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RESEARCH ARTICLE

The U.S. Elasticity of Import Demand for Potash

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Abstract

To sustain its agricultural output, the U.S. relies heavily on imports of potash. Using two different methodologies, this study finds that U.S. import demand falls by approximately four percent in the short run and nine percent in the long run for a 10% rise in the potash import price. Price transmission with leading exporter Canada is imperfect, with U.S. prices rising only 7.7% in the short run when Canadian prices rise by 10%. The findings suggest that policies such as import tariffs would raise costs for U.S. agricultural producers because there are few potash substitutes.

Keywords: Demand; elasticity; error correction; fertilizer; imports; price transmission

JEL classifications: F1; Q11; Q12

1. Introduction

Modern agricultural and food systems depend critically on plant nutrients such as potassium, which along with nitrogen and phosphate make up the three macronutrients essential to plant growth (Huang, 2009; Katovich, Thabtah, and Day, 2018). Agricultural crops take up significant amounts of potassium and if potassium is deficient in the soil, plant growth is stunted and yields decline. When the supply of potassium in the soil is not adequate, a fertilizer program must supply it. Potash is the common name for fertilizer that supplies the element potassium.

The U.S. market for potash fertilizer is of particular importance for two reasons. First, the U.S. is a top-three agricultural producer in the world, and a major exporter of food and agricultural products (Beckman, Dyck, and Heerman, 2017). Ensuring that the U.S. has sufficient supplies of potash fertilizer is therefore critical to ensuring that the world has sufficient supplies of food (Penuelas, Coello, and Sardans, 2023). At the same time, the U.S. must rely almost entirely on imports for supplies of potash. The U.S. produced only 400 thousand metric tons of potash in 2023 against consumption of 5,300 thousand metric tons (U.S. Geological Survey, 2024). Global potash reserves are concentrated in three countries: Canada, Russia, and Belarus. The U.S. imports approximately 95% of its potash consumption requirements, with imports sourced from Canada (83%), Russia (6%), Belarus (6%), and other countries (5%). By contrast, the U.S. imports only 12 and 9% of the other two main nutrients for U.S. agriculture, nitrogen and phosphate (U.S. Geological Survey, 2024).

With no direct substitute, potash demand has increased rapidly as the world has become more populated and more prosperous (Cocker, Orris, and Wynn, 2016). As a globally demanded commodity produced in a small number of locations, potash has historically had volatile prices and occasional tight availability (Huang, 2009). Recently the U.S. government has more closely monitored the stability of imports from Canada due to occasional import disruptions (U.S. Geological Survey, 2024). These occurred during the COVID-19 pandemic, which placed constraints on border trade, as well as during more recent strikes by Canadian railway and port workers. U.S. imports from Russia and Belarus are even more precarious, and are increasingly constrained due to political concerns. The high dependence of the U.S. on potash imports raises questions about the workings of the potash import market.

The purpose of this study is to measure the responsiveness of U.S. potash import demand to price, both in the short run and the long run. As part of our objective, we explore alternative methods of estimating the elasticity, one of which is direct estimation using reduced-form econometrics. The other approach takes a multi-country approach that is more common in the agricultural trade literature, and which allows for the behavioral responses of multiple countries involved in potash trade. In this latter approach, we must estimate price transmission elasticities in addition to the behavioral responses of individual exporting and importing countries. International price transmission for a commodity like potash may be imperfect, meaning that price changes in the supplying nation do not manifest immediately or completely into price changes locally.

To our knowledge no previous studies have estimated the elasticity of U.S. import demand for potash. We fill this gap in the literature by providing the first estimates and price transmission elasticities for fertilizer imports, specifically for potash. As such, our study contributes to a small literature on the economics of potash markets. Most studies in this literature have focused on producer decision-making with respect to fertilizer application rates. Fertilizer demand by U.S. farmers has long been studied, with seminal papers showing how application rates vary with the output price of the commodity being grown, or the price of the fertilizer itself (Griliches, 1958; Gunjal, Roberts, and Heady, 1980; Hertel, Stiegert, and Vroomen, 1996).

Less has been done to investigate the international nature of how the U.S. sources potash. In this vein there is a small literature focusing on border disputes between Canada and the U.S., including the imposition of countervailing duty actions by the U.S. against Canadian exporters of potash (Picketts, Schmitz, and Schmitz, 1991; Vroomen and Canning, 1995). In addition, since production is concentrated in a small number of mines around the world, isolated disturbances can have outsized effects on producers in importing countries like the U.S. Beyond political disturbances, supply disruptions are also caused by natural disasters. For example, Gnutzmann, Kowalewski, and Śpiewanowski (2020) show that a one percent rise in global potash mine disasters results in a three percent decrease in potash production. This further highlights the need to study potash import demand.

In the two papers closest to ours, Denbaly and Vroomen (1993) use an error-correction model to show that the fertilizer demand for U.S. corn is inelastic in both the short and the long run. Al Rawashdeh, Xavier-Oliveira, and Maxwell (2016) extend their work to the global level, assessing the historical drivers of global potash demand, generating estimates of global potash demand elasticities, and producing forecasts of future potash consumption using dynamic econometric techniques. They show that the price elasticity of demand for global potash is more elastic in the short run than in the long run, but inelastic in both the short and long run. These papers did not account explicitly for imperfect price transmission across markets. This is important because distinguishing the effect of price rigidities, on the one hand, from import behavior, on the other hand, helps clarify the role of these factors on import volumes.

In turn, we focus on import demand dynamics, as opposed to domestic-only papers that abstract from the international nature of supply. We also focus on the United States instead of global aggregate markets. We demonstrate that U.S. import demand is dynamic, with elasticities more elastic in the long run than the short run. We believe our approaches provide a refinement to our knowledge of international potash markets and how to characterize U.S. import demand.

This topic is of increasing importance in a policy environment where recent U.S. administrations have been more open to implementing tariffs on imported goods than in decades past. If this should happen in the case of potash, our estimated elasticities can be used to conduct a partial analysis of potash tariffs or related border restrictions. Our results suggest that given the inelastic nature of import demand, a tariff on potash would only slightly reduce potassium nutrient use in agricultural production in the short run. The result would be cost inflation for producers, and weakened agricultural competitiveness of the U.S.

