The Market Impact of Proposed US Uranium Import Quotas on the U.S. Nuclear Power Industry

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Executive Summary

Proponents of an import quota on uranium suggest that the impact of a quota ensuring a 25 percent U.S. market share for domestic uranium mining would be modest. Quota proponents support this claim with an analysis that estimates that the total annual incremental cost of such a quota to the domestic nuclear power industry would be just over $300 million per year, or about $0.41 per megawatt-hour. Further, supporters suggest that such a cost increase would have virtually no impact on the economics of merchant nuclear generators. We find that the analysis is deeply flawed and quota-related cost increases will have a detrimental impact on the already struggling merchant nuclear power sector.

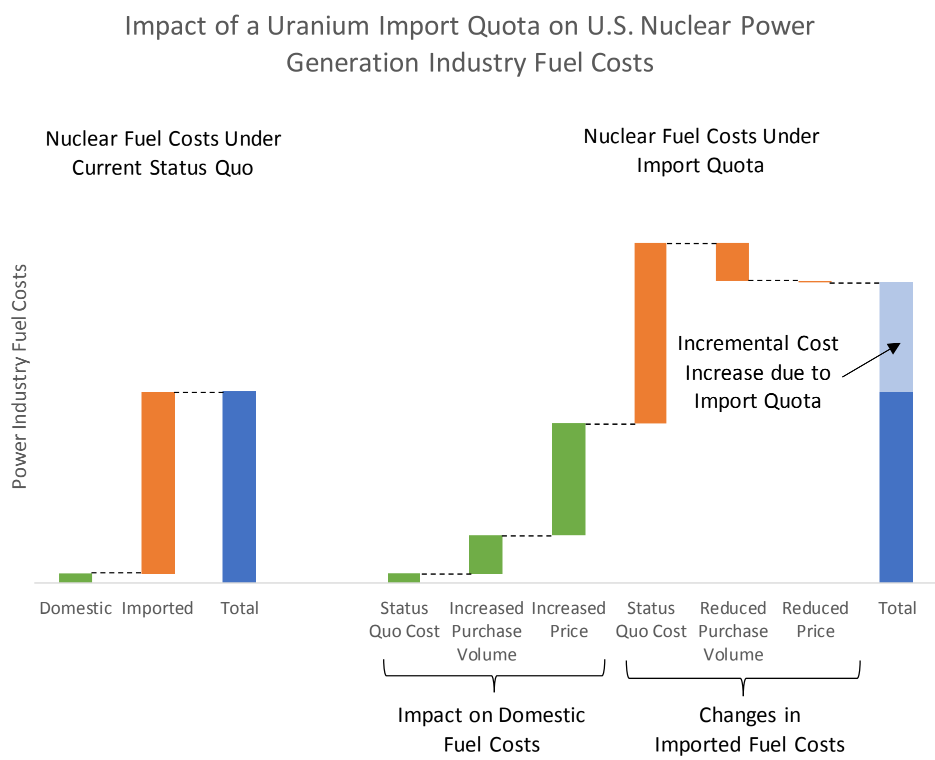
The core driver of quota proponents' analytical results is a finding that the market price of domestic uranium will only need to rise by a modest amount to induce a massive, unprecedented increase in production. This analysis is deficient, however, because it relies on a data sample with historical U.S. production levels that fall well below the level that would be needed to support the proposed quota and thus sheds little light on what would happen if production where increased far beyond these levels. That is, the analysis suffers from an extreme "out of sample" estimation problem. If more reasonable common-sense assumptions regarding the price elasticity of supply for domestic uranium production are utilized to estimate the likely uranium price response to the increase in production needed to meet the quota requirements, then the resulting range of prices is both very wide and much higher than quota proponents' estimate. When utilized to estimate the cost increase of the proposed quota for the U.S. nuclear power industry, this methodology yields a much higher estimate – the costs are likely to be about $500 to $800 million per year in the steady state, or about $0.65 to $1 per MWh, but could potentially be higher in the early years of the policy, particularly if implemented without a phase-in or similar protections against a near-term price spike.

The proposed quota would have detrimental effects on the U.S. nuclear power industry, particularly for merchant nuclear generators. Even without a quota, merchant nuclear generators currently receive insufficient market revenues to cover their ongoing cash operating costs in most regions of the country. This has resulted in the retirement of several nuclear facilities in recent years and the announced retirement of additional facilities in the coming years. Merchant nuclear generators are unable to pass fuel cost increases through to market prices and would thus bear the full incremental cost of the quota against this challenging backdrop. The proposed quota would thus likely lead to the incremental retirement of additional nuclear facilities beyond those already announced. The employment impact of the retirement of a single nuclear facility likely offsets any increase in mining employment due to the proposed quota. In addition, incremental retirements due to the quota would permanently diminish demand for uranium, increase electricity costs for consumers, decrease the resiliency of the electric system, and drive up emissions of carbon and other pollutants.

The Uranium Import Quota Proposal

Proponents of uranium import quotas have proposed a quota on uranium imports into the United States that ensures a 25 percent U.S. market share for domestic uranium mining ("25 percent quota").[1] While such a quota would have numerous secondary effects that ripple throughout the global uranium industry, its primary impact would be to drive up domestic uranium prices to whatever level is necessary to incent the increase in domestic production needed to meet the quota requirements, resulting in a significant price difference between U.S. and foreign sourced uranium. The resulting impact on the U.S. nuclear power generation industry would be to force the industry to replace ongoing purchases of relatively cheap imported uranium with more expensive domestic uranium. This effect is illustrated in Figure 1:

Figure 1



An import quota has both price and volume effects. The volume effect manifests simply as a decrease in the volume of imported uranium purchases by domestic consumers and an offsetting increase in domestically-sourced purchases to meet the requirements of the quota. There is little uncertainty around the volumetric effect; the requirements of the import quota would likely be explicit and the overall domestic demand for nuclear fuel is entirely price-insensitive in the near term if no nuclear plants retire in response to the increase in cost (which is a real risk, as discussed later in this paper). The key uncertainty around the impact of an import quota lies in the price effects. To meet the

[1] Before the United States Department of Commerce, Petition for Relief Under Section 232 of the Trade Expansion Act of 1962 from Imports of Uranium Products that Threaten National Security, Energy Fuels Resources (USA) Inc. and Ur-Energy USA, Inc. Petitioners, Jan 16, 2018.

requirements of the quota, domestic uranium producers must greatly increase their production output relative to recent history and would need make the necessary capital investments to support a much higher production level, which will require a higher sustained market price for domestic uranium as more expensive incremental sources of supply must be accessed. On the flip side, the increased domestic production would displace a similar amount of international production, which would tend to dampen global uranium prices and will thus reduce the cost of the remaining imported uranium utilized by U.S. power generators. Given the very small size of the U.S. uranium mining industry relative to the international uranium market, however, the reduction in global uranium prices is likely to be orders of magnitude smaller than the effect on domestic uranium prices. It is thus this differential price impact of the quota that ultimately drives the cost increase for the nuclear power generation industry. While the overall directional impacts of an import quota are undisputed, the key uncertainty in any specific projection of its impact is the magnitude of the price effect on domestic uranium prices. If the price effect is modest, the overall impact of the quota on power industry costs will be modest. If it is large, the impact on power industry costs will be significant.

