Crop Diversification in Agricultural Supply Chains

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1 Introduction

Supply uncertainty is a major challenge that agricultural supply chains face. Mainly due to climate effects, crop yields change from year to year. Yield uncertainty and price risk immensely affect farmers' decision making mechanism. In order to mitigate price risk, farmers can choose to plant more than one crop at the same time, which is referred to as intercropping. In this case, there is competition among crops for land and farmers calculate the optimal land allocation based on their anticipation of commodity prices. The allocation decisions, along with the realization of yields, in turn affect the total supply of various crops and hence the commodity prices. This circular feedback mechanism between the supply of commodities and commodity prices generates the need to fully understand farmers' decision making mechanism when evaluating the performance of agricultural supply chains.

All the parties along the agricultural supply chain are immensely affected by yield uncertainty. This paper aims to clarify how different crop options with different yields affect the profits of farmers and buyers. We study the effect of multiple crop options on operational decisions along the agricultural supply chain. Flexibility of intercropping can be of great importance for the durability of a farmer's operations. Especially for small farmers, it is essential to guarantee a certain amount of cash flow in order to maintain their daily needs as well as the farming business. Hence, intercropping serves as a tool to mitigate the risk involved in their cash flow stream. This brings out the need to better understand what kinds of crops bring the highest revenue and lowest risk when planted at the same time and what conditions make intercropping beneficial. We aim to investigate these questions by allowing for correlation in the yields of the crops that are available to the farmer.

We first explore the benchmark case where the farmer has only one crop option and the flexibility to ration capacity. The question of whether it is better for the farmer to cultivate a second crop instead of leaving the excess land bare is studied next. We study the effects of having the second crop option on the optimal allocation of the base crop and also the effect of yield uncertainty on buyers' profits. We then move

on to the more general case where the farmer has two crop options with the flexibility of capacity rationing and study the characteristics of the optimal land allocation.

2 The Setting

We model an agricultural supply chain using a representative buyer for each commodity and a representative farmer. This setting is then relaxed by allowing for multiple farmers and a continuum of farmers. For analytical simplicity, we focus on the case where the farmer has two crop options. It is assumed that buyers source commodities from the farmer through the spot market and convert them into the final product with a one-to-one relationship. Each buyer can only procure one commodity. Both the buyers and the farmer are assumed to be risk neutral. Buyers face a consumer demand that has a uniform distribution in the retail market, which allows us to study a linear demand curve in the spot market. Linear demand curves are widely used in the literature for tractability purposes. In our setting, buyers procure only from the spot market and spot prices are pinned down endogenously by the market clearing condition. The farmer faces random yield in both crops and the yields are correlated. When studying yield uncertainty in both crops, we mainly focus on the correlation in yields caused by climate effects. We implement a setting that allows us to compare different crops based on their resistance to bad weather conditions. This structure enables us to see which crops benefit the farmer the most when intercropped with the base crop.

The timeline of events is given as follows. In period 1, the farmer make allocation decisions. In period 2, yields are realized and buyers source commodities from the spot market. In period 3, consumer demand for the final product is realized. We characterize the optimal allocation strategy for the farmer and interpret its outcomes on buyers' profits. We then study the value of having the second crop option. The cases with multiple farmers and a continuum of farmers are also explored.

3 Summary of Results

We first derive the optimal allocation in the benchmark case where the farmer has only one crop option with the flexibility of capacity rationing. We find that if the capacity is large enough, the farmer strategically leaves some portion of the land bare in order achieve the maximum profit. The solution is then extended to the case where the farmer has two crop options with the capacity exhaustion restriction, which allows us to study the conditions where the second crop is valuable enough so that the farmer chooses to plant it instead of leaving the excess land bare. It is shown that the effect of the introduction of the second crop option on

the optimal land allocated to the base crop can be positive or negative depending on how the second crop performs compared to the base crop in adverse climate conditions. We find that even if the second crop is superior to the base crop in terms of yield, in order to prevent spot prices from decreasing, the farmer may choose to keep the supply of the second commodity under a certain level, hence increasing the land allocated to the base crop. We also find that the production quantity of a commodity is decreasing in the variability of the yield and increasing in the yield variability of the alternatives. As a result, buyers are better off when the alternative commodity has high yield variability since this allows them to enjoy higher supply and lower spot prices. An interesting finding is that under certain conditions, buyers' profits are increasing in the yield variability of the commodity they demand.

When the farmer's profit in the benchmark case is compared against the case with two crop options along with the capacity exhaustion restriction, it is seen that the latter is not always better than the former. Due to endogeneity of spot prices, the farmer may value the capacity rationing flexibility more than the availability of the second crop option. Hence, the farmer may prefer to strategically plant the base crop and leave the excess land bare rather than planting the second crop on the excess land even if the expected yield of the second crop is higher than the base crop. Even if the farmer optimizes allocation between the two crops, if he/she does not have the flexibility to ration capacity, he may be worse off than having only one crop option. It is known that leaving land bare has year-to-year benefits for the farmer since the minerals in the land recover during that period. However, we show that, even in a single shot game, the farmers may benefit from strategically leaving some portion of the land bare due to the pricing effect.

The more general case where the farmer has two crop options along with the flexibility of capacity rationing is then studied. In this case, if the capacity is scarce, the farmer optimally uses up all the capacity and depending on how crop yields compare to each other, he/she might choose to plant one or both of the crops. When the capacity is abundant, the farmer strategically leaves excess land bare. We then relax the representative farmer assumption and investigate the cases with multiple farmers and a continuum of farmers. In the case with multiple farmers, when the capacity is scarce, there is over production of the more valuable commodity compared to the efficient solution. Moreover, when there is abundant capacity, over production occurs for both of the commodities. The solution with a continuum of farmers is on the other hand the limit of the solution with multiple farmers.