The subsequent sections of the paper are organized as follows. The next section presents an economic framework of import demand, emphasizing the traditional agricultural economics approach to estimating the elasticity, which includes consideration of imperfect price transmission. The following sections presents data, results, and findings in turn, including a section on single-equation estimation of the U.S. import demand elasticity. The conclusions section provides a summary of limitations and directions for future research. We also consider how the results have policy implications for both the international trade and domestic production of potash.

2. Trade model approach to import demand elasticity

We start with an import demand model that extrapolates from approaches demonstrated in Bredahl, Meyers, and Collins (1979), Reimer, Zheng, and Gehlhar (2012), and Hillberry and Hummels (2013). This is a multi-country, price transmission approach to calculating an elasticity of U.S. import demand with respect to the U.S. import price. Let U.S. import demand be defined as:

$$Q_{mf} = \sum\nolimits_i Q_{xi} - \sum\nolimits_j Q_{mj}, \tag{1}$$

where Q_{xi} is the excess supply (exports) of exporting country i, and Q_{mj} is the excess demand (imports) of importing country j other than the U.S. Equation (1) implies that the U.S. imports world excess supplies that are not going to any other country. Now the question is how does U.S. import demand change as the price of imports changes for the U.S. The calculation of the elasticity of import demand with respect to U.S. import price begins with:

$$\frac{dQ_{mf}}{dp_{US}} = \sum\nolimits_i \frac{dQ_{xi}}{dp_i}\frac{dp_i}{dp_{US}} - \sum\nolimits_j \frac{dQ_{mj}}{dp_j}\frac{dp_j}{dp_{US}}. \tag{2}$$

We then multiply through and divide by a number of terms:

$$\frac{dQ_{mf}}{dp_{US}}\frac{p_{US}}{Q_{mf}}Q_{mf} = \sum\nolimits_i \frac{dQ_{xi}}{dp_i}\frac{p_i}{Q_{xi}}\frac{dp_i}{dp_{US}}\frac{p_{US}}{p_i}Q_{xi} - \sum\nolimits_j \frac{dQ_{mj}}{dp_j}\frac{p_j}{Q_{mj}}\frac{dp_j}{dp_{US}}\frac{p_{US}}{p_j}Q_{mj}. \tag{3}$$

Now divide through by Q_{mf} and restate the derivation in percentage changes:

$$\frac{dlnQ_{mf}}{dlnp_{US}} = \sum\nolimits_i \left[\frac{dlnp_i}{dlnp_{US}}\left(\frac{dlnQ_{xi}}{dlnp_i}\frac{Q_{xi}}{Q_{mf}}\right)\right] - \sum\nolimits_j \left[\frac{dlnp_j}{dlnp_{US}}\left(\frac{dlnQ_{mj}}{dlnp_j}\frac{Q_{mj}}{Q_{mf}}\right)\right]. \tag{4}$$

The elasticity of import demand is then:

$$E_{mf} = \sum\nolimits_i E_{pi}E_{esi}\frac{Q_{xi}}{Q_{mf}} - \sum\nolimits_j E_{pj}E_{edj}\frac{Q_{mj}}{Q_{mf}}, \tag{5}$$

where $E_{pi} = \frac{dp_i}{dp_{US}}\frac{p_{US}}{p_i}$ is the price transmission elasticity for exporting country i, $E_{pj} = \frac{dp_j}{dp_{US}}\frac{p_{US}}{p_j}$ is the price transmission elasticity for importing country j, E_{esi} is the elasticity of excess supply in country i, E_{edj} is the elasticity of excess demand in country j, Q_{xi} is the excess supply (exports) of country i, and Q_{mj} is the excess demand (imports) of country j other than U.S. The terms $\frac{Q_{xi}}{Q_{mf}}$ and $\frac{Q_{mj}}{Q_{mf}}$ represent trade shares that another country has relative to U.S. imports.

The above formulation provides an economic framework by which to interpret the import demand elasticity, and relate it to underlying factors. Equation (5) is different than single-equation estimation of the import demand elasticity, an approach that we will also consider below. Equation (5) implies that a general formulation would consider the behavioral responses of other countries – both exporters and importers – and the imperfect nature of price transmission between countries over the short- and long-run. We now turn to models of how to estimate the individual parameters within equation (5).

3. Import demand elasticity model

To estimate the elasticities E_{esi} and E_{edj}, we can estimate a net export (i.e., import) demand equation, which is central importance in the empirical trade literature (Hillberry and Hummels, 2013). A procedure for estimating the elasticities that is consistent with economic theory is to assume that the elasticity of supply of imports is infinitely elastic and to estimate the quantity of imports demanded on the price of imports relative to all other goods, along with an income variable (Thursby, 1988). This problem can be derived from utility or production theory, depending on whether imports are viewed as final or intermediate goods (Kohli, 1982). We will view potash as an intermediate product, meaning that it's an input to the final agricultural good that is produced. The theory does not guide us to the appropriate functional form, whether lags should be used, or other issues. The specification is therefore mostly an empirical issue. We seek to attain consistent elasticity estimates, but otherwise a simple model is preferred on the basis of both Occam's razor and ease of estimation (Thursby, 1988). With this context we estimate:

$$lnQ_t^i = \sum\nolimits_{s=1}^{q} \alpha_{1s} \ln(Q_{t-s}^i) + \beta_0 + \beta_1 lnP_t^i + \beta_2 ln\mathbf{Z}_t^i + \beta_3 Trend_t + \varepsilon_t, \tag{6}$$

where Q_t^i is the net export position of country i (negative means they are a net importer), P_t^i is the relevant potash price for country i, and $\mathbf{Z}_t^i$ are additional variables included in the model to account for other factors that may affect the response. Empirically, we characterize U.S. import demand as dependent on the U.S. import price of potash, real disposable income per capita, price of corn (as a proxy of derived demand), and the exchange rate. We also include a flexible time trend to capture general changes involving technology or preferences. Given the small size of the potash import market relative to others, some of the macro-economic regressors will be exogenous, a topic to be addressed in more detail below.

We will estimate equation (6) using both static and dynamic approaches, the former without lag terms and the latter using the full specification. The static model will capture adjustments in imports as if they take place fully within a time period. By contrast, the dynamic model allows for the possibility of delay in trading responses that occurs over multiple time periods; imports tend to increase gradually to the long-run equilibrium level. The dynamic approach will center on Cuddington and Dagher (2015), particularly specification (1.2) on page 187. Their autoregressive (AR) lag approach to cointegration helps account for dynamic processes of the series, and employs lagged values of the dependent variable as explanatory variables, along with other explanatory variables with or without lags.