Proponents of the 25 percent quota claim that the incremental price effect of a quota on domestic uranium will be relatively small, approximately $20 to $30/lb, which translates to an ongoing incremental industry cost of just over $300 million per year in the steady state, per the mechanisms described above. Quota proponents refer to a paper by Professor Timothy J. Considine ("Considine Paper"), analyzing annual industry-wide price and volume data reported by the U.S Energy Information Administration ("EIA") over the period from 1994 to 2016, to support this claim.[2] As we will discuss, the analysis in the Considine paper is deeply flawed, and a more reasonable analysis of the same data suggests an expected cost increase of at least twice that claimed by quota proponents coupled with an extremely wide range of uncertainty. Before turning to a discussion of the analysis in the Considine paper, however, it is useful to review the underlying structure and economics of the U.S. and international uranium mining industries and place the proposed 25 percent quota within this context.

Structure and Economics of the Uranium Industry

The U.S. nuclear power generation industry has on average consumed just under 50 million pounds of uranium concentrate (U_3O_8 or "yellowcake") per year to fuel approximately 100 Gigawatts of nuclear capacity over the past 24 years. While there is year-to-year variance in the amount consumed driven by outages and the fuel cycle timing of individual plants, U.S. demand has remained relatively constant over the 1994 to 2017 period covered by the available data and analyzed in the Considine Paper.[3] In recent years, U.S. uranium consumption has represented about third of total global demand.

U.S. uranium demand has been primarily sourced from foreign sources across the entire available data sample.[4] Figure 2 below shows total U.S. Uranium demand by year, along with the supply sources used

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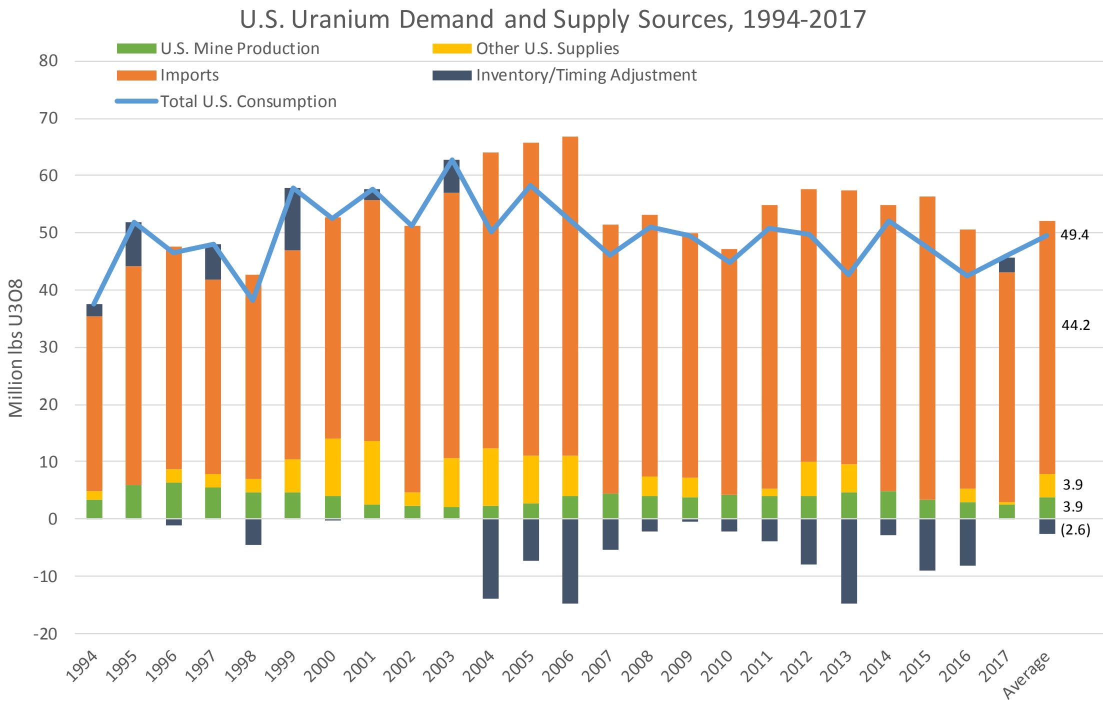
[2] Timothy J. Considine, "The Market Impacts of US Uranium Import Quotas," Jan 2018, at 23-25 ("Considine Paper")

[3] In our analysis, we also incorporate data from 2017 which has come available from the Energy Information Administration subsequent to the release of the Considine Paper. The Considine Paper analyzed data from 1994 to 2016.

[4] Prior to period covered by the data sample analyzed by Professor Considine U.S. Uranium production was higher. For instance, in 1980, U.S. mine production peaked at 43.7 million pounds before declining to between 11 and 15 million pounds per year for the second half of the 1980s. Given the extremely different market conditions present

to satisfy that demand. While total U.S. consumption has averaged 49.4 million pounds per year, only about 4 million pounds per year have been sourced from domestic mining, with another 4 million pounds per year coming from other domestic sources (such as sales from government sources) and the balance of about 44 million pounds per year coming from imported uranium.[5] While there has been year-to-year variance, supply sourced from domestic mining in particular has varied within a relatively tight band – 2 to 6 million pounds per year – without a discernable long-term trend for the entire period. While quota proponents characterize the industry as "in decline," that decline happened prior to 1994.

Figure 2



Source: U.S. Energy Information Administration, *2017 Domestic Uranium Production Report*, May 2018 ("EIA Production Report"), Table 9, and *2017 Uranium Marketing Annual Report*, May 2018 ("EIA Marketing Report"), Table S1a.

Going forward, U.S. domestic uranium demand for the 2018 to 2022 period is expected to decline by about 10% relative to the 1994-2017 average, from 49.4 to 44.6 million pounds per year[6] due to retirements of financially challenged plants and delays and cancellation of expected new build nuclear

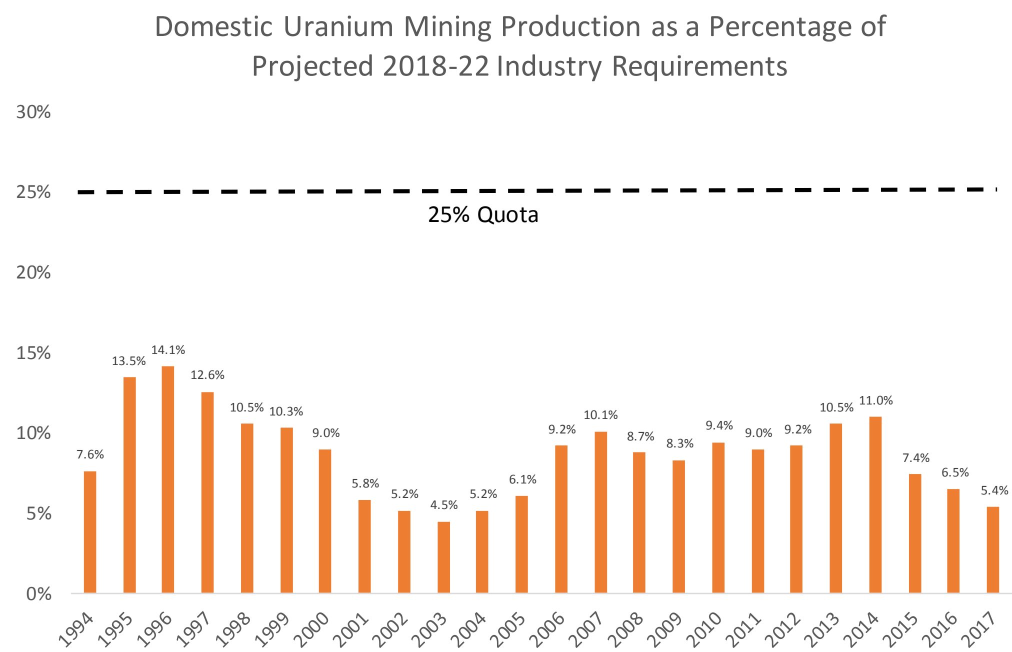
during this period, however, it sheds little light on the likely impact of the proposed quota. See U.S. Energy Information Administration, *2012 Annual Energy Review,* Table 9.3.

