A PE MODEL OF NEON EXPORTS FROM UKRAINE

Samantha DeCarlo

Samuel Goodman

David Riker

ECONOMICS WORKING PAPER SERIES
Working Paper 2022–07–C

U.S. INTERNATIONAL TRADE COMMISSION
500 E Street SW
Washington, DC 20436

July 2022

A PE Model of Neon Exports from Ukraine
Samantha DeCarlo, Samuel Goodman, and David Riker
Economics Working Paper 2022–07–C
July 2022

Abstract

We have built an industry-specific partial equilibrium model of Ukrainian neon exports as an extension of the analysis of supply shocks and the international supply chain in DeCarlo and Goodman (2022). The value of adding the simple yet formal economic model is that it quantifies the impact of the 2015 and 2022 conflicts on industry prices and on the diversity and flexibility of the industry's international supply chain.

Samantha DeCarlo
Chemicals and Textiles Division, Office of Industries
samantha.decarlo@usitc.gov

Samuel Goodman
Chemicals and Textiles Division, Office of Industries
samuel.goodman@usitc.gov

David Riker
Research Division, Office of Economics
david.riker@usitc.gov

1 Introduction

Neon is a critical input for lasers used in semiconductor production. Ukraine is a major supplier of neon to the world, and so the continuing conflict from the Russia-Ukraine war has the potential to significantly disrupt the semiconductor supply chain. This issue is addressed in DeCarlo and Goodman (2022). After highlighting the production process, end uses, and supply chains in the neon industry, DeCarlo and Goodman discuss how data on Ukrainian rare gas exports during the Russian occupation of the Crimean Peninsula in 2015 can be indicative of potential effects in the neon gas market due to the ongoing war in Ukraine.

In this short working paper, we extend the analysis in DeCarlo and Goodman (2022) by adding a simple yet formal model. Economic modeling consists of fitting equations based on economic theory to the data, and then using these calibrated equations to quantify the economic impact of changes in trade policy or other industry conditions. Industry-specific partial equilibrium (PE) models can be practical tools for estimating economic effects, because they have practical data requirements and they can be customized to capture distinctive features of an industry. Mueller and Riker (2020), Daun and Riker (2021), and Riker (2022) are recent examples of how PE models can be used to address a variety of different trade issues.[1]

In this case, the value of building a PE model to supplement the analysis in DeCarlo and Goodman (2022) is that the model allows us to predict the impact of the 2022 conflict on industry prices given an assumption about the reduction in export quantity. Specifically, the model uses the responses of industry prices to a significant past supply shock and the subsequent change in supply chain diversity to estimate the price response to a new supply shock. The model also allows us to assess the change in the diversity and flexibility of the

[1] A large collection of PE models of trade policy are publicly available at the U.S. International Trade Commission's PE Modeling Portal at `https://usitc.gov/data/pe_modeling/index.htm`.

industry's international supply chain over time.

The model predicts that the 2022 supply shock will increase neon prices by 84% in 2022 if the decline in the quantity of Ukrainian neon exports in 2022 matches the 35% decline in 2015, and by 195% if the decline in the quantity of exports is twice as large. Either way, the price increase forecast for 2022 is much smaller than the 242% price increase in 2015, because there has been significant diversification of the international supply chain away from Ukraine since 2015. After presenting projected price increases in 2022, we show how the model can be used to assess changes in the flexibility of the supply chain once the price and quantity changes from the new supply shock are known.

The rest of this paper is organized into five parts. Section 2 provides a description of the industry from DeCarlo and Goodman (2022). Section 3 presents the modeling framework. Section 4 describes the data inputs of the model. Section 5 reports model estimates. Section 6 offers caveats and conclusions.

2 Key Facts about the Neon Industry

For ease of reference, this section quotes from the description of the neon industry in DeCarlo and Goodman (2022) to provide context for the economic model:

> Neon is a rare gas, comprising 0.0018 percent of the atmosphere. Separating it from other atmospheric gasses, like oxygen and nitrogen, involves a process akin to a home dehumidifier—liquefaction. In liquefaction, air is progressively cooled and compressed until each component gas condenses at its boiling point. Only the largest air separation units (ASUs) include neon capture systems because neon's low concentration in air means that smaller ASUs will not produce commercial quantities. Large ASUs have historically been co-located with steel manufacturing, as the basic oxygen steelmaking process requires a high volume

of pure oxygen obtained through this type of gas separation.