In addition to the autoregressive (AR) lag approach, we employ an autoregressive distributed lag (ARDL) with an error correction term as a robustness check in order to sufficiently capture both the short- and long-term changes in the potash market. This dynamic approach has similar properties to specification (22) on page 79 of Shrestha and Bhatta (2018).

The ARDL with an error correction term or simply put an error correction model (ECM) version of an ARDL, unlike other time series models, is appropriate even if the time series has a mixed order of integration (some variables are stationary while others are nonstationary) and captures both short-run and long-run equilibrium (Shrestha and Bhatta, 2018). While the ARDL is more appropriate in terms of statistical relevance than the AR(1) models, the AR(1) is simpler to interpret than the ARDL since the ARDL inherently handles the mixed order of integration without explicitly differencing the series (ensuring that no variable is differenced more than once to achieve stationarity). Therefore, we employ both ECM version of an ARDL and the AR(1) models to estimate import demand elasticity for the U.S. potash market, with the ARDL serving as a robustness check to the AR(1) results. To be clear, AR and other time series models could sufficiently capture the elasticities for non-stationary series that have their linear combination to be stationary (Reimer and Annan, 2023). However, ARDL gives the flexibility to test whether there is a long-run equilibrium using the Pesaran, Shin, and Smith (2001) bounds test for long-run equilibrium. We note that a structural vector autoregressive model could capture the interdependencies between the U.S. and Canadian potash markets more comprehensively. Unfortunately such an approach would require more data than available, so we rely upon the above-mentioned time-series models to represent dynamic responses.

4. Price transmission model

Our general elasticity formulation (5) also requires estimation of price transmission elasticities, which provide an understanding of short- and long-run price relationships. Price transmission for a product like potash that is traded between countries will be imperfect, meaning that the U.S. import price will not adjust immediately or to the full extent of the change in marginal cost in the supplying nation. Price transmission is a fundamental concept in economics, with greater flexibility of prices typically associated with relatively more efficient resource allocation (Meyer and von Cramon-Taubadel, 2004). The extent of price transmission can be affected by border and domestic policies, transport and transaction costs, the exchange rate, product differentiation, scale economies, and the degree of concentration (Conforti, 2004; Reimer, Zheng, and Gehlhar, 2012).

For example, U.S. potash importers may not update their retail prices as quickly as marginal cost conditions adjust within the supplying nation. In addition, if the supplying nation has a weakening currency – as has happened recently with Canada – this may raise their marginal costs more quickly than prices received, owing to a lag in price adjustments.

As another example, consider that Canadian potash mining is controlled by three firms, consistent with an oligopolistic market structure. Under oligopolistic market power the price is set above marginal cost and the firms may earn a positive economic profit. Since U.S. import prices are not aligned directly with marginal costs, changes in Canadian economic conditions may not manifest themselves fully in terms of the U.S. import price.

All of these factors imply that whenever there is a change in marginal costs in the supplying nation, the importing nation may not see a full adjustment, nor one that happens quickly (in the short run). The lags in these adjustments and other institutional rigidities impede the price transmission process. Imperfect adjustment of this nature causes import prices to adjust to exporter prices in the manner of a partial-adjustment model. Since domestic prices are constrained from directly following world prices, full adjustments never occur within a given period (Abbott, 1979). Price transmission models are typically carried out using reduced form models to investigate the effects of market changes from one market to another (Esposti and Listorti, 2013).

To get the price transmission elasticities, E_{pi} and E_{pj}, we estimate a partial adjustment model for each country other than the U.S. To estimate E_{pi} from equation (5) we follow Abbott (1979) and Mittal and Reimer (2008). This involves regressing how the local price varies with a one percent change in the reference price. The approach assumes that the price of a commodity is adjusted as if there is an *ad valorem* tariff. The adjustment may not literally be a tariff, but can arise from other border policies, transport costs, transaction costs, market power, exchange rates, and domestic policies (Conforti, 2004). The idea is that full adjustments are not likely to occur within a given period. This can be captured by the following partial-adjustment model:

$$lnP_t^i = \beta_0 + \beta_1 lnP_{t-1}^i + \beta_2 lnP_t^{REF} + \beta_3 Trend_t + \varepsilon_t, \quad (7)$$

where P_t^i is the domestic price at time t, P_{t-1}^i is a lag of the dependent variable (the domestic price), and P_t^{REF} is the reference price (e.g., U.S. import price), the β's are parameters to be estimated, and ε_t is an error term with classical properties, except as described below. The

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parameter β_2 is a short-run price transmission elasticity. The trend variable represents other general changes over time that may influence the domestic price of potash, and is a cubic spline with four knots to allow for non-linearities over time (Ghanem and Smith, 2022). The overlapping trend in this approach can account for general changes over time (such as the financial crisis), and the other supply disruption indicators. All continuous variables are in their natural logs, which implies that the estimated coefficients can be interpreted in the form of elasticities.

While the parameter β_2 is the short-run elasticity, the long-term price transmission elasticity is $\beta_2/(1-\beta_1)$ (e.g., Abbott, 1979; Sadoulet and Janvry, 1995). The estimate on β_2 will show the percentage change in U.S. potash market prices to a one-percent change in the global potash market.

One major concern with estimating equation (7) is that the lagged price of potash is included as a predictor variable, which may bias the results when the equations are estimated using ordinary least squares. However, because the equation is a partial adjustment model, this will not be a major issue with our estimation equation. Parameters of a partial-adjustment model can be consistently and efficiently estimated by least squares (Greene, 2012).

It should be noted that results of estimating equation (7) may not be directly interpreted as causal inferences. The goal is to predict and identify the specific relationships between domestic and U.S. potash prices.

We will also rely on autoregressive models, which unlike a linear regression have a relationship between the dependent variables and their past values. We will use AR(1) (autoregressive model of order one) methods following the standard ARIMAX specification that uses the maximum likelihood estimation (Greene, 2012).