[5] These supply sources add to 52.0 million pounds per year because the industry has expanded inventory over the 1994-2017 period by an average of 2.6 million pounds per year.

[6] EIA Marketing Report, Table 12.

generation capacity.[7] Over the past 20 years, the U.S. mining industry has produced between 4 and 11% of this projected future demand level, well short of the 25% level that would be needed to supply the domestic mining quota suggested by quota proponents.

Figure 3

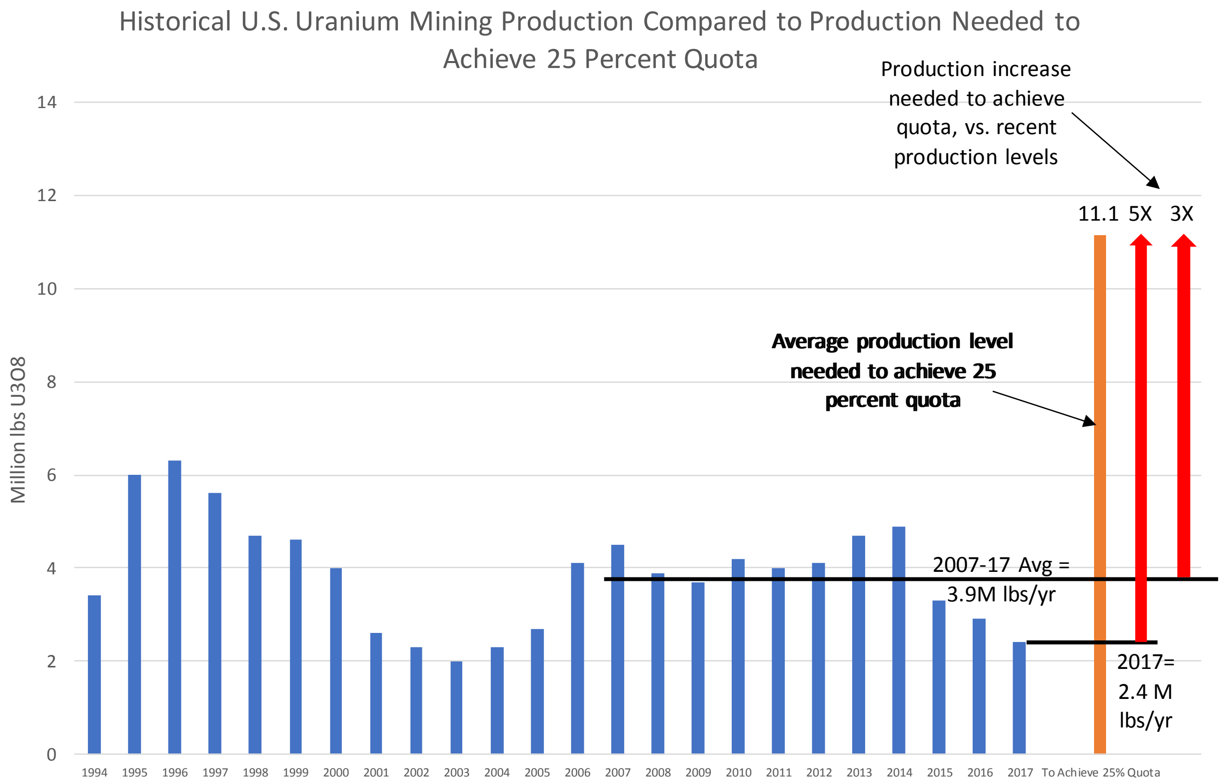


Source: EIA Production Report, Table 9 and EIA Marketing Report, Table S1a.

Given projected future demand, the U.S. domestic mining industry would need to raise production to about 11.1 million pounds per year to meet the requirements of the proposed quota. This represents an unprecedented expansion of production well beyond the highest level that the industry has achieved since 1994. Production at this level would represent close to a threefold increase relative to recent (2007 to 2017) average production, and close to a fivefold increase over 2017 production.

[7] Six nuclear generating units representing about 5% of nation-wide capacity have retired in the past 5 years, while another eight units representing another 11% of capacity have announced retirement (this figure includes the recently-announced decision to retire the Davis-Besse, Perry, and Beaver Valley plants). In addition, of the four previously under-construction units nationwide, two (V.C. Summer) have been canceled while the other two (Vogtle) have been delayed by 5 years relative to their original projected in-service date.

Figure 4

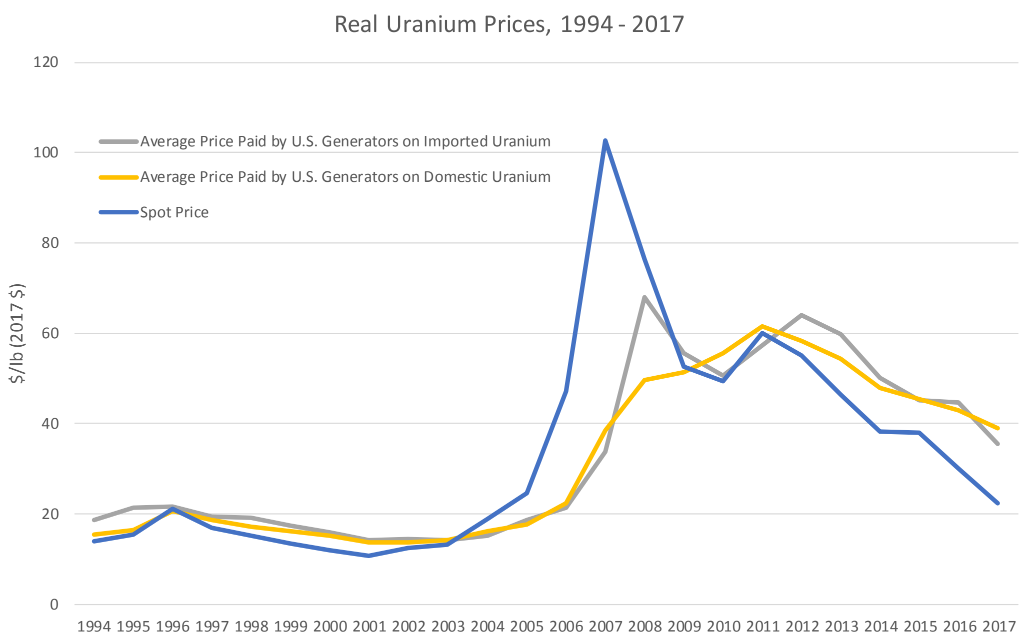


Source: EIA Production Report, Table 9 and EIA Quarterly Production Report, Table 1.

