MONTY-HALL THEOREM
:
BAYES-PRICE RULE (BAYES THEOREM) FOR A THREE PARAMETER EVENT SPACE

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ABSTRACT

This research report presents the statement of the Monty-Hall Theorem and provides a constructive proof by solving the *classical* Monty-Hall Problem. It establishes the fact that the probability of winning the prize is indeed unaffected by a *switched-choice* – very much unlike the most prevalent and widely accepted position held by the Leading Subject-Matter-Experts.

Keywords: Monty-Hall Theorem; Bayes-Price Rule; Bayes Theorem

AMS MSC Mathematics Subject Classification: 60A99; 60C99; 62A99; 62C99.

1. INTRODUCTION

The *classical* "Monty-Hall Problem", also referred to as the "Three-Door Problem" is based on a game show "Let's Make a Deal" wherein the host reveals a losing choice to the guest, who had earlier made an initial choice, and in turn offers the guest an enticing option to switch from the initial choice to a second available choice with an aim to enhance the chances of winning the prize. The most prevalent & widely accepted position, as reported in literature, among the leading Subject-Matter-Experts, mathematicians, statisticians, logicians, and rational intellectuals, is that an appropriate detailed study & analysis of the scenario using the well accepted standard approach of Probability & Statistics, would lead to a recommendation to the guest to switch to the second available choice based on the knowledge obtained from the host revealing a losing choice.

We present the statement of our newly formulated Monty-Hall Theorem, and provide a constructive proof by solving the *classical* Monty-Hall Problem. It establishes that the probability of the guest winning the prize is indeed 1/2 irrespective of whether the guest stays with the initial choice or goes for a switched choice after gathering the information from the host who reveals a losing choice.

2. PROBLEM DESCRIPTION - INPUT DATA

Let us consider the so-called *classical* Monty-Hall Problem as reported widely in the literature - with a prize hidden behind one of the three doors; a guest making an initial choice of a door to claim the prize; the host who knows the location of the prize as well as the initial choice made by the guest, now *reveals a distinctly different and yet a losing choice*, by opening a third door. Then the host also offers the guest, an option to switch from the initial choice to the now available second choice, anticipating an enhanced chance of winning the prize, based on the knowledge obtained about a losing choice.

Let us represent the events/actions associated with the three doors:
(1) let xr $\in$ {1,2,3} be the door r behind which the prize x is hidden;
(2) let yp $\in$ {1,2,3} be the initial choice of the door p chosen by the guest y;
(3) let zq $\in$ {1,2,3} be the door q opened by the host z to reveal a losing choice.

Let the symbol 'ai' denote the event/action [E{(a=i)}] for any 'agent' a $\in$ {x,y,z} and 'door' i$\in${r,p,q}={1,2,3}.

It is essential to note here that xr and yp are mutually independent of each other as well as independent of zq; whereas zq itself is dependent on both xr and yp, as per the rules of the game. Also, note that the focus must be on the decision-making process & the action to be taken by the guest. So, the *problem formulation* (*modelling*) must necessarily be from the view-point of the guest.

3. ASSUMPTIONS

It is assumed that the prize is hidden randomly behind one of the three doors, each of the events [xr$\in${1,2,3}] being considered equiprobable. Also, the initial choice of the door [yp$\in${1,2,3}] chosen by the guest is also a random (blind) choice.

The host knows the door behind which the prize is hidden and also the door that is the initial choice of the guest. Therefore, the event/action of the host z opening door q, zq$\in${1,2,3} to show a losing choice, is dependent on both yp and xr, as per the rules of the game show. That is, (zq ≠ yp) & (zq ≠ xr). This dependency of zq on yp and xr does indeed limit the available options. It turns out that when yp ≠ xr the host doesn't have any option except to turn to the one and only one remaining door zq ≠ (yp ≠ xr); whereas when yp = xr the host has the option of choosing between the two doors, that is, zq ≠ (yp = xr). Because the host has this option, at least in a restricted sense, of choosing which of the two doors to open, it introduces an uncertainty for the guest to predict/expect/anticipate the host's decision/action in this regard. Here, it is *assumed* that whenever zq ≠ (yp = xr) the host's choice between the two available options is indeed *equiprobable*.

Table-1 lists the 12 mutually-exclusive together-exhaustive possible alternatives for the combined-triple-event space along with the relevant apriori probabilities.