5. Data and time series properties

We use annual data from 1960 to 2022 as reported in Table 1. Data on potash prices, imports, and exports come from the U.S. Geological Survey (2023) with additional information from FAO (2024a) and World Bank (2023a). World potash prices are from the World Bank (2023b), and other variables are from the National Agriculture Statistics Service (2023), the Board of Governors of the Federal Reserve System (2024), and the U.S. Bureau of Economic Analysis (2024a, 2024b). Organic fertilizer is measured as kilograms of cattle manure (dairy and non-dairy) applied to soil, and is from FAO (2024b). Geopolitical risk is constructed by Caldara and Iacoviello (2022) and is based on a count of newspaper articles covering geopolitical tensions. It spikes during wars and after 9/11.

Table 1 shows that on average, U.S. potash imports averaged four million tons and ranged from 0.2 to 6.5 million tons over the span of the analysis. There is a considerable amount of year-to-year volatility, signaling the responsiveness of import demand interacted with export supply. U.S. potash prices were also volatile, ranging from 124 to 832 dollars per ton with a mean of 330. The world potash price averaged 228 dollars per ton and ranged from 115 to 732 dollars per ton. In a few cases potash prices were not available for a country. In these cases, obtaining price data for potash is difficult because researchers must rely on information sourced from a small number of market participants or companies (Katovich, Thabtah, and Day, 2018).

One implication of using time series data is that all continuous variables should be stationary for statistical inference. Non-stationarity may result in spurious correlations and regressions. In this case, parameter estimates are misleading and such results may be inaccurate to make any informed decisions. We first use a unit root test to ensure that the variables are stationary, particularly the dependent variable, before applying any time series model. To test for stationarity, we used the Augmented Dickey-Fuller test. For this test, the null hypothesis is that the variables are non-stationary, and the alternative hypothesis is that the variables are stationary (Dickey and Fuller, 1979; Greene, 2012; Said and Dickey, 1984). Table 2 reports the main unit root tests.

Table 1. Descriptive statistics

	Units	Mean	Min	Max
U.S. potash imports	Million tons	4.0	0.2	6.5
U.S. real income	$ per capita	30,042	13,387	51,519
U.S. potash price	$/ton	330.2	123.6	832.2
Exchange rate	USD-CAD	1.2	1.0	1.6
World potash price	$/ton	227.6	114.7	731.9
U.S. phosphate price	$/ton	52.2	25.1	140.0
U.S. corn price	$/bushel	5.2	2.5	11.9
U.S. interest rate	Percent	4.8	0.1	16.4
Organic fertilizer	Million kg	509.6	439.8	653.0
Geopolitical risk	Ratio	0.4	0.1	0.9

Notes: Annual data for 1960–2022. All prices and revenues are deflated using the 2017 implicit GDP deflator from the St Louis FRED database. Since January 2020, the world potash price has been based on Brazil's CFR granular spot price; earlier, it was f.o.b. Vancouver ($/mt).

Table 2. Augmented Dickey-Fuller stationarity test for continuous variables

	Variables in their levels	Variables in their first difference
	MacKinnon approximate p-value	
U.S. potash price	0.729	<0.01
World potash price	0.748	<0.01
U.S.-Can. exchange rate	0.401	<0.01
U.S. interest rate	0.463	<0.01
U.S. real personal income per capita	0.074	<0.01
U.S. corn price	0.249	<0.01
Organic fertilizer	0.084	<0.01
Geopolitical risk	0.344	<0.01
U.S. potash imports	<0.001	–

Notes: The null hypothesis is that the variable is not stationary. All variables were in their natural logs before performing the stationarity test.

A number of variables were non-stationary, but were found to be stationary at their first difference. We will return to our methods for handling the issue of non-stationarity in describing the models below.

6. Import demand elasticity: Direct estimation

Before we present results using the multi-country, price-transmission approach of equation (5), we present an alternative methodology, which is to estimate the elasticity of U.S. import demand directly from (6) using the relevant data. In particular, we will estimate E_{edj} for the United States directly. The trade literature has a long history of direct estimation of this elasticity, without explicit consideration of the behavioral responses of other countries, and the imperfect nature of price transmission over the short and long-run.

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We follow the net export demand formulation in (6), and let the dependent variable be U.S. import demand. Right-hand side variables include the U.S. import price, real disposal income per capita, price of corn (corn is a major user of potash), the U.S.-Canada exchange rate, a U.S. Great Recession indicator (from 2007 to 2009), and a flexible time trend using cubic splines with four knots to account for non-linearity over time (Ghanem and Smith, 2022).

Table 3 presents results for the short-run and long-run import demand elasticity of potash. Model 1 is a least-squares model that includes the potash import price, corn price, exchange rate, and a recession indicator. It shows that a 10% percent increase in U.S. import price corresponds to a 6.32% decrease in import demand, with statistically significance at the one percent level. Model 2 improves upon model 1 by fitting an AR(1) dynamic model in which there is a lag of the dependent variable. The import demand elasticity is now -0.363 with a lagged import coefficient of 0.585. The latter means that a 1% increase in the previous year corresponds to a 0.585% increase in import demand this year. This implies there are lags or momentum such that potash imports in the previous year have a significant impact on potash imports this year.

In both models 1 and 2, corn price is statistically significant and positive, suggesting that higher revenues from corn production increase potash demand. This is consistent with our hypothesis that there is a derived demand for potash. Similarly, the coefficient on the U.S.-Canada exchange rate is consistent in models 1 and 2, with a weaker dollar leading to substantially reduced demand for potash imports. A 10% weakening of the U.S. dollar is associated with an 10–13% fall in U.S. import demand. In neither case was the recession indicator statistically significant. The Portmanteau (Q) p-value was greater than 0.05 for all models, indicating that they are free of autocorrelation.

Models 1–2 maintain an assumption that the U.S. is a price taker in international potash markets. This could be justified from the fact that in 2023, the U.S. consumed 5,300 thousand metric tons of potash compared to a world production of 39,000 thousand metric tons. The U.S. is a "small country" in the international potash market, because it consumes only 13.5% of the world total.