The key uncertainty surrounding the effects of the proposed 25 percent quota on the U.S. nuclear power industry is what impact this unprecedented increase in domestic mining production has on domestic uranium prices. Historical prices help to inform and bound the potential impact on price, but ultimately are greatly limited in their predictive utility because there is no historical experience in the past 24 years with production levels of the magnitude contemplated by a 25 percent quota.

Figure 5 below shows the three major types of uranium prices reported by EIA over the 1994 to 2017 period. EIA reports both an average domestic and foreign price paid by U.S. power generators for uranium, along with a spot price. Over the sample period, the domestic and foreign average price has generally moved together with occasional short-lived periods of divergence. This is consistent with the historical lack of a domestic production quota that could cause the foreign and domestic price to significantly diverge. Going forward in the presence of a quota, we would expect the domestic price to rise well above the import price on a sustained basis. Importantly, both the foreign and domestic price represent a blended average price of all purchases in that year, rather than the marginal price paid on incremental purchases. That is, both sets of prices reflect both new contract prices (such as spot purchases and newly-signed long term prices) as well as prices paid on long-term contracts signed in prior years under different market conditions. The spot price, which represents the price paid for one-time purchases in that year, is a better indicator of current marginal prices. As such, it tends to lead the blended average prices by 1 to 2 years. For example, the sustained upward move in spot market prices beginning in 2006 was not fully reflected in the blended average prices until 2008. A more recent downturn in prices was first reflected in spot prices in 2012 but not in the blended average prices until 2013/14.

Figure 5



Source: EIA Market Report, Table S1b.

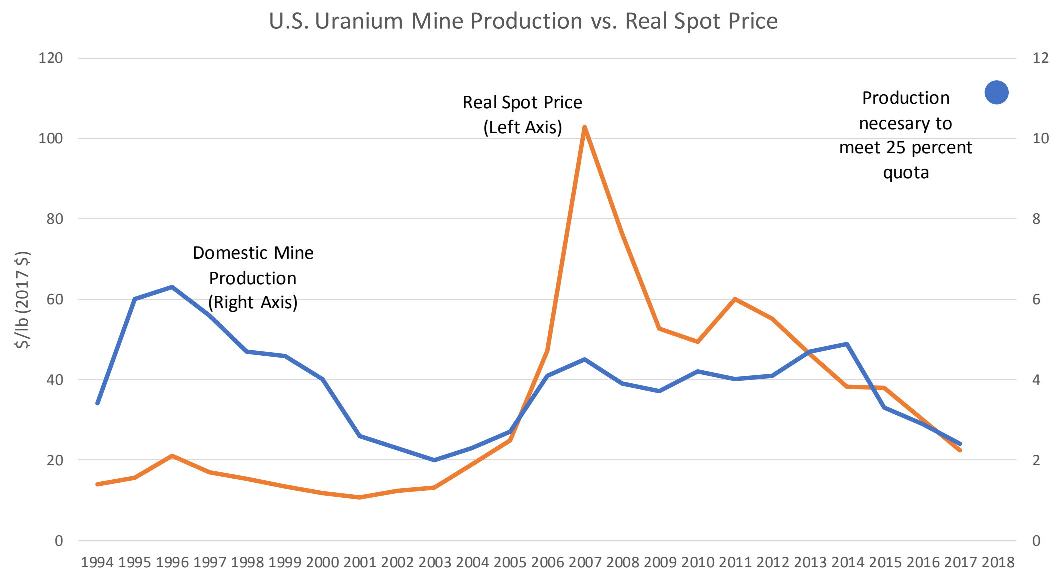
It is apparent from a casual inspection of the price data that the market likely underwent a structural shift sometime in the 2005 to 2007 range. Prior to this point, market prices were both lower and much less volatile. Following this point the reverse is true, particularly with respect to spot prices. Considine and others acknowledge this shift and attribute it to declining global uranium reserves and the resulting migration of marginal production globally to higher cost resources.[8]

When spot prices are examined in conjunction with production, the magnitude of the challenge of meeting the proposed quota becomes apparent. As Figure 6 shows, for a period from 2007 to 2012, real spot prices ranged between $50 and $100/lb, averaging $66/lb, far above the current spot price level of about $22/lb,[9] while U.S. mine production refused to budge much above 4 million pounds per year, about a third of the level needed to satisfy the quota requirements. The failure of the U.S. mining industry to increase production in response to a sustained price signal far above the present price suggests that the price needed to induce production increases at the level sufficient to satisfy the quota would be much higher still.

[8] Considine Paper at 15.

[9] The Considine Paper generally uses an estimate of $24/lb to characterize the current spot price. The final average 2017 spot price value reported by EIA in the 2017 Uranium Marketing Report is $22.36/lb.

Figure 6

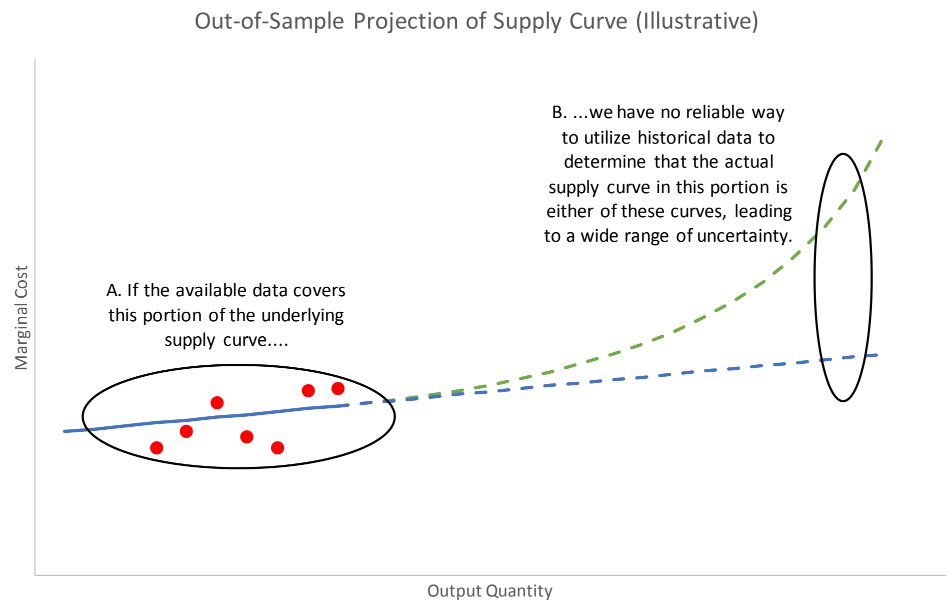


Source: See Figures 3 and 5.