While neon is universally associated with brightly colored signage, its largest downstream application is lasers. The semiconductor industry accounts for up to 90 percent of neon gas laser demand. In manufacturing semiconductor chips, a mixture of gases (termed excimer gas) generates the single wavelength of light used for deep ultraviolet photolithography. Within the gas mixture, neon is typically a buffer and carrier gas that helps minimize defects during the photolithography process, increasing the overall yield of usable chips. U.S. manufacturers that use excimer gas must verify it meets their requirements for purity and quality. Qualification of a gas source can take 3 to 18 months, and if a customer were to switch sources, the process would have to be redone.

Ukraine supplies approximately half of the world's neon and is a major source of the ultra-high purity neon used in chip manufacturing. Over the past decade, it has been estimated that Ukraine has supplied up to 90 percent of U.S. imports of neon. Ukraine also exports substantial volumes to major chip producing nations in Asia. The current conflict in Ukraine raises concerns about the security of that supply.

After 2014, some chip manufacturers diversified their neon sources, and Ukraine has since lost about 20 percent of global market share. China has added significant capacity over the past decade, and at least one U.S. firm has expanded domestic production of neon. Reportedly, the primary barrier for market entry is the scarcity of neon which limits the number of commercially viable neon purification sites. There is also an issue of scale: the U.S. excimer gas market only amounts to about $40 million, despite its overall criticality to laser gases.

3 Modeling Framework

The modeling framework is mathematically simple, and it has practical data requirements. The model focuses on the largest segment of the neon market, neon used in lasers in the production of semiconductors. Neon used in signs has a lower purity and cannot be substituted for ultra-high-purity neon in lasers without significant re-processing, so neon used in lasers is a separate and distinct segment of the market. The model assumes that the global demand for neon used in lasers is perfectly price inelastic, since substitution of neon gas in a laser would result in a complete change in the process of semiconductor manufacturing and the cost of neon inputs are a negligible fraction of the total cost of semiconductor production.

It takes time to add new sources of supply, since new suppliers must qualify their process, and this limits substitution in the short run. The model assumes that there is no differentiation in demand between neon from different source countries within the lasers segment once the sources are qualified.

The model consists of two equations, an equilibrium condition and a supply curve for neon produced outside of Ukraine. First, the global demand for qualified product in period t (Q_t) is the sum of qualified supply from Ukraine (X_t) and qualified supply from the rest of the world (X_t^*).

$$Q_t = X_t \ + \ X_t^* \tag{1}$$

Second, the supply of neon from the rest of the world (X_t^*) is a function of a supply shift parameter (α_t), the global price (P_t), and a price elasticity (ε_t).

$$X_t^* = \alpha_t \ (P_t)^{\ \varepsilon_t} \tag{2}$$

We expect that the price elasticity of qualified supply from the rest of the world is low but not zero, since producers have very limited capacity to adjust production within a year but some flexibility to draw from their neon stockpiles, and neon produced for signs and other end uses cannot be diverted to laser production without significant re-processing.

These two equations can be combined into a single equation:

$$Q_t = X_t \ + \ \alpha_t \ (P_t)^{\ \varepsilon_t} \tag{3}$$

The price elasticity of qualified supply from the rest of the world (ε_t) can be calculated as an arc elasticity using the prices and quantities in two adjacent periods with a significant supply shock, period t prior to the shock and period $t+1$ when the supply shock occurs.

$$\varepsilon_t = \frac{ln\,(Q_{t\,+\,1} \ - \ X_{t\,+\,1}) \ - \ ln\,(Q_t \ - \ X_t)}{ln\,(P_{t\,+\,1}) \ - \ ln\,(P_t)} \tag{4}$$

The model makes a clear distinction between a change in the *diversity* of the supply chain (reflected in a shift in Ukraine's global market share) and a change in the *flexibility* of the supply chain (reflected in a change in the supply responsiveness measure ε_t).

Finally, we can use equation (5) and the definition of ε_t from equation (4) to calibrate the supply shift parameter for period t.

$$\alpha_t = (Q_t \ - \ X_t) \ (P_t)^{\ -\varepsilon_t} \tag{5}$$

4 Data Inputs of the Model

All of the data used in the model are from DeCarlo and Goodman (2022). The model focuses on the same two supply shocks analyzed in DeCarlo and Goodman (2022), the invasion of the Crimean Peninsula in 2015 and the war in 2022. The model includes annual data for three years: 2014 is the year before the earlier supply shock, 2015 is the year that includes the earlier supply shock, and 2021 is the year before the new supply shock.