Yet what if the U.S. cannot be considered a price taker? Table 3 presents alternative models that account for this possibility. If the U.S. is not a price taker, there could be reverse causality between potash price and import demand. To account for this possibility, we use phosphate price as the instrument for potash price and fit an instrumental variable (IV) version of model 2 in Table 3. Phosphate price is justifiable as an instrument because potash and phosphate rock are mined and concentrated in a few regions, making them similar in supply. We use a Kleibergen-Paap rk Wald F statistic as a first stage F statistic (e.g., Kleibergen and Paap, 2006; Stock and Yogo, 2005). The null hypothesis is that the instrument is weak and does not have sufficient explanatory power to satisfy the exclusive restriction assumption (exogenous and relevant), although we cannot directly test for exogeneity. The first stage F statistic for model 3 is 63.94, thereby indicating a p-value less than 0.05. This suggests that we reject the null hypothesis, and have a justification that phosphate price is a reasonable instrument for potash price. So even when using an IV estimator, the results of model 3 are very consistent with the results for model 2. This would seem to confirm that our results are robust to other specifications and estimation strategies. Comparing the AR(1) estimate of −0.363 and IV AR(1) estimate of −0.352, the former is slightly more elastic. While the difference is not statistically different, the least-squares estimates could slightly overestimate the true effect of the explanatory variable on potash imports.

While the parsimonious model 2 of Table 3 appears to be a solid approach, we also compare it to more general approaches. Models 4 and 5 in Table 3 present alternatives of models 2 and 3 with additional variables, while also testing for structural breaks in the time series. Variables such as real disposable personal income per capita and interest rates were not included because they were found to be highly correlated with U.S. potash prices. However, models 4 and 5 include organic fertilizer (FAO, 2024b) as well as the geopolitical risk measure of Caldara and Iacoviello (2022) applied to Russia and Belarus versus the United States. Higher use of organic fertilizer tends to

Table 3. Potash import demand elasticity estimation: U.S. only

	Model 1: Static	Model 2: AR(1)	Model 3: IV AR(1)	Model 4: AR(1)	Model 5: ARDL
Own price	−0.632***	−0.363***	−0.352**	−0.337**	−0.292**
	(0.108)	(0.114)	(0.141)	(0.154)	(0.134)
Corn price	0.359***	0.238**	0.234***	0.198**	0.192*
	(0.133)	(0.091)	(0.091)	(0.092)	(0.114)
Exchange rate	−1.342**	−1.045**	−1.026**	−1.077*	−1.131*
	(0.623)	(0.430)	(0.438)	(0.627)	(0.631)
Recession	0.019	−0.191	−0.194	−0.183	−0.197*
	(0.183)	(0.216)	(0.198)	(0.221)	(0.108)
Organic fertilizer				−0.345	−0.162
				(0.967)	(1.169)
Geopolitical risk				−0.836*	−0.540
				(0.458)	(0.423)
Imports(-1)		0.585***	0.589***	0.412**	−0.168
		(0.131)	(0.129)	(0.154)	(0.124)
Constant	−300.198***	−98.855**	−97.213**	−153.927***	−128.872**
	(24.455)	(38.627)	(39.811)	(56.105)	(59.455)
Error correction term					−0.557***
					(0.139)
Observations	63	62	62	62	61
Structural break dummies	No	No	No	Yes	Yes
Cubic time trend	Yes	Yes	Yes	Yes	Yes
Corrected AIC	−2.01	−43.00	−42.98	−34.17	−35.13
Portmanteau (Q) P-value		0.625	0.607	0.585	0.334
R-squared	0.927	0.955	0.955	0.962	0.673
Long run bounds test p-value					0.005
Long run elasticity	–	−0.875***	−0.857***	−0.574**	−0.632***
		(0.282)	(0.290)	(0.238)	(0.203)

Notes: The dependent variable is domestic (U.S.) import demand. All continuous variables are in their natural logs. The equations are estimated employing annual data from 1960 to 2022. The regressions use cubic splines with four knots, as described by Ghanem and Smith (2022), to account for non-linearity over time. Portmanteau (Q) P-value greater than 0.05, indicating that the models are free of autocorrelation. The models are estimated using OLS, AR(1) process, and ECM version of an ARDL. The models excluded variables that were highly correlated with U.S. potash prices (i.e., real disposable personal income per capita and interest rate). The robust standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

have a negative impact on potash imports, which might be expected given that it is a partial substitute. However the relationship is not statistically significant at conventional significance levels in either models 4 or 5. The reason may be that organic fertilizer is applied to only a very small share of the overall acres of cropland in the United States. Most of it is sourced from livestock operations that are in fixed geographical location, and hauling can be cost prohibitive for farm operations outside the immediate area. As a result, there may not be a high degree of substitution with potash fertilizer.

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Higher geopolitical risk associated with Russia and Belarus was found to be associated with lower potash import demand. The relevant coefficients were −0.836 for model 4 and −0.540 in model 5. The negative effect may be explained by the fact that geopolitical risk may cause freight to be diverted from areas with geopolitical problems, or at least that freight rates rise to an extent that importation by the United States is no longer economically feasible. However the coefficient was significant at the 10% level in model 4 only. The uneven presence of statistical significance may be due to the fact that Russia and Belarus are only minor suppliers of potash to the United States.

The structural break dummies and the U.S. recession dummy are envisioned to account for economic crises, policy changes, or significant market disruptions that are likely to exist in the potash market. In addition to the recession dummy, four structural break points were identified using the Bai and Perron (1998) test for unknown breakpoints, and dummy variables were developed based on the break points' confidence interval year ranges.

Model 5 also has an additional change from model 4 in that it is an error correction term model (ARDL), making for a more flexible model approach. The error-correction coefficient was estimated to be −0.557 for model 5, which is statistically significant and negative, as expected. This implies that the model adjusts approximately 55.7% deviations toward the long-run equilibrium in each time period. The moderate size of the estimated coefficient indicates that the equation will recover or return to the long-run equilibrium somewhat quickly when there is a shock. The long-run bounds test p-value is 0.005 (less than 0.05), thereby indicating that there is a long-run relationship.

Of interest is the fact that even with using a much more flexible time-series specification, along with additional control variables, the estimated elasticities in models 4 and 5 are quite similar to those of simpler models in Table 3. This suggests that a relatively parsimonious model can capture the fundamental relationships of a more complex dynamic model.

To summarize using model 2 as an example, a 1% increase in U.S. import price is associated with a 0.363% (short run) and 0.875% (long run) decrease in import demand (Table 3). In conclusion, the results of Table 3 also show that the price elasticity of potash is inelastic for both the short- and long-run models, consistent with related studies (e.g., Al Rawashdeh, Xavier-Oliveira, and Maxwell, 2016).