Quota proponents' analysis of the impact of the 25 percent quota greatly understates the likely impact on domestic uranium prices

The key question for the purposes of the impact of the proposed quota is what marginal price is needed to induce domestic producers to expand production to the level required by the quota. In other words, any analysis of the quota needs to describe the supply curve for domestic uranium production. The analytic difficulty in describing the supply curve is that the available data on domestic production clusters around a segment of the supply curve that is far removed from the segment of the supply curve that will be important for driving uranium prices in the event a 25 percent quota is imposed. In econometric parlance this is known as a "out-of-sample" projection problem. Simply put, the relationship between price and domestic uranium production observed in recent years only allows us to confidently describe the supply curve in the limited range of actual historical domestic production – between 2 and 5 million pounds per year. The historical data does not allow us to predict with confidence the shape of the supply curve as production moves from 5 million pounds per year to the over 11 million pounds per year needed to meet the terms of the 25 percent quota. This problem is illustrated in Figure 7 below:

Figure 7



The Considine paper presents a complex 19-equation model intended to describe the workings of the domestic and international uranium markets. While the model is complex, for the purposes of determining the impact of the quota, the primary driver is the model's description of the domestic uranium supply curve, that is, how the marginal cost of domestic production, and thus the domestic uranium market clearing price, increases with output level. For the purposes of developing this supply curve, Considine relies on the same 1994 to 2016 annual EIA data set comprising prices paid by domestic uranium consumers and domestic production. Specifically, Considine performs a regression analysis using this dataset to describe the relationship between domestic prices and output as follows:

> Domestic-Origin Price = A*Domestic Origin Mining Shipments + B*Post-2007 Dummy Variable + C*Prior Year Domestic-Origin Price
>
> Where A, B, and C are parameters estimated via the regression on the historical data.

There are two clear problems with this formulation. First, as discussed above, the range of values on historical domestic-origin mining shipments falls far short of the levels contemplated by the quota, leading to a severe out-of-sample projection problem when the equation is utilized to project future prices at much higher production levels. Second, the use of a single linear dummy variable to separate the pre- and post- 2007 portions of the dataset likely distorts results as well. As noted above, uranium market prices became both higher and more volatile from 2007 onward due to fundamental structural changes in the market identified by Considine and others. By using a simple dummy variable to capture this effect, supply curve equation reduces this change to a simple fixed parameter that essentially estimates the average spread between pre- and post-2007 prices but fails to account for any changes the sensitivity of price to changes in production levels.

The impact of these problems with Considine's domestic supply curve equation become apparent when we examine the price projection that results when the equation is applied in service of estimating the impact of the 25 percent quota. Considine projects that, with a 25 percent quota and a resulting expansion in domestic production to over 11 million pounds per year, on a sustained basis domestic prices will rise by just over $30 per pound from his assumed current spot price level of $24 per pound to roughly $55 per pound.[10] That is, a roughly fivefold increase in production over the present level will result in prices slightly more than doubling relative to their current level. This projection is illustrated in Figure 8 below.

This projection strains credibility, for several reasons. First, since 2007, real spot market prices have frequently approached or exceeded $55 per pound without inducing increases in domestic production beyond roughly 5 million pounds per year, less than half the amount needed to satisfy the quota requirements. Indeed, over the entire 2007 to 2017 period that Considine designates as the "modern" global uranium market, U.S. domestic production averaged 3.9 million pounds per year while real spot prices averaged $51 per pound. Against this context, Considine's projection of a $55 per pound ex-quota price essentially suggests that U.S. producers can be induced to nearly triple production over recent average levels with a roughly 8 percent increase in price over the recent average real price. These relative price/production movements imply a price elasticity of supply of 25, assuming perfectly inelastic demand. This degree of price elasticity is not credible.

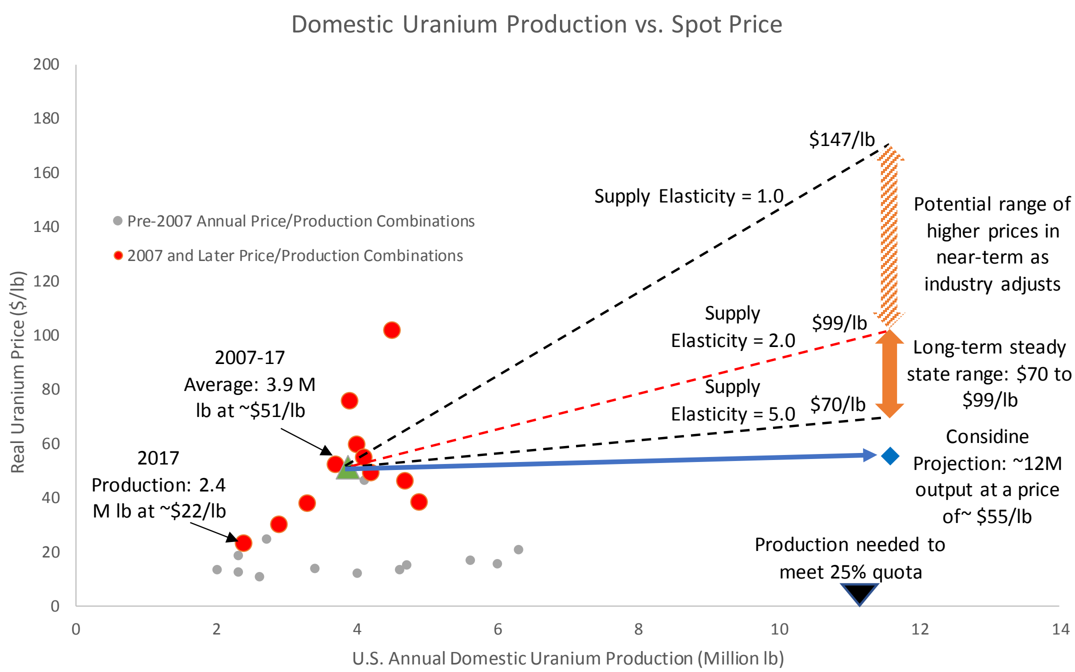
A conventional common-sense assumption in cases where the shape of the true underlying supply curve of a product is unknown is to simply assume a price elasticity of supply of one, which effectively states that to induce a given percentage increase in supply, prices must increase by an equal percentage. That is, to induce the near tripling of domestic supply relative to recent average production needed to satisfy the quota, prices would also need to nearly triple. Supply elasticity for most resource-extraction industries typically fall below 1.0, meaning that a given percentage increase in supply would require a larger percentage increase in price.[11] Alternatively, a simple regression of price on mining production for the 2007-17 period yields parameter estimates that suggests a supply elasticity of roughly one. Given the potential for the industry to adjust over a number of years by re-starting idled mines and developing new sources of supply, however, we assume a higher degree of supply elasticity in the longer-term steady state, that is, once the industry has been able to adjust to the higher level of domestic demand over a period of several years. For the steady state, we assume an elasticity of between two (that is, for each 1% increase in price, supply is assumed to increase by 2%) and five (that is, for a 1% increase in price, quantity supplied increases by 5%). If the quota were implemented

[10] Considine Paper Figure ES1, applied to the current market price of $24/lb. Note that the percentage changes in Figure ES2 of the Considine paper imply a projected future status quo price of approximately $31/lb, suggesting that Professor Considine is projecting that prices will rise by about $7/lb above their present level even in the absence of a quota. Given that no particular evidence or analytics are presented for this assumption, we assume a baseline no-quota market price of $24/lb.

