Modeling the Market Fluctuations of Ammonia Price

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Abstract

The fertilizer industry is one of the most prominent sectors of chemical engineering and manufacturing: by way of example, it generates in the United States of America more than USD 155 billion in economic revenues annually and provides more than 495,000 jobs (The Fertilizer Institute, 2022). Indeed, since half of all food grown worldwide today is made possible through fertilizers, and, as demand continues to increase, their role will only become more important as a key ingredient in feeding a rising global population. Among fertilizers, ammonia is the primary reference compound, as it represents the raw material for the vast majority of their manufacturing and shows the highest production volumes (Isella and Manca, 2022). Based on the previous, pioneering works of Manca (2013, 2015, 2016) on commodity price forecasting, this paper presents a systematic approach to predict the evolution of the ammonia price in the next years for the feasibility-study framework of dynamic conceptual design. Specifically, different autoregressive models are proposed to forecast the distribution of (i) commodity prices that contribute to the definition of the ammonia price and (ii) the ammonia price itself.

**Keywords**: dynamic conceptual design, econometric modeling, price and cost forecast, short-/long-term predictions, fertilizer industry.

* 1. Introduction

Feasibility studies for designing, retrofitting, or revamping chemical plants unavoidably require updating capital (CapEx) and operating (OpEx) expenditures. While several tools are longtime established for CapEx estimation (*e.g.*, Guthrie’s formulas and cost indexes), very few have been developed for the OpEx. Indeed, raw materials, products, and utility costs/prices are mostly evaluated through a “discounting back approach”, *i.e.* they are assumed constant for the whole time horizon embraced by the feasibility study. However, such an assumption often proves to be too simplistic as it does not consider at all the oscillations and fluctuations that can strongly affect market prices. These are the main motivations behind the works of Manca (2013, 2016), which proposed a novel methodology to model the time evolution of commodity prices for feasibility studies and dynamic conceptual design. The present manuscript reflects those considerations in the fertilizer sector and, specifically, in the ammonia industry. Indeed, since ammonia synthesis is the most carbon-intensive process in the chemical industry (Isella and Manca, 2022), many feasibility studies regarding alternative, carbon-mitigating process layouts (to cite only a few: Armijo and Philibert, 2020; Wang *et al.*, 2021; Isella *et al.*, 2023) have been published to push the decarbonization of the fertilizer industry. Therefore, the main goal of this work is to provide a tool for ammonia price forecasting that might lead to much more robust feasibility studies for ammonia (and its derivatives) production.

* 1. Methodology

As extensively discussed in Manca (2013), the dynamic evolution of commodity prices may be traced back to one or more reference components, which must be chosen according to the market field of interest. By doing so, the economic dynamics of the commodity may be expressed as a function of the time series of the reference components' market quotations. More precisely, Autoregressive Distributed Lag (ADL) models have been identified as the optimal candidates for identifying such functional dependencies.

Concerning the ammonia (NH3) price, two reference components have been taken into account: crude oil and natural gas. Indeed, being ammonia currently synthesized almost entirely from fossil fuels, its price shows a remarkable correlation with them. Specifically, as far as the Northern American geopolitical scenario is concerned, West Texas Intermediate (WTI) and Henry Hub (HH) are considered for crude oil and natural gas prices, respectively. In this regard, U.S. Energy Information Administration (EIA, 2023) databases allow retrieving both WTI and HH prices, while Illinois production cost reports from the Agricultural Marketing Service of the U.S. Department of Agriculture (USDA AMS, 2023) are considered for the ammonia prices. The monthly price datasets were limited to a time frame spanning from January 2018 to September 2023 (69 months). The next paragraphs focus on each component assessed (the two references, *i.e.* WTI and HH, and the commodity, *i.e.* ammonia), and highlight the ADL models used to describe their economic dynamics.

* + 1. WTI price modeling

The ADL model for WTI price forecast grounds on its autocorrelogram (see Fig. 1A). Indeed, the correlation peaks of WTI price as against itself subjected to increasingly long-time shifts occur at 1- and 2-month time lags (0-month time lag is neglected instead since autocorrelograms are by definition equal to 1).

 

**B**

**A**

**Figure 1:** (Panel A) WTI price autocorrelogram; (Panel B) WTI price forecast model.

From this, it follows that a suitable ADL model for WTI price forecast is:

 (1)

To perform the regression, the whole dataset was split into two subsets: 80% of data points (*i.e.* from January 2018 to July 2022) were used for the identification procedure, while the remaining 20% was used to run the cross-validation procedure. Fig. 1B shows the model's accuracy, while Table 1 reports the resulting parameters.