Sl.No.	[xr]	[yp]	[xr&yp]	[zq]	[xr&yp&zq]		P[xr]	P[yp]	P[zq | (xr & yp)]	P[xr&yp&zq]
01	1	1	11	2	112		1/3	1/3	1/2	1/18
02	1	1	11	3	113		1/3	1/3	1/2	1/18
03	1	2	12	3	123		1/3	1/3	1	1/9
04	1	3	13	2	132		1/3	1/3	1	1/9
05	2	1	21	3	213		1/3	1/3	1	1/9
06	2	2	22	1	221		1/3	1/3	1/2	1/18
07	2	2	22	3	223		1/3	1/3	1/2	1/18
08	2	3	23	1	231		1/3	1/3	1	1/9
09	3	1	31	2	312		1/3	1/3	1	1/9
10	3	2	32	1	321		1/3	1/3	1	1/9
11	3	3	33	1	331		1/3	1/3	1/2	1/18
12	3	3	33	2	332		1/3	1/3	1/2	1/18

Table-1: Twelve *combined-triplet-event* possibilities along with its *joint-probabilities*.

[xr]: prize x behind door r; [yp]: guest y choses door p; [zq]: host z reveals door q

Twelve Mutually-Exclusive Together-Exhaustive Alternative-Possibilities

4. MONTY-HALL THEOREM : *CLASSICAL MONTY-HALL PROBLEM*

Given that the initial choice of the guest is, say door-1 (event [y1]); and that the host opens the door, say door-3 (event [z3]) to reveal a losing choice, that is different from the door behind which the prize is hidden, and also different from the initial choice of the guest; then the probability of the guest winning the prize is given by the *aposteriori* (conditional to [z3]) *probability* of the prize being hidden behind the door-1 (event [x1]); that is, P[x1 **|** z3]. In the case of the *classical* Monty-Hall Problem, this value may be computed by the application of the *Bayes-Price Rule* (*Bayes Theorem*) for the case of *three parameter event(sample)space*; and it is equal to 0.50 - therefore the option of the switched choice doesn't yield any enhancement in the chances of winning the prize.

PROOF

The proof is simply by solving the problem, following the below enumerated steps.

For each required value, a general expression is given first; followed by the *classical* case.

(1) INPUT DATA

P[x1]; P[x2]; P[x3]; P[y1]; P[y2]; P[y3];
P[z3 | x1y1]; P[z3 | x1y2]; P[z3 | x2y1]; P[z3 | x2y2];
P[z2 | x1y1]; P[z2 | x1y3]; P[z2 | x3y1]; P[z2 | x3y3];
P[z1 | x2y2]; P[z1 | x2y3]; P[z1 | x3y2]; P[z1 | x3y3];

(2) JOINT PROBABILITIES FOR INDEPENDENT EVENTS [xr & yp]

P[x1y1] = P[x1]*P[y1]; P[x1y2] = P[x1]*P[y2]; P[x1y3] = P[x1]*P[y3];
P[x2y1] = P[x2]*P[y1]; P[x2y2] = P[x2]*P[y2]; P[x2y3] = P[x2]*P[y3];
P[x3y1] = P[x3]*P[y1]; P[x3y2] = P[x3]*P[y2]; P[x3y3] = P[x3]*P[y3];

(3) VALIDITY CHECK FOR NON-ZERO APRIORI PROBABILITIES

Check and confirm the *validity of input data values* for application of Bayes-Price Rule (Bayes Theorem). The presence of *zero-value* for any of the *apriori probabilities* leading to the intended conditional used to derive the required *aposteriori* (*conditional*) *probabilities*, can result in *spurious results*. Appropriate alternative approach may be needed in such cases. For the *classical* Monty-Hall Problem, the *joint probabilities* listed above leading to the required conditionality of the host opening a door (say z3) will be used in the below calculations.

(4) APRIORI PROBABILITY FOR [z3] AS PER THE RULES OF THE GAME

P[z3] = P[z3 | x1y1]*P[x1y1] + P[z3 | x2y1]*P[x2y1] + P[z3 | x1y2]*P[x1y2] + P[z3 | x2y2]*P[x2y2];
= P[x1y1z3] + P[x1y2z3] + P[x2y1z3] + P[x2y2z3];
= 1/18 + 1/9 + 1/9 + 1/18;
= 1/3;

(5) APRIORI CONDITIONAL (w.r.t. x1) MARGINAL (w.r.t. yp) PROBABILITY FOR z3

P[z3 | x1] = (P[z3 | x1y1] * P[x1y1] + P[z3 | x1y2] * P[x1y2]) / (P[x1]);
= (P[z3x1y1] + P[z3x1y2]) / (P[x1]);
= (1/18 + 1/9) / (1/3);
= 1/2;

(6) APOSTERIORI CONDITIONAL (w.r.t. z3) MARGINAL (w.r.t. yp) PROBABILITY FOR x1

P[x1 | z3] = (P[z3 | x1] * P[x1]) / (P[z3]);
= (1/2 * 1/3) / (1/3);
= 1/2;

END OF PROOF

5. DISCUSSION

It is to be noted here that the theorem and the proof uses some specific labels for the doors, just for convenience; namely, door-3 [z3] for the door opened by the host to reveal a losing choice, and door-1 [y1] for the guest's initial choice, thus leading to a decision making problem for the guest that requires the computation of the value P[x1 | z3] and its complementary value P[x2 | z3]. However, the result is neither restricted by nor dependent on these specific labels. This is evident from the symmetry in the data entries in Table-1, which shows that xr and yp are interchangeable for any given zq, and that the entries are identical for the three subsets corresponding to each of the values for zq $\in$ {1,2,3}. Or, if one wishes, one can re-write the theorem in three parts, one corresponding to each of the cases with the host opening a door zq $\in$ {1,2,3}.