[11] For example, recent studies of the U.S. Natural Gas Market have generally found long-run price elasticity of supply below one. See e.g. Micaela Ponce and Anne Neumann, "Elasticities of Supply for the U.S. Natural Gas Market," DIW Berlin, 2014 (finding a long-run price elasticity of supply of 0.76); Vipin Arora (U.S. Energy Information Administration), "Estimates of the Price Elasticities of Natural Gas Supply and Demand in the United States," MPRA Paper No. 54232, Mar 2014 (finding long-run price elasticity of supply between 0.07 and 0.43); Numerous studies of the global oil market have generally found supply elasticities below 0.3. See e.g. Dario Caldera, Michelle Cavalli, and Matteo Iacoviello, "Oil Price Elasticities and Oil Price Fluctuations," Board of Governors of the Federal Reserve System International Finance Discussion Papers Number 1173, July 2016, Tables A.3 and A.4 (conducting a broad literature survey and finding a range of oil price elasticity of supply estimates with a median estimate of 0.13 and a high estimate of 0.27).

abruptly, however, with no phase-in or other measures to protect against price spikes in the near-term while the industry adjusts to the much higher level of demand, an elasticity of one is a reasonable estimate of the upper end of the range of potential prices. Applied to the average 2007 to 2017 real uranium spot price of $51/lb, a supply elasticity of two to five implies a price of $71 to $99/lb is needed to induce the near-tripling of recent average production needed to satisfy the requirements of the proposed quota in the steady-state, while in the near-term, with an elasticity of one, prices could potentially rise as high as nearly $150/lb. This range is conservative with regards to typical supply elasticities and is also consistent with a conservative reading of the recent empirical history of prices and domestic production. Over the period of elevated spot prices from 2007 to 2012, real spot prices ranged between about $50 and $100/lb, averaging $66/lb, while domestic production averaged about 37% (about 4.1 million lbs/yr) what it would need to to satisfy the quota demand (see figure 6). This range of prices produced by these supply elasticity assumptions is shown in Figure 8. The entire range is well above Considine's single point estimate.

Figure 8



Source: EIA Production Report, Table 9; EIA Quarterly Production Report, Table 1; EIA Marketing Report, Table S1b; Considine Paper at 2.

While this range of potential ex-quota prices is very wide, it is reflective of the uncertainty involved in the extreme out-of-sample projection necessary to use historical data to project the impact of the 25 percent quota. The risk of a spike in domestic uranium prices towards the top of the range would be most acute in the early years of the proposed quota, and would be particularly problematic if the quota starts at the 25 percent level and is not phased in or combined with some other policy (such as a price cap) that protects against price spikes. This is because supply elasticity tends to be lower in the short-run before the industry has a chance to make longer-term investments needed to expand supply in response to higher prices. Considine's estimate of the price impact of the quota, on the other hand, is presented as a singular point estimate without acknowledging this wide range of uncertainty.

Ultimately, this analysis shows the limitations of using historical data to project an extreme out-of-sample future scenario. While the data clearly suggests that Considine's estimate is unreasonable, any analysis based on historical data still has a very wide range of uncertainty. In this sort of situation, a bottom-up analysis of the current capability and associated costs of the domestic mining industry to expand production to the level needed to support the quota is a useful complement to a top-down analysis of historical data. Performed properly, such an analysis would survey all the sources of incremental domestic supply (greenfield mines, expansions of existing facilities) and determine for each the breakeven price, including risk-adjusted return on capital, needed to induce investment and production from that supply source in response to the domestic quota, including any risks associated with the continued existence of the quota itself over the life of the project. Aggregated together, such an analysis would produce a bottom-up view of the domestic supply curve reaching to the level needed to support the quota, albeit dependent on many assumptions regarding project costs, cost of capital, etc. If performed properly, such an analysis provides a useful alternate means of estimating the price impact of expanding production to the quota level that, in conjunction with estimates based on top-down analysis of historical data, can serve to narrow the range and improve confidence in the likely impact of the quota.

While we have not performed such a bottom-up study, off-the-shelf commercial analytics which provide estimated project-by-project breakeven cost estimates do exist that provide a rough indication of where such a bottom-up study specifically tailored to the quota might land. Most commercial analytics suggest a range of simple breakeven prices for U.S. projects towards the bottom end of the range of prices produced by our historical analysis, that is, around $70/lb or somewhat less.[12] Such studies are not calibrated to the specifics of a domestic quota, however, for several reasons, and as such should be viewed as a likely floor on the ultimate price needed to satisfy the quota, particularly in the initial years after implementation. First, such studies generally assume that projects can be developed, permitted, and staffed in a timely, relatively frictionless manner. This is not unreasonable when the industry is in a steady state with only a small number of domestic projects under development at a given time. Meeting the quota, however, would require a rapid and sustained ramp-up of industry capacity, with many projects entering development simultaneously. Under these conditions, labor and equipment costs and availability, permitting, and financing would likely be much more challenging and costly than under more sedate steady-state conditions, leading to actual realized costs considerably higher than engineering estimates. Second, while uranium mining projects typically have a 10 to 25 year life, most domestic producers would likely view the expected life of the quota as considerably less than this, perhaps on the order of 3 to 5 years, and will accordingly demand a higher price in the near-term than their life-of-project economics would suggest, in order to compensate for the risk of lower prices in the later years due to expiration of the quota.[13] Finally, most projects take one to three years at a minimum

[12] *See* generally, NAC International, *Nuclear Fuel Market Issues and Insights 2017*; and UxC Consulting Company, LLC, *Uranium Suppliers Annual*, Dec 2017.

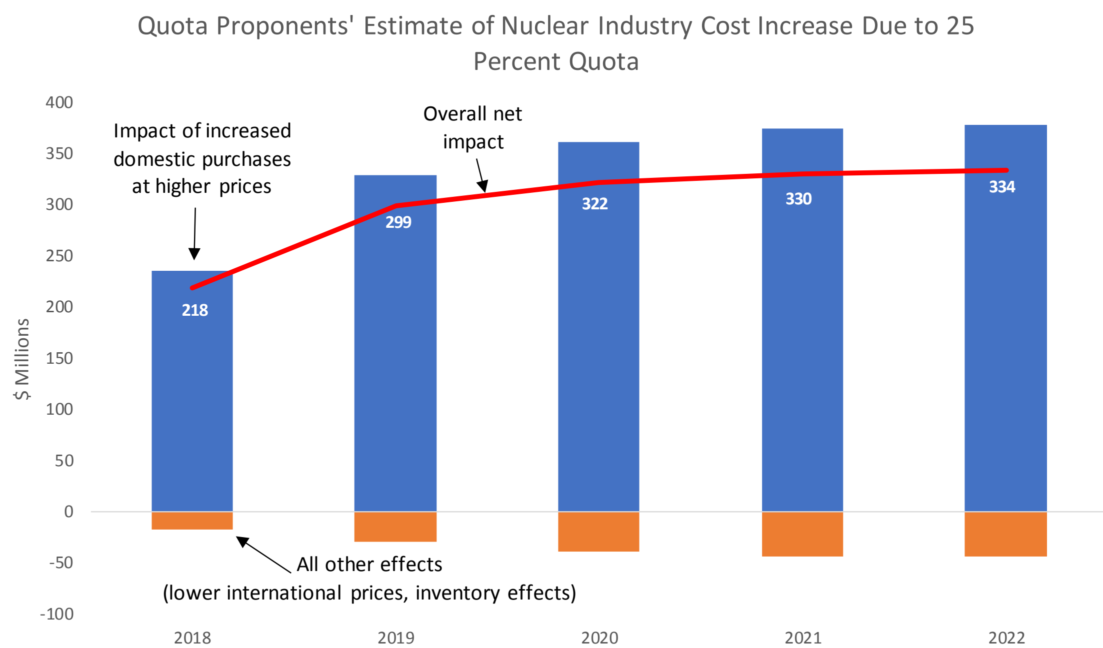
[13] The phenomena of investors seeking a considerable risk premium when making investments with large binary uncertainties (as in situations where the return on investment is very dependent on public policy variables such as quotas or subsidies) is well documented in the economic literature. *See*, generally Avinash K. Dicit and Robert S. Pindyck, *Investment Under Uncertainty*, Princeton University Press, 1994.

