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Onur BOYABATLI
Singapore Management University, oboyabatli@smu.edu.sg

Dang Quang Nguyen
Singapore Management University, dqnguyen.2008@smu.edu.sg

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Capacity Management for Commodity Processors

Onur Boyabatli
Singapore Management University

Quang D. Nguyen
Singapore Management University
This paper studies the capacity investment portfolio of a commodity processor that uses a single primary input to produce two outputs in fixed proportions. The input and one of the outputs are commodities and are traded on the spot markets whereas the other output is a non-commodity product. The processing of input and each output require dedicated production capacities, and constitute to the capacity investment portfolio of the processor. The fixed proportions technology and commodity input-output features are relevant for several agricultural commodity markets. For example, in the palm industry, palm fresh fruit bunches are processed at palm oil mills to produce crude palm oil and palm kernel in fixed proportions. Both fresh fruit bunches and crude palm oil are commodities and are traded on the spot markets. Other relevant applications of the model in the agricultural business include, but not limited to the processing of corn to produce ethanol and animal feed and processing of soybean to produce soybean oil and soybean meal.

We model the processor’s capacity investment decision problem as a two-stage stochastic recourse problem. We assume that the processor has fixed contractual obligations to be satisfied (with penalties involved in case of shortage) in the output markets, and can source the input from its own plantation up to a fixed limit from a fixed price. In stage 1, the processor decides the capacity levels for input processing and output production with respect to input and output spot price uncertainties. We assume that the spot prices are correlated and follow a bivariate normal distribution. In stage 2, spot prices are realized, and the processor decides the input processing and output production levels within the capacity limits and the spot market activities for the input and the two outputs. In particular, the processor decides the volume of input to source from its own plantation, and from the spot market, the input processing level, the quantity of input to sell back to the spot market, the production quantity of each output, the amount of demand to satisfy for each output market, the volume of commodity output to source from and sell back to the spot market. There exist transaction costs in the input and output spot markets. The objective of the firm is to maximize the expected total profit at stage 1.
Our paper contributes to several streams of literature. As reviewed in Van Mieghem (2003), stochastic capacity investment literature analyzes the capacity investment portfolio of multi-product firms in a myriad of models. Different from these papers, we focus on a commodity processor that has access to input and output spot markets and has a fixed proportions production technology. The proportional input-output production technology is related to co-production systems where multiple outputs are produced simultaneously in a single production run with random proportions (Tomlin and Wang 2008). Different from this stream of papers, we assume a fixed proportions technology, but focus on capacity investment portfolio in the availability of spot markets. There is a vast literature on contracting in presence of spot markets. We refer readers to Boyabath et al. (2011) for a recent review. Closest to our work Dong et al. (2010) study the value of conversion flexibility of a multi-product firm where a high quality output can be converted in a low quality output. We do not allow output substitution. Our analysis is focused on determining the optimal capacity investment portfolio, and the impact on this portfolio of the spot price uncertainty (variability and correlation) and cost characteristics (capacity investment costs, production costs, spot transactions costs) as well as on the profitability of the commodity processors.

We solve for the optimal capacity investment portfolio in closed form. Our comparative statics analysis provides some rules of thumb for capacity management. For the impact of spot price uncertainty, we show that the processor benefits from a lower correlation between the input and output spot prices. This is because with a lower correlation, there will be a higher likelihood when the input spot price is low (high) that the output spot price will be high (low). When the input spot price is low, the processor can buy input at a cheaper price and, after processing, can sell the commodity output at a high price. When the input spot price is high, the processor optimally does not buy from spot (and indeed, may resell the input in the spot) and lower output spot price is less consequential. In short, low output spot price and high input spot price become less consequential with a lower correlation because of the increased likelihood of using available options upstream or downstream (or both). In a similar line of reasoning, we show that the processor also benefits from a high spot price variability.

For the impact of spot price uncertainty on the optimal capacity investment portfolio, we show that this impact critically depends on the profitability of non-commodity output market. When there are no transaction costs in the spot markets, we establish conditions under which a lower correlation or a higher variability decreases the optimal capacity investment portfolio. In these instances, the changes in these parameters induces the processor not to invest in non-commodity
capacity. Although the input and commodity output capacities increase with a lower correlation and a higher variability for a given non-commodity output capacity level, the drastic decrease in the latter may induce a lower input capacity level, which, in turn, induces a lower commodity output capacity investment level. Other than these boundary invest/no-invest decisions, we show that, in general, the impact of spot price uncertainty on the optimal capacity investment portfolio mimics the impact on the optimal expected profit: A lower correlation or a higher variability increases the capacity investment portfolio. We extend our results to the case with spot market transaction costs numerically by using a calibration based on a palm processor located in Southeast Asia.

For the impact of cost characteristics, we show that a local cost change in one of the output markets (such as a change in the production cost) propagates in the capacity portfolio and alters the capacity level for the input and the other output. As the input capacity investment level depends on both outputs, a change in one of the output markets alters the input market which, in turn, alters the other output market due to the fixed proportions technology.

References