**Table 1:** Parameters of the linear regression for the WTI price.

|  |  |  |  |
| --- | --- | --- | --- |
| [USD/bbl] | [-] | [-] | [-] |
| 4.4439 | 1.2386 | −0.3028 | 0.8888 |

* + 1. HH price modeling

The ADL model for HH price forecast builds on its autocorrelogram (see Fig. 2A) and on its correlogram to WTI quotations (see Fig. 2B). Indeed, crude oil is a valid reference component to natural gas, and the correlogram shows that the highest correlation between HH and WTI market quotations occurs when introducing a 2-month time lag. On the other hand, the autocorrelogram shows the best autocorrelation in HH prices at a 1-month time lag.

  

**C**

**B**

**A**

**Figure 2:** (Panel A) HH price autocorrelogram; (Panel B) WTI-HH price correlogram; (Panel C) HH price forecast model.

It follows that a suitable ADL model for HH price forecast is:

 (2)

Once again, to perform the regression, two subsets were considered: 80% of data points (*i.e.* from January 2018 until July 2022) for identification and 20% for cross-validation. Fig. 2C shows the model's accuracy, while Table 2 reports the resulting parameters.

**Table 2:** Parameters of the linear regression for the HH price.

|  |  |  |  |
| --- | --- | --- | --- |
| [USD/MBtu] | [bbl/MBtu] | [-] | [-] |
| −0.4208 | 0.0243 | 0.6999 | 0.7969 |

* + 1. NH3 price modeling

The ADL model for NH3 price forecast is based on its autocorrelogram (see Fig. 3A), on its correlogram as against WTI quotations (see Fig. 3B), and on its correlogram as against HH quotations (see Fig. 3C). Indeed, ammonia price shows a good correlation with WTI and HH prices: on one hand, a 0-month time lag for the WTI-NH3 correlogram, and, on the other hand, a 2-month time lag for the HH-NH3 correlogram. The autocorrelogram shows instead that the highest autocorrelation in NH3 prices happens at a 1-month time lag.

 

**B**

**C**

**A**

**D**

**Figure 3:** (Panel A) NH3 price autocorrelogram; (Panel B) WTI-NH3 price correlogram; (Panel C) HH-NH3 price correlogram; (Panel D) NH3 price forecast model.

It follows that a suitable ADL model for NH3 price forecast is:

 (3)

Again, two subsets were considered: 80% of data points (*i.e.* from January 2018 until July 2022) for identification and 20% for cross-validation. Fig. 3D shows the model's accuracy, while Table 3 reports the resulting parameters.

**Table 3:** Parameters of the linear regression for the NH3 price.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| [USD/t] | [bbl/t] | [MBtu/t] | [-] | [-] |
| −15.6096 | 0.9674 | −1.7087 | 0.9676 | 0.9365 |

* 1. Results

After having developed the ADL models for WTI, HH, and NH3, the ammonia price forecast tool can predict future ammonia price scenarios. For this purpose, an additional source of stochasticity is introduced in Eqs. (1), (2), and (3) by multiplying them by a random contribution term for each specific commodity.

 (4)

 (5)

 (6)

**Table 4:** Additional parameters from the linear regressions performed for WTI, HH, and NH3.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| [-] | [-] | [-] | [-] | [-] |
| −0.0113 | −0.0746 | 0.1424 | 0.2201 | 0.1081 |

Specifically,  and  (see Table 4) are the ith-component relative error’s standard deviation and mean, respectively, from the previous regression procedures. Conversely,  returns a random scalar drawn from the uniform distribution in the interval (−1,+1).

 

**B**

**A**



**C**

**Figure 4:** (Panel A) Future WTI price forecasts; (Panel B) Future HH price forecasts; (Panel C) Future NH3 price forecasts. All forecast periods span from January 2023 to January 2027.

Finally, 500 distinct scenarios were assessed to predict future ammonia prices. The forecast procedure was initialized in January 2023 (to allow the outcomes’ partial validation, since the prices up to September 2023 are already known to date) and carried out until January 2027. Figure 4 shows the results for all three components.

* 1. Discussion and conclusions

This paper showed a methodology aimed at forecasting ammonia price dynamics so that forthcoming feasibility studies of ammonia and fertilizer manufacturing plants may be more accurate and robust than if the conventional “discounting back approach” (*i.e.* all commodity and utilities prices kept constant over the entire timescale assessed) is considered. As it relies just on econometric considerations (*i.e.* it regards the price trends only), this criterion does not take into account economic real variables such as the supply-and-demand law. However, it copes better with medium- and long-term time horizons compared to more rigorous (but short-sighted) economic models.

Moreover, the whole procedure is pretty simple, being essentially based on linear regressions (ADL models are employed) which simply need as input data the historical prices of crude oil, natural gas (*i.e.* the reference components), and, of course, ammonia.

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