to develop, with greenfield projects often taking 5 to 10 years. Thus, in the early years of a quota, there is considerable risk that prices could de-couple from fundamentals and instead reflect scarcity conditions if the needed projects are unexpectedly delayed or cancelled. Thus, these off-the-shelf bottom-up analytics generally reinforce the notion that the risk of very high prices, possibly well over $100/lb, is most acute in the early years of a quota, and while the price risk may lessen over time, prices are still likely to remain in the longer-term steady-state range of $70 to $100/lb suggested by our historical analysis.

Impact of proposed 25 Percent Quota on U.S. Nuclear Power Industry

While there are several aspects of Considine's analysis that impact the ultimate effect of the quota on nuclear industry costs, the price effect of the quota is by far the dominant driver of the ultimate impact. Figure 9 below decomposes Considine's estimate of the impact of the 25 percent quota on U.S nuclear power generator costs between the impact of increased purchases of domestic uranium at higher prices, and all other effects, such as offsetting declines in international uranium prices and inventory effects. The core driver of the impact is the fact that, rather than purchasing uranium supplies from both domestic and international suppliers at the status quo market price of $24/lb assumed by Considine, the domestic uranium industry will need to, on the margin, replace a quarter of its existing purchases with much higher-priced domestic uranium (either about $55/lb or between $70 and $147/lb, depending on whether the relatively low Considine post-quota estimate or the more reasonable elasticity-based estimate is utilized).

Figure 9

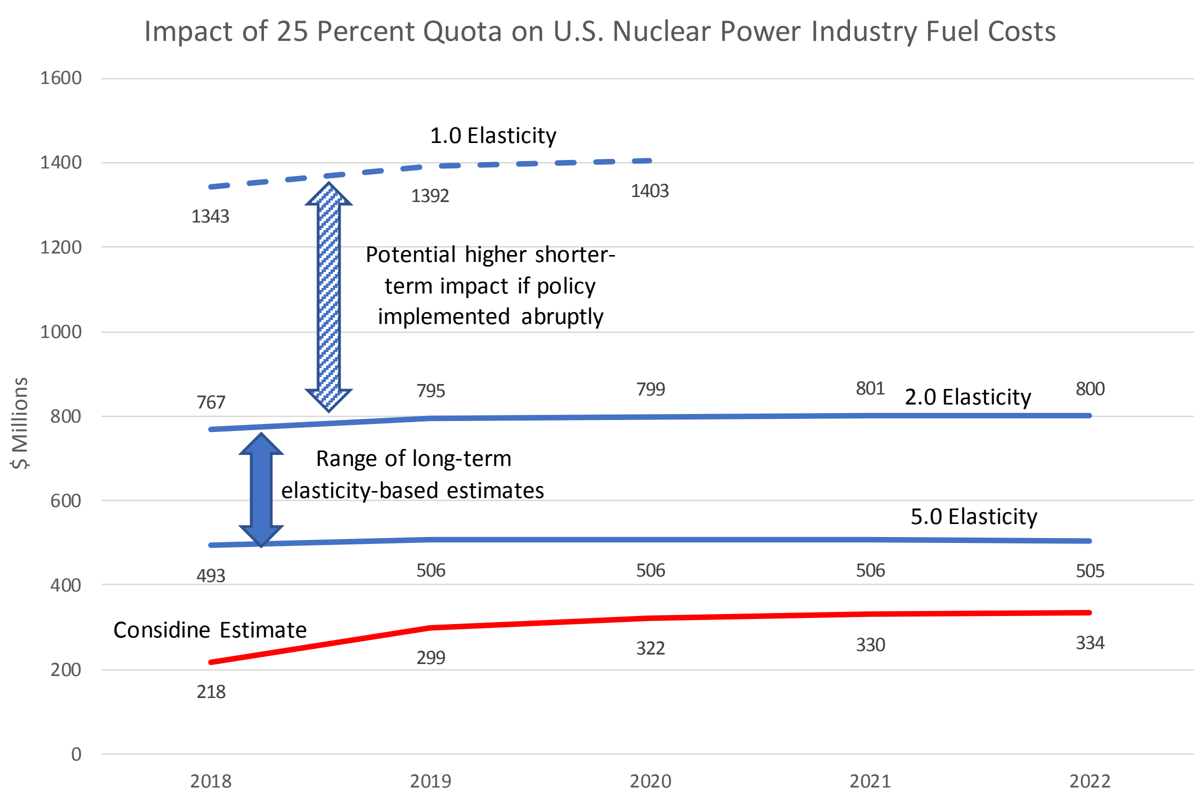


Source: Considine Paper Table 7 with authors' analysis.

As Figure 9 shows, in the long-term steady state, according to Considine's analysis about 10% of the effect of increased domestic purchases at higher prices is offset by other effects.

If we replace Considine's estimate of the price impact of the quota with the elasticity-based range developed above, the projected impact of the quota on domestic nuclear power producer's costs is both much higher and more uncertain. As Figure 10 below shows, with a supply elasticity of between two and five, the incremental cost of the 25 percent quota to U.S. nuclear power generators is between $500 and $800 million per year. In the early years of the quota, however, if the policy is implemented without a phase-in or similar price guardrails, the impact could be much higher. This compares to Considine's steady state estimate of about $330 million per year. Given estimated future U.S. nuclear power production of about 775 TWh per year through 2022,[14] the steady-state range translates to a fuel cost increase of $0.65 to $1.03 per MWh, compared to $0.41 per MWh per the Considine estimate.

Figure 10



Source: Authors' analysis. Note that this analysis assumes in each scenario that a similar price elasticity applies to the international uranium price, which results in international uranium price declines of 1%, 4% and 7% in the 5.0, 2.0 and 1.0 elasticity scenarios respectively.

Quota proponents claim that the proposed quota will have minimal impact on the U.S. nuclear power generation industry. This claim is wrong for two reasons. First, as discussed previously, quota proponents' estimate of the impact of the quota on U.S. nuclear generator fuel costs – approximately

[14] U.S. Energy Information Administration, *Annual Energy Outlook 2018*, Feb 2018, Table 8.