The trade data in the model are for HS heading 2804.29, which is comprised of rare gases isolated via air separation. This heading is not strictly limited to neon that enters the laser supply chain. It includes the small share of neon exported for other uses as well as some other rare gases, including krypton and xenon.

Table 1 reports the model inputs. The average unit value (AUV) of Ukrainian neon exports serves as a proxy for the industry price in each period. The model estimates the quantity global demand for the product (Q_t) by dividing observed exports from the Ukraine (X_t) by Ukraine's global market share in the same year. For our forecast of the exogenous decline in the quantity of Ukrainian neon exports due to the 2022 conflict, we consider two alternatives: a 35% decline (matching the percent reduction between 2014 and 2015) and a 70% decline (twice this earlier percent reduction).

Table 1: Model Inputs

	Value
Quantities (in m^3)	
Ukrainian Exports in 2014	251,324
Ukrainian Exports in 2015	162,116
Ukrainian Exports in 2021	203,144
Prices (in $ per m^3)	
AUV of Ukrainian Exports in 2014	50.86
AUV of Ukrainian Exports in 2015	173.97
AUV of Ukrainian Exports in 2021	228.17
Market Shares (%)	
Ukrainian Share of the Global Market in 2014	70
Ukrainian Share of the Global Market in 2021	50

There were significant fluctuations in export quantities, with a 35% reduction between 2014 and 2015. There was also a significant reduction in the Ukraine's global market share between 2014 and 2021, from 70% to 50%, which indicates supply chain diversification over this period. Finally, prices were elevated in 2021, even before the present Russia-Ukraine war.

5 Model-Based Estimates

Table 2 reports the model's prediction for the price of neon in 2022 for two alternative assumptions about the exogenous decline in the quantity of Ukrainian exports. The model uses Ukrainian export quantities in 2014, 2015, and 2021 and the Ukraine's market share in 2021 to predict the price increase resulting from the negative supply shock in 2022. The calculations in Table 2 provisionally assume that the elasticity does not change over time ($\varepsilon_{2021} = \varepsilon_{2014}$), since we do not yet have adequate data for 2022 to calculate a new elasticity ε_{2021}. The calculations also assume that there is no change in total global demand from 2021 to 2022. In these estimates, the model inputs from Table 1 determine the parameter values according to equations (4) and (5), and the forecast price is based on to equation (6), which is derived from equation (3).

$$P_{2022} = \left(\frac{\frac{X_{2021}}{\mu_{2021}} - X_{2021}\,(1 - \delta_{2022})}{\frac{X_{2021}}{\mu_{2021}} - X_{2021}} \right)^{\frac{1}{\varepsilon_{2014}}} P_{2021} \tag{6}$$

μ_t is Ukraine's global market share in period t, and δ_{2022} is the exogenous percent decline in exports due to the 2022 conflict. This version of the model takes our forecast for X_{2022}, our assumption about the exogenous supply shock, and translates it into a forecast for P_{2022}.

Table 2: Model Outputs with New Price Unknown

	Decline by 35%	**Decline by 70%**
Calibrated Parameters		
Supply Shift Parameter α_{2014} (in m^3)	15,671	15,671
Price Elasticity of Supply ε_{2014}	0.49	0.49
Supply Shift Parameter α_{2021} (in m^3)	14,153	14,153
Forecast Price Change		
Predicted AUV in 2022 (in \$ per m^3)	420.65	672.96
% Change in Price in 2022	84%	195%

The price increase from 2014 to 2015, proxied by average unit values, was 242%. In contrast, Table 2 predicts that prices will increase by 84% in 2022 if the exogenous decline in the quantity of Ukrainian exports matched the decline in 2015 (35%) and will only increase by 195% in 2022 even if the exogenous decline in the quantity of exports is twice as large (70%). The reason for the smaller predicted price responses in 2022 is the diversification of the international supply chain away from Ukraine, which is reflected in the reduction in the Ukraine's global market share in neon from 70% to 50%.

Table 3 reports estimates for a second version of the model that *assumes* that the price and quantity increases due to the new supply shock are *known*. Since 2022 prices and quantities are not yet available, we use three alternative assumptions about the 2022 AUV ($300, $400, or $500 per cubic meter) and two alternative assumptions about the exogenous percent decline in the quantity of exports from Ukraine (35% or 70%) to illustrate this second version of the model.