To provide further confirmation of the robustness of the results in Table 3, additional models were considered and reported in an online appendix. Table A1 reports overidentification test results to further confirm the validity of the instruments (Models 6 and 7), and sensitivity analyses of the ARDL results were performed to confirm the long-run equilibrium using the long-run bounds test (Models 8 and 9). The results are consistent with expectations and strengthen our confidence in our ability to capture long-run equilibrium and the validity of the instruments. The results remain consistent with those of Table 3. Similarly, in Table A2 we report all five structural breakpoints, F-statistic values, and the associated Bai & Perron 5% critical values to enhance transparency.

7. Import demand elasticities for other countries

In this section we use model 2 to generate net export demand elasticities for key exporters and importers, respectively. Equation (6) is estimated using AR(1) methods in a standard ARIMAX specification. Because the response variable was stationary at levels, all variables are in their levels to satisfy the stationarity assumption for the AR(1) process. The empirical results for major exporters and importers are shown in Tables 4 and 5, respectively.

One of the primary variables of interest is the coefficient on the own price of each country's net export position. For the major exporters, the own price value ranges from −0.038 (Germany) to −0.395 (Canada). The pattern of results may reflect the extent of reserve capacity by country.

Table 4. Potash net export demand elasticity for major exporters

	Canada	Russia	Belarus	Israel	Jordan	Germany
Own price	−0.395*	−0.316	−0.375	−0.176	−0.162**	−0.038
	(0.203)	(0.256)	(0.230)	(0.175)	(0.075)	(0.078)
Income	5.283***	−0.367	0.620	4.142***	−0.818***	2.653***
	(1.839)	(0.873)	(0.647)	(0.592)	(0.176)	(0.613)
Crop intensity	5.174	−33.294***	6.703	0.355	−0.177	6.794**
	(6.781)	(10.033)	(9.583)	(0.522)	(0.18)	(2.824)
Net export (−1)	0.877***	0.066	−0.146	−0.276	−0.038	0.631***
	(0.185)	(0.291)	(0.175)	(0.194)	(0.203)	(0.133)
Trend	−0.014	0.067	0.082	−0.065***	0.023***	−0.052***
	(0.050)	(0.048)	(0.076)	(0.005)	(0.004)	(0.013)
Constant	−17.642	−42.199	−175.979	102.974***	−23.907***	66.359***
	(81.457)	(76.643)	(122.151)	(7.320)	(7.792)	(19.862)
Observations	61	21	20	20	35	61
Long run elasticity	−3.211*	−0.338	−0.327	−0.138	−0.156**	−0.103
	(1.646)	(0.275)	(0.201)	(0.137)	(0.073)	(0.211)

Notes: The dependent variable is the absolute value of potash net export, and the main variable of interest is the foreign (international) potash price. All continuous variables are in their natural logs. The equations are estimated employing annual data from 1961 to 2021 (except for those that are missing). The models are estimated using AR(1) process that uses the maximum likelihood from the standard ARIMAX process. The dependent variable is stationary, so we kept all variables in their levels without first differencing to satisfy the stationarity assumption for the AR(1) process. The robust standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Canada is the leading exporter with greatest reserves, while Germany is a very minor exporter with relatively little flexibility (U.S. Geological Survey, 2024).

Another interesting variable is the coefficient on the lag of net export. This value ranges from a low of −0.038 (Jordan) and to a high of 0.877 (Canada), although the estimate is statistically significant for only Canada and Germany. This implies that the previous year's net export position influences the decision of these two countries to produce and export potash to other countries in the current year. As expected, the estimates are more elastic in the long run than in the short run for all major exporters, confirming that trading decisions are not instantaneous and cannot be completed in one year.

We now turn to the major importers' responsiveness in Table 5. The own price value ranges from approximately −0.001 for India, to −0.534 in the case of China. The estimates are statistically significant for Korea, Argentina and China. The potash price elasticity estimates for the major importers imply that India's net export position is not dependent on prices, in contrast to a country like China. Among the importers, it's only China for which the previous year net export position is statistically significant at the 1% level, albeit its long run effect is significant at the 10% level. For the cases of Japan and China (only), the long-run elasticity is more elastic than the short-run.

Results are mixed with respect to the additional control variables included in the models in Tables 4 and 5. We do not find consistency in terms of signs and significance. This finding may stem from the fact that economic conditions and cropping decisions vary by country, and could be influenced by omitted variables that we were not able to represent fully in each specification.

Table 5. Potash net export demand elasticity for major importers

	India	Japan	Korea	Mexico	Argentina	Brazil	China	Indonesia
Own price	0.000	−0.061	−0.307***	−0.262	−0.230**	−0.010	−0.534*	−0.071
	(0.222)	(0.165)	(0.107)	(0.176)	(0.093)	(0.014)	(0.288)	(0.396)
Income	0.203	0.011	0.257*	2.603	−0.539	−0.001	−0.143	4.699***
	(0.679)	(0.619)	(0.149)	(2.257)	(0.450)	(0.554)	(0.215)	(1.323)
Crop intensity	−3.211	−3.792***	3.213***	−0.469	−2.126	−1.376***	8.011***	−2.206
	(11.764)	(1.139)	(0.955)	(2.183)	(1.783)	(0.484)	(1.208)	(3.173)
Net export (-1)	0.274	0.267	−0.099	−0.119	−0.325	0.056	0.437***	−0.107
	(0.261)	(0.246)	(0.236)	(0.134)	(0.271)	(0.202)	(0.118)	(0.221)
Trend	0.012	−0.029***	0.050***	0.027	0.082***	0.070***	0.096***	−0.066***
	(0.035)	(0.005)	(0.013)	(0.032)	(0.003)	(0.002)	(0.001)	(0.004)
Constant	1.150	80.868	−96.517***	−62.678	−141.438	−123.096	−193.998***	116.376***
	(90.213)	(0.000)	(26.329)	(59.934)	(0.000)	(0.000)	(4.542)	(6.720)
Observations	20	40	40	20	22	32	35	20
Long run elasticity	0.000	−0.084	−0.280***	−0.234	−0.174**	−0.011	−0.950*	−0.064
	(0.305)	(0.225)	(0.097)	(0.157)	(0.070)	(0.015)	(0.511)	(0.357)