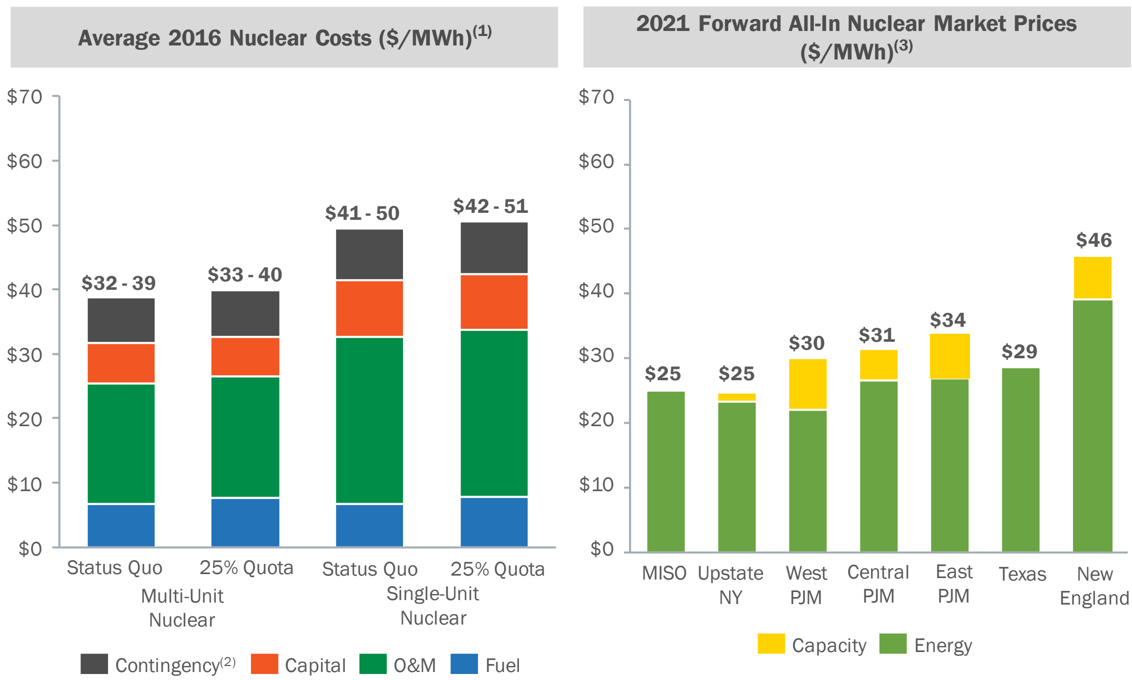
$0.40 per MWh – is far too low; a more reasonable estimate is about $0.65 to $1 per MWh, with a wide range of uncertainty up to about $2/MWh. Second, quota proponents mischaracterize how even a modest cost impact is likely to affect nuclear power generators. Considine dismisses the impact of the quota on the economics of merchant nuclear generators simply because the cost increase that he calculates is relatively small relative (he estimates between 0.8% and 1.2%) to the total wholesale price of electricity.[15] Beyond this dismissal, he does not examine further whether and how such a cost increase is likely to affect the industry.

The key problem that Considine fails to recognize is that for an industry that is barely able to cover its costs as-is, even a small cost increase can lead to producers exiting the market. And furthermore, the unique economics of nuclear generators make them especially vulnerable to cost increases due to external factors. Nuclear power generation is characterized by very low variable costs and high fixed costs. Fuel is typically only about 15 to 25 percent of the total cash costs of operating a nuclear plant, with the remainder comprised of labor, maintenance, sustaining capital expenditures and other fixed costs that, while they are largely avoidable if a plant retires, do not vary with plant output. The result of this cost structure is that it is almost always economically optimal to run a nuclear plant at full output under all circumstances if it is not on outage. For nuclear units in competitive markets, however, this cost structure also means that nuclear plants are almost always infra-marginal price-takers in electric energy markets. That is, they receive a price that is set by a marginal generator with higher variable costs (typically a gas or coal unit) and rely on the resulting margin between the market price and their own variable costs to cover their relatively high fixed costs of operation. Because of this, merchant nuclear generators have essentially no ability to pass cost increases through to market prices. Any cost increases are borne by the plant itself and increases the likelihood that the plant will be unable to cover its total costs of operation.

Even without the increased costs associated with the proposed quota, U.S. nuclear plants in competitive markets are under extreme financial pressure. In most markets today, nuclear generators are either unable or barely able to cover their total fixed costs of operation, including compensation for the risk associated with owning and operating a nuclear facility. This pressure has led six nuclear units representing close to 5 GW, or close to 5% of total U.S. capacity, to retire in recent years. Further, another twelve units representing over 11 GW of capacity have announced plans to retire in the coming years. Finally, ten nuclear units in the states of Illinois, New York, and New Jersey have secured state support in the form of zero emission credits, without which they would have been unable to remain in operation. Against this backdrop of extreme financial pressure, an incremental cost increase of $1/MWh would be devastating to the industry and would likely lead to additional retirements beyond those noted above. Figure 11 below compares the total forward-looking cost of operation for both dual-unit and single-unit nuclear plants with the available market revenues in major U.S. electricity markets.

[15] Considine Paper at 26-27.

Figure 11



(1) Source: Nuclear Energy Institute, "Nuclear Costs in Context," August 2017
(2) Contingency (or risk) is calculated as 10% of total costs plus $4/MWh
(3) Based on 6/4/2018 NYMEX forward energy prices for relevant hub less 2015-2017 average basis differential to nuclear plants

Even without the increased costs associated with the proposed quota, merchant nuclear plants fail to cover their ongoing cash costs in most regions even before consideration of any compensation for risk. Because many plants are either close to the edge of losing money on an ongoing basis or are already losing money, even a modest increase in ongoing costs will likely result in incremental retirements. Even the lower cost of $0.41/MWh calculated by quota proponents could easily lead to incremental retirements – when producers are unable to cover their costs in the status quo, even a small increase in costs can cause them to exit the market.

Additional nuclear retirements would have several detrimental consequences. From an employment perspective, a single nuclear plant typically directly accounts for about 700 to 1,000 jobs, and indirectly supports another 2,000 to 7,000 additional jobs.[16] Given that the U.S. uranium mining industry only employed just under 1,600 people total at its peak over the 1994-2016 period, and only 424 today,[17] a single incremental nuclear plant retirement is likely to fully offset whatever employment gains in the uranium mining industry result from the quota, while multiple retirements would drive significant net job losses. Second, by accelerating nuclear retirements, the quota will end up eroding the very demand that it depends on to support the industry on an ongoing basis. Third, nuclear retirements will result in

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[16] See Berkman, Mark and Murphy, Dean, The Brattle Group, *Pennsylvania Nuclear Power Plants' Contribution to the State Economy*, Dec 2016 (5 plants support 4,685 direct and 11,215 secondary jobs), *New York's Upstate Nuclear Power Plants' Contribution to the State Economy*, Dec 2015 (3 plants support 2,657 direct and 22,143 secondary jobs), and *Salem and Hope Creek Nuclear Power Plant's Contribution to the New Jersey Economy*, Nov 2017 (2 plants support 1,400 direct and 4,400 secondary jobs).
[17] EIA Production Report, Table 6.

increased power market prices for customers and increased emissions of carbon and other air pollutants, as has been amply documented in other studies. Finally, as has been documented in several recent studies and proceedings concerning grid resilience, the nations' nuclear units are a key, irreplaceable part of a power supply system that is resilient to both natural and man-made disruption. Set against this backdrop, the proposed quota is a costly and misguided policy that is likely to result in a significant net loss to the country when all impacts are considered.