Table 3: Model Outputs for Alternative New Price and Quantity Changes

	Alt. 1	**Alt. 2**	**Alt. 3**	**Alt. 4**	**Alt. 5**	**Alt. 6**
Price and Quantity Changes						
AUV in 2022	300	400	500	300	400	500
% Change in Price in 2022	31%	75%	119%	31%	75%	119%
% Change in Quantity in 2022	-35%	-35%	-35%	-70%	-70%	-70%
Calibrated Parameters						
Supply Shift Parameter α_{2014}	15,671	15,671	15,671	15,671	15,671	15,671
Price Elasticity of Supply ε_{2014}	0.49	0.49	0.49	0.49	0.49	0.49
Supply Shift Parameter α_{2021}	527	11,146	25,450	5	1,199	5,161
Price Elasticity of Supply ε_{2021}	1.10	0.53	0.38	1.94	0.95	0.68

The inputs of this second version of the model are the alternative assumptions about market price and export quantity increases in the top panel of Table 3. The outputs of the model are the full set of parameters in the bottom panel of Table 3. This version of the model not only estimates the change in the supply shift parameter from α_{2014} to α_{2021} but also the change in the price elasticity of supply from ε_{2014} to ε_{2021}.

After fitting the supply shift parameter α_{2021} to 2021 data, a lower value of P_{2022} (or a larger exogenous decline in the quantity of Ukrainian exports) translates into a higher elasticity value ε_{2021} and indicates a more flexible international supply chain. Once we have observed P_{2022} and Q_{2022}, we will be able estimate a specific value for ε_{2021} rather than the set of six alternatives in Table 3. In this way, we will be able to assess changes in the flexibility of the supply chain.

We already know from data on market shares in Table 1 that the industry's international supply chain became *more diversified*; in all but one of the six alternatives in Table 3 the supply chain also became *more flexible*. Once the price and quantity increases are known, this second version of the model can be applied retrospectively. Every time we observe price and quantity increases due to a significant supply shock, we can use the model to update our assessment of the flexibility of the industry's international supply chain.

6 Caveats and Conclusions

Our model of the impact of the conflicts on neon exports from Ukraine is one example of the usefulness of adding PE modeling to descriptive industry analysis. The model predicts that the 2022 supply shock will increase neon prices by 84% in 2022 if the decline in the quantity of Ukrainian neon exports in 2022 matches the exogenous 35% decline in 2015, and by 195% if the decline in the quantity of exports is twice as large. The price increases in 2022 reflect significant diversification of the international supply chain away from Ukraine. Once we know the new market price and export quantity in 2022, we will be able to use the model to assess whether the industry's international supply chain has become more flexible.

There are several caveats to keep in mind, and these suggest areas for further research. First, the available trade statistics on rare gases include more than neon that is used in lasers, and it would be helpful to have data that are disaggregated by element and by end use.

Second, the model uses annual data but could consider more frequent data, possibly monthly. Third, the model is simplified to only require the data already presented in DeCarlo and Goodman (2022). It is possible to make the model more elaborate, for example by explicitly modeling the structure of neon production in the rest of the world and the management of neon stockpiles, but the more elaborate model would require additional data inputs.

Finally, similar PE models can be applied to other industries to predict the effects of supply shocks and to assess changes in the diversity and flexibility of international supply chains. In each case, the model should be designed around data limitations and should try to capture key features of the industry. For example, the features of the neon industry that are captured in our model are its highly inelastic demand and large exogenous supply reductions due to conflict, as well as the availability of relevant trade data but little production, consumption, or price data for the industry. In applications to other industries, key features will be different, and models should be customized accordingly.

References

Daun, T. and Riker, D. (2021). Trade Liberalization, Displacement, and Unemployment in a PE Framework. U.S. International Trade Commission Economics Working Paper 2021-11-B.

DeCarlo, S. and Goodman, S. (2022). Ukraine, Neon, and Semiconductors. U.S. International Trade Commission Executive Briefing on Trade, April.

Mueller, P. and Riker, D. (2020). Practical PE Models of Trade and FDI Policy Uncertainty. U.S. International Trade Commission Economics Working Paper 2020-08-A.

Riker, D. (2022). Different Types of Trade Shocks in an Upstream-Downstream PE Model. U.S. International Trade Commission Economics Working Paper 2022-06-A.