Notes: The dependent variable is the absolute value of potash net export, and the main variable of interest is the foreign (international) potash price. All continuous variables are in their natural logs. The equations are estimated employing annual data from 1961 to 2021 (except for those that are missing). The models are estimated using AR(1) process that uses the maximum likelihood from the standard ARIMAX process. The dependent variable is stationary, so we kept all variables in their levels without first differencing to satisfy the stationarity assumption for the AR(1) process. The robust standard errors in parentheses. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

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Table 6. Potash price transmission elasticity for major exporters

	Canada	Russia	Belarus	Israel	Jordan	Germany
Lag own price (β_1)	0.256	0.286	0.325	0.628***	0.278*	0.182
	(0.182)	(0.180)	(0.235)	(0.217)	(0.159)	(0.184)
U.S. price (β_2)	0.765***	0.903***	0.817***	0.704***	0.822***	0.917***
	(0.156)	(0.274)	(0.267)	(0.158)	(0.155)	(0.159)
Trend	0.001	−0.001	−0.001	0.001	0.001	0.001
	(0.002)	(0.011)	(0.010)	(0.003)	(0.002)	(0.002)
Constant	−2.143	2.093	2.925	−1.778	−2.486	−2.955***
	(3.499)	(21.920)	(20.772)	(6.442)	(3.453)	(3.030)
Observations	60	25	27	60	60	60
Long run elasticity	1.028***	1.265***	1.210***	1.892***	1.139***	1.121***
	(0.209)	(0.383)	(0.396)	(0.425)	(0.215)	(0.195)

Notes: The dependent variable is foreign (international) potash price, and the main variable of interest is the domestic (U.S.) potash price. All continuous variables are in their natural logs. The equations are estimated employing annual data from 1961 to 2021 (except for Belarus and Russia that has missing values prior 1990s). The models are estimated using AR(1) following the standard ARIMAX specification. All variables are in their first difference to satisfy the stationarity assumption for the AR(1) process. The robust standard errors in parentheses. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

8. Price transmission across borders

Tables 6 and 7 present the results of the price transmission equation (7) above. The models are estimated using AR(1) following the standard ARIMAX specification. A key result of interest is β_1, the coefficient on the lag of own price. Values closer to one imply flexible price transmission while values closer to zero signify the presence of impediments to price transmission. Estimates range from a low of 0.072 (Indonesia) and to a high of 0.628 (Israel). All of these results are inelastic; there is statistical significance in about half of the cases. In all cases the coefficient is positive, suggesting a tendency towards path dependence.

Another key result of interest is the coefficient on the U.S. price (β_2), which is the short-run price transmission elasticity. It indicates the percent by which the domestic price changes in the near term as the world price increases by one percent. It ranges from a low of 0.369 for Argentina to a high of 0.917 for Germany. It is statistically significant at the 1% significance level for all countries except Argentina. This suggests that U.S. to German potash prices move together closely; this is less the case for Argentina, by contrast. To our knowledge these are the first results in the literature with respect to price transmissions estimates for any sort of fertilizer, let alone potash. The positive sign and coefficient size of these results are consistent with other studies relating to highly traded commodities (Reimer, Zheng, and Gehlhar, 2012).

The long run estimates are calculated as $\beta_2/(1-\beta_1)$. These results are reported in Tables 6 and 7. In the case of Canada, β_1 is 0.256 and β_2 is 0.765, meaning that the long-run price transmission with the U.S. is 1.028. The fact that 1.028 exceeds 0.256 implies that long-run price transmission is more flexible (elastic) than short-run elasticities. This holds in all the cases. This finding is also fairly consistent with other agricultural commodity price transmission models, which estimate long-run price transmission elasticities to be less than 0.9 (e.g., Mittal and Reimer, 2008).

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Table 7. Potash price transmission elasticity for major importers other than the U.S

	India	Japan	Korea	Mexico	Argentina	Brazil	China	Indonesia
Lag own price (β_1)	0.219	0.277*	0.104	0.524***	0.448*	0.448	0.267*	0.072
	(0.150)	(0.162)	(0.117)	(0.114)	(0.253)	(0.344)	(0.138)	(0.190)
U.S. price (β_2)	0.863***	0.848***	0.945***	0.624***	0.369	0.506**	0.763***	0.872***
	(0.175)	(0.156)	(0.186)	(0.177)	(0.266)	(0.217)	(0.150)	(0.216)
Trend	0.001	0.002	−0.001	0.002	0.008**	0.005	0.001	−0.001***
	(0.002)	(0.002)	(0.002)	(0.003)	(0.003)	(0.003)	(0.002)	(0.000)
Constant	−1.841	−3.637	1.882	−3.292	−15.102**	−9.109	−2.085	2.747***
	(3.515)	(3.636)	(3.644)	(5.412)	(6.398)	(5.920)	(3.161)	(0.104)
Observations	60	60	60	60	58	60	60	54
Long run elasticity	1.105***	1.173***	1.055***	1.311***	0.668	0.917**	1.041***	0.940***
	(0.224)	(0.215)	(0.207)	(0.373)	(0.483)	(0.394)	(0.205)	(0.233)

Notes: The dependent variable is foreign (international) potash price, and the main variable of interest is the domestic (U.S.) potash price. All continuous variables are in their natural logs. The equations are estimated employing annual data from 1961 to 2021 (except for Argentina and Indonesia that has a few missing values). The models are estimated using AR(1) following the standard ARIMAX specification. All variables are in their first difference to satisfy the stationarity assumption for the AR(1) process. The robust standard errors in parentheses. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

9. Import demand elasticity: Multi-country, price transmission approach

Recall that equation (5) provides a means of calculating the elasticity of U.S. import demand that incorporates the individual price transmission estimates for all other countries in Tables 6 and 7. Equation (5) also employs the net export demand elasticities for the countries in Tables 4 and 5. The main body of Table 8 summarizes the estimates generated earlier, as well as the final results for equation (5).

The results of key interest are the short- and long-run elasticities of U.S. import demand at the bottom of Table 8. The short-run import demand elasticity is −0.40 (with 95% confidence interval of −0.575 to −0.233). The long-run import demand elasticity is more flexible, at −0.59 (with 95% confidence interval of −0.817 to −0.372) for the long run. The confidence interval in both cases does not include zero, implying the estimates are statistically significant at the 5% level.

