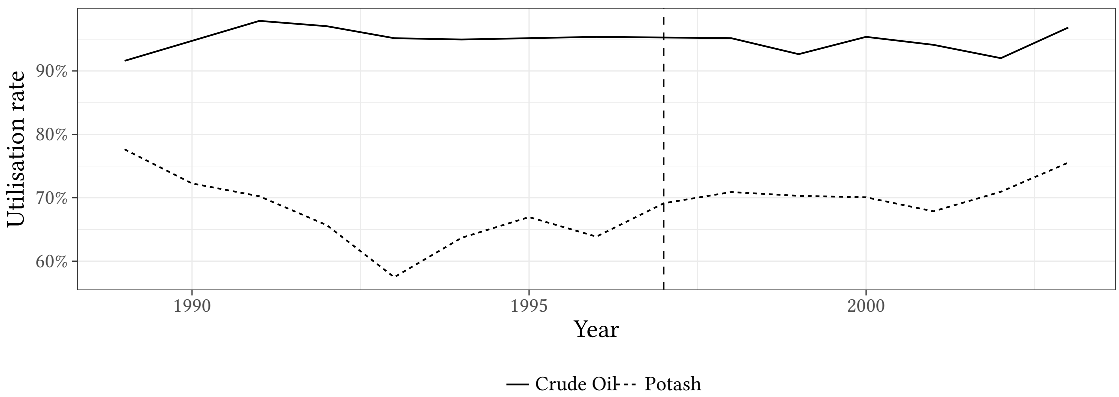
# Accidents	Actual	Expected
0	682	682.04
1	7	6.93
>1	0	0.04

To test whether actual and expected frequencies differ, we use Chi-squared test with 2 degrees of freedom. The associated test statistic and p-value are:
$\chi^2 = 0.036$, $p = 0.9821$

There is no evidence that the observed frequency distribution differs from a Poisson distribution.

Source: Authors' calculations

FIGURE A1
Potash and Crude Oil Utilisation Rate in 1989 - 2003



Source: USGS, Potash Corp, Natural Resources Canada, Kilian (2008) and authors
Vertical lines denote the timing of potash mine disasters.