How Are HuRLOs™ Priced?

<u>INTRODUCTION</u>

HuRLOs™ — Hurricane Risk Landfall Options™ — are commodity options that will allow market participants to hedge against or speculate on the risk that any hurricane will make landfall on the Atlantic or Gulf coasts of the U.S. that meets the damage threshold (explained below) and, if so, where that landfall will first occur. In 2010, seventy-five different HuRLOs will be available in three Series for mock-demonstration trading. Seventy-four HuRLOs in each series correspond to a hurricane making landfall first in a specific coastal county or region that meets the damage threshold and one HuRLO in each series, called the "No Landfall" HuRLO, represents the event that no next hurricane makes landfall in the enumerated U.S. coastal counties or regions for the rest of the calendar year, or that landfalling hurricanes do not meet the damage threshold. Each series corresponds to a different hurricane making landfall on the U.S. Atlantic or Gulf coasts that meets the damage threshold, if any. The damage threshold is the minimum amount of total economic damage a landfalling hurricane is estimated to have caused in the county or region that experienced landfall first, as estimated by Eqecat, Inc., necessary for the HuRLOs for the particular landfall location to be subject to automatic exercise and settlement. The damage threshold for each hurricane in its landfall location is $1,000,000.00.

When a hurricane makes landfall first in one of the seventy-four coastal counties or regions, that landfall will trigger automatic exercise and settlement of the applicable HuRLOs if the damage threshold is met. If no hurricanes make landfall in any of the enumerated U.S. coastal counties or regions for the balance of the current year, or the landfalling hurricanes do not meet the damage threshold, the "No Landfall" HuRLOs will be subject to automatic exercise and settlement.

The premiums collected from HuRLO purchases are aggregated into a Mutualized Risk Pool (MRP) for each HuRLO Series, to be allocated among holders of the HuRLOs for the coastal county or region where a hurricane makes first landfall, or holders of the No Landfall HuRLOs if no next hurricane makes U.S. landfall in the current calendar year (or the landfalling hurricanes do not meet the damage threshold).

Unlike with traditional weather derivatives, HuRLO market participants will not need to find a counterparty to take the other side of the commodity contract in the primary market. Market participants who have purchased a HuRLO will be able to sell that HuRLO in the secondary market to other market participants at an agreed upon price. No short sales will be allowed. The following discusses how HuRLO prices are determined in the primary market.

<u>HOW HuRLOs ARE PRICED IN THE PRIMARY MARKET</u>

HuRLO prices in a given series are based on the calculations of an adaptive control algorithm, which tracks changes in market probabilities π_t^i for each outcome

(coastal segment, or No Landfall), *i*, based on the buying behavior of the market participants in each HuRLO Series. Prices P_t for outcome *i* at any given time *t* are proportional to these probabilities, including a time-value-of-money adjustment that equalizes prices for purchases that may be made months apart:

$$P_t^i = \pi_t^i \times c \exp[rj/365] \qquad .$$ (1)

Here *c* is a constant defining the overall magnitude for prices and settlements in the HuRLO markets ("par" value, which will be $1,000), *r* is an annualized interest rate, and *j* is the number of days since the market opened for the current season.

The key element of price determination in Equation 1 are the HuRLO market (i.e., pricing) probabilities π_t^i. At any given time *t* these reflect the probabilities for each of the 75 HuRLO outcomes in a particular Series, as judged in aggregate by market participants. Following the purchase of each additional new HuRLO in a particular HuRLO Series, the prices for all 75 HuRLOs in such series are recalculated to reflect a larger market probability for the outcome, *i*, that has just been purchased. Because the probabilities for all outcomes must sum to 1 in each HuRLO Series, market probabilities for the 74 outcomes that were not purchased in the most recent transaction are decreased proportionally in the applicable HuRLO Series.

These probability (and, therefore, pricing) calculations are repeated after the purchase of each additional HuRLO. So, for example, if a block of 100 HuRLOs were ordered for a county *i*, the repricing calculations would be iterated 100 times during the order-filling process. The result would be that each of the 100 HuRLOs in this block would cost slightly more than the previous HuRLO purchased in the block — the demand for HuRLOs in county *i* would progressively increase the price of subsequent HuRLOs in this county while depressing prices for the options in the remaining 74 outcomes in the particular HuRLO Series. Prices will move more quickly for a given level of buying activity when the market is comparatively thin (the MRP is relatively small), and will move more slowly when the market is comparatively well developed (the MRP is relatively large).

The probability updating procedure used to determine pricing is a stochastic approximation algorithm [1], although the specific equations used in the HuRLO markets represent a new member of this class of algorithms. We have derived mathematical proofs that demonstrate convergence of the pricing probabilities to the consensus of market participants' probabilities for the outcomes, under various assumptions about investor behavior. That is, the adaptive control algorithm for updating the pricing probabilities automatically *learns* investors' probabilities for the outcomes in response to their collective actions in the market.