Recall that when we directly estimated the elasticity of U.S. import demand, it was −0.363 (Table 3), which is similar to the alternative approach that uses an entirely different methodology (−0.40). The long run estimates for the direct and indirect approaches for estimating the U.S. potash import demand are also quite similar.

This suggests that our results may be robust to the two different methodologies considered in this study. The second approach has the advantage of better characterizing exporting and importing country behavior, and also capturing price rigidities across international borders. Despite this richness, the similarity of results suggests that we may not have needed to explicitly account for the behavior and price transmission of other importers and exporters, at least for the case of potash within this study.

10. Conclusions

This study estimates the responsiveness of U.S. import demand for potash using two different methodologies. We find that the short- and long-run elasticities of import demand are approximately −0.4 and −0.9, respectively. The results are reasonably consistent regardless of whether we directly estimate the elasticity in a single equation, or whether we use a much more complex approach that accounts for the behavioral responses of multiple countries involved in

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Table 8. U.S. import demand elasticity calculated with price transmission elasticities

Country	Short run price transmission elasticity	Long run price transmission elasticity	Net export elasticity	Share parameter (net trade divided by U.S. imports)	Short run	Long run
Net exporters						
Canada	0.765	1.028	−0.395	0.85	−0.256	−0.343
Russia	0.903	1.265	−0.316	0.56	−0.159	−0.222
Belarus	0.817	1.210	−0.375	0.41	−0.126	−0.187
Israel	0.704	1.892	−0.176	0.15	−0.018	−0.049
Jordan	0.822	1.139	−0.162	0.09	−0.012	−0.016
Germany	0.917	1.121	−0.038	0.15	−0.005	−0.006
					−0.575	−0.824
Net importers						
India	0.863	1.105	0.000	0.18	0.000	0.000
Japan	0.848	1.173	−0.061	0.02	−0.001	−0.002
Korea	0.945	1.055	−0.307	0.03	−0.007	−0.008
Mexico	0.624	1.311	−0.262	0.02	−0.003	−0.007
Argentina	0.369	0.668	−0.230	0.00	0.000	−0.001
Brazil	0.506	0.917	−0.010	0.46	−0.002	−0.004
China	0.763	1.041	−0.534	0.33	−0.136	−0.186
Indonesia	0.872	0.940	−0.071	0.33	−0.021	−0.022
					−0.171	−0.230
U.S. import demand elasticity:					**−0.40**	**−0.59**
					(−0.575 to −0.233)	(−0.817 to −0.372)

Notes: Figures in parentheses represent 95% confidence intervals.

potash trade, as well as imperfect price transmission across countries. Under Occam's razor, researchers might prefer the simpler single-equation method, especially as it requires less data.

The findings that U.S. potash import demand is more elastic in the long run than in the short run are significant. The intuition is that in the long run, farmers may be able to switch suppliers or adjust their fertilizer application routines. They may pause applications of fertilizer if the price gets too high, even with the negative impact on yield. Over the long run fixed costs themselves become variable, leading to more adaptability by end users of potash fertilizer. For example, producers can switch between crops requiring less potash fertilizer (e.g., soybeans and wheat) and those which require more potash (e.g., corn and cotton). Short-run responses may also be moderated by the imperfect nature of price transmission, since foreign price changes do not translate immediately into local price changes.

We additionally establish that the exchange rate and corn price have important roles in import demand. In particular, if the U.S. dollar depreciates by 10% relative to the Canadian dollar, short-run import demand falls 10.5%, all else the same. In turn, 10% higher corn prices are associated with 2.4% higher demand for potash imports, all else the same.

It is important to acknowledge the limitations of our data and approach. Our methods do not enable us to make strong causal statements regarding the relationships posited here, as our data are aggregated and our models may suffer from standard identification issues. Among other issues, there may be omitted variables that can affect our models. However, these caveats may not be a major issue with time series models, since the aim is to predict the response based on past values and to quantify relationships among variables that are known to be related.

The estimates of this study are a new contribution to the nascent literature on potash markets. We make a methodological contribution by showing that traditional international trade models are not essential to estimation success, at least in the case of potash. In turn, existing studies have been either domestic-only papers that abstract from the international nature of supply, or focused on global aggregate markets without consideration of individual countries. Our approaches provide detail for one country (the United States) while accounting for key international factors such as exchange rates, imperfect price transmission, and the behavioral responses of other countries.

The study has important policy implications owing to the fact that the U.S. relies almost exclusively on imports for this critical plant nutrient. While the bulk of U.S. potash needs are met by Canada, a traditional ally, there have been occasional supply disruptions. Perhaps the best policy response is to maintain open trade with countries that have plentiful supplies of potash. Policies to avoid would be taxes on imports (tariffs) and related trade interventions. The U.S. may also explore development of its own domestic potash industry. Constraints to domestic production and processing capabilities should be examined in light of whether new policies could be helpful, such as permitting reform or production subsidies. Depending on the goals of policymakers, these would generally be preferred to third-best trade policies as a means of stimulating domestic industry.

Potash will likely remain a major issue since the U.S. is an important source of food for the world's growing population. Dependence on imported potash is one issue that the U.S. must continually address in order to maintain its status as an agricultural powerhouse. Without potash in the U.S. there could be higher food prices as well as shortages in food availability for the world at large. Understanding the relationships between U.S. and international potash prices may help policymakers develop more effective strategies to reduce the escalation of production costs for farmers.

We can think of several avenues for future research. First, refinements to our estimates could be achieved if one combined farm-level data on fertilizer usage, with macro-economic factors related to global potash supply. If sufficient data are available, structural auto-regressive models and other multifaceted time-series approaches could also be used to explore interdependent linkages that we leave unaddressed in this study. Also, future research could examine global trade flow patterns in the potash market using gravity model of trade. With supply extremely concentrated at the global level, it's possible that potash prices are not determined in a competitive manner at the global level. An investigation of market power may also be appropriate. Finally, future research could extend this kind of analysis to other essential agricultural inputs in the United States and around the world.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/aae.2025.10.

Data availability. The data that support the findings of this study are available from the corresponding author, Kenneth Annan, upon reasonable request.

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