MARKET INITIALIZATION

HuRLO markets are "seeded" with an initial stake in the MRP for each HuRLO Series. In return for this initial investment, the seeding institution receives HuRLOs in

each of the 75 outcomes in each HuRLO Series. Because there is not yet a market probability for each of these 75 outcomes, prices for the initial stake are allocated according to historical (i.e., climatological) probabilities, π^i_0, reflecting the historical risks. The result is that the initial number of HuRLOs in each outcome is equal, and given by
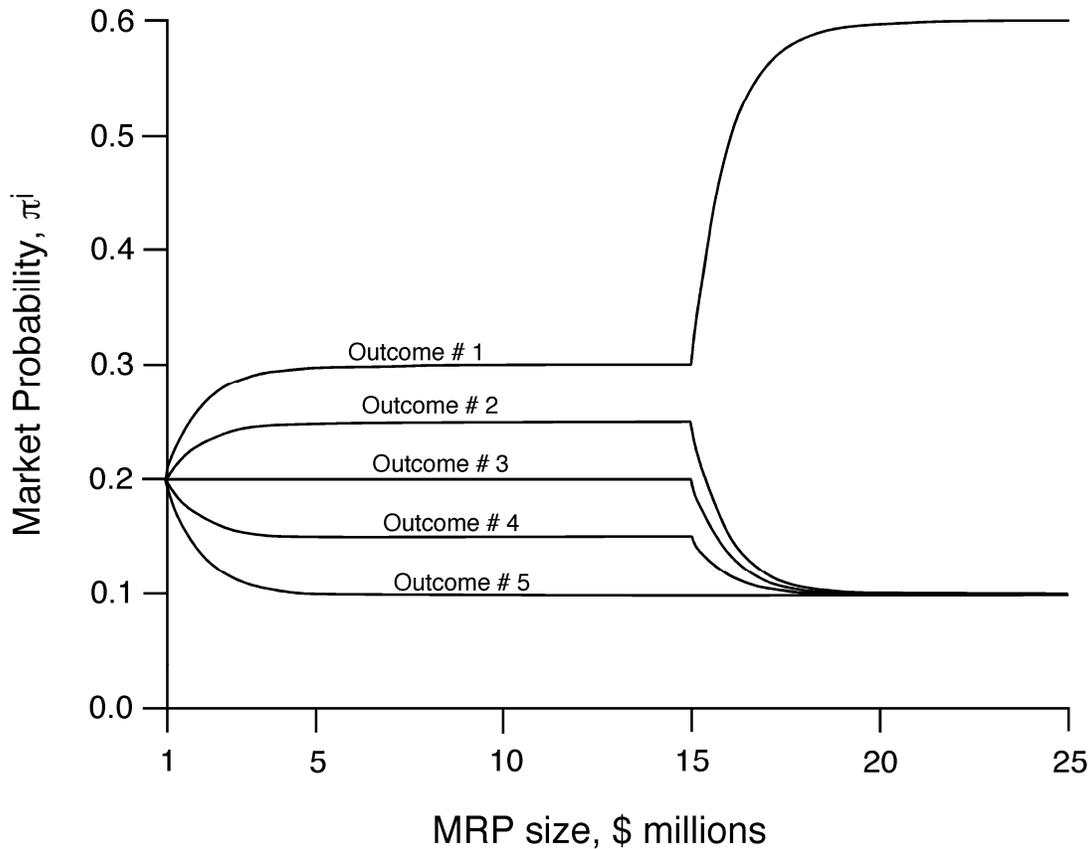
$$ n^i_0 = \frac{MRP_0}{c} \quad . \tag{2} $$

For example, if the MRP for one HuRLO Series is seeded initially with MRP_0 = $1,000,000, and c = $1,000, then that HuRLO market begins with n^i_0 = 1000 HuRLOs in each outcome i. This allocation follows from Equation 1, with $j = 0$.

AN IDEALIZED EXAMPLE

The figure illustrates the capacity of the adaptive control pricing algorithm to converge to market participants' beliefs about the outcome probabilities, as revealed by their buying activity. Here the initial MRP is $1,000,000 and par is $1,000, as above. Only five outcomes have been defined for this hypothetical market. The initial probability assessment (by the market seeder) is that all five of these outcomes are equally likely, as indicated on the graph for MRP_0 = $1,000,000.

The market participants do not agree that all the outcomes are equally likely, and instead they invest money in proportion to the following probabilities for HuRLO outcomes 1 through 5, respectively: 0.30, 0.25, 0.20, 0.15, and 0.10. Driven by this buying behavior, the pricing probabilities promptly move from their initial values toward the participants' beliefs, and the convergence is essentially complete after approximately $3,000,000 of participant investment in the market. This investment pattern continues until MRP = $15,000,000, at which time new information becomes available that indicates the probability for HuRLO outcome #1 is 0.6, and the probabilities for the remaining outcomes are all 0.1. From this point forward 60% of the new money coming into the market is invested in options for HuRLO outcome #1, with the remainder split equally among the other four outcomes. Again the market responds promptly, and the pricing probabilities have essentially converged to the participants' beliefs after an additional $3,000,000 has been invested.

Market Probability, π^i

0.6

0.5

0.4

0.3 Outcome # 1

Outcome # 2

0.2 Outcome # 3

Outcome # 4

0.1 Outcome # 5

0.0

1   5   10   15   20   25

MRP size, $ millions

SOME MISCELANEOUS SPECIAL RULES

Minimum settlement. If buying becomes very concentrated in one or a few HuRLO outcomes before the MRP has accumulated sufficient liquidity, settlements for HuRLOs in that outcome may be diluted. Dilution is not allowed to exceed a percentage of par, which will be 60%, or $600, in 2010. If an additional HuRLO purchase would drive the potential settlement below this level, the price for that HuRLO is increased, to cover the minimum settlement.

Minimum pricing probability. To ensure numerical stability, pricing probabilities are not allowed to fall below 0.0001. Accordingly, the minimum HuRLO price is 0.0001 c, or $0.10 if c = $1,000.

REFERENCE

[1] H.J. Kushner and G.G. Yin. *Stochastic Approximation and Recursive Algorithms and Applications.* Springer-Verlag, 2003.