Also, one can always consider a scenario wherein the three doors are exactly identical from the viewpoint of the guest, and that the initial choice of the guest is then labelled as door-1, and that the door that is opened by the host is then labelled as door-3, thus leaving the remaining door to be labelled as door-2. Therefore, it gets established that *irrespective of whichever be the door opened by the host, each of the remaining two doors have equal probability of having the prize hidden behind it*.

6. EARLIER ERRONEOUS RESULT

The Monty-Hall Theorem reaffirms common-sense based rational & intellectual reasoning, confirmed by the results obtained through the computations shown in the proof. Note that the Monty-Hall Problem is not a problem with possibly multiple correct solutions. Therefore, the above theorem indirectly points out the erroneous result that has been the widely accepted position by the Leading Subject Matter Experts who claim that a switched choice has a clear advantage, with the chances of winning the prize being 2/3 as against only 1/3 for staying with the initial choice.

There seems to be various approaches adopted by the Leading Subject Matter Experts, to derive the very same erroneous result. Almost all of them are centered around the use (rather the erroneous use) of the four apriori probabilities: (1) P[z3x1y1]; (2) P[z3x2y1]; (3) P[z3x1y2]; (4) P[z3x2y2]; leading to the intended conditional [z3] that is supposed to be used appropriately to derive the required *aposteriori* (*conditional*) *probabilities*: P[x1 | z3] to be compared with P[x2 | z3] in the decision-making problem faced by the guest.

Some consider only the two apriori terms (1) & (2) while leaving out (*error of omission*) the other two terms (3) & (4) mentioned above; as-if fixing [z3y1] as the conditionality rather than [z3]; and derive the aposteriori probabilities: P[x1 | z3y1] to be compared with P[x2 | z3y1] - only to recommend a switched choice from [y1] to [y2] – which in itself is indeed a serious *Logical Fallacy*. This is exactly similar to the physical analogy of chasing the proverbial mirage-waters, wherein that perception itself vanishes, since the very conditions that caused such a perception are violated (no more valid) by the very action of moving towards it.

Some others seem to go wrong in their application of the Bayes-Price Rule (Bayes Theorem) - *error of commission* - in a situation with zero value associated with apriori probabilities P[y2] & P[y3] - as-if fixing [y1] as a pre-condition – an issue of concern that has been clearly mentioned in the above proof while *insisting on a check for the validity of input data* before further processing to derive aposteriori (conditional to [z3]) probabilities.

One of the most striking errors is the claim that the chances of winning by staying with the initial choice is given by (P[x1y1z2]+P[x1y1z3]) whereas the chances of winning by a switched choice is given by (P[x1y2z3]+P[x1y3z2]) as-if fixing [x1] as a pre-condition while not taking advantage of the additional knowledge gained from the host opening the door [z3] revealing a losing choice!

Similarly, another equally intriguing approach adopted by some others is to compare (P[x1y1z3]+P[x2y2z3]) with (P[x1y2z3]+P[x2y1z3]) while correctly considering [z3] as the aposteriori condition although not updating the required probabilities for evaluation & comparison of the two possible alternatives [y1] & [y2] available for the guest!

We are amazed as to how these approaches can be justified by either any rational intellectual reasoning or any theory based on the fundamentals of Probability & Statistics. This is indeed an atypical case of *erroneous mathematical formulation* of the problem giving rise to an *erroneous model*, and/or even possibly some erroneous problem solving leading to *erroneous results*, further confirmed (!?!) by *erroneous computer simulation* etc. involving the Leading Subject Matter Experts who are expected to warn us from such misleading possibilities.

7. A CHALLENGE TO THE LEADING SUBJECT MATTER EXPERTS

Let us rephrase the Monty-Hall Problem, now adorned with a *jewel-on-the-crown* as below:

(1.1) The prize is hidden behind one of the three doors.
(1.2) I the guest make an initial choice of which door it could be, say door-1, to claim my prize.
(1.3) Then Monty the host opens a different door, say door-3, revealing a losing choice.
(2.1) I am given an option to withdraw/cancel the earlier choice of door-1 and switch to door-2.
(2.2) I appreciate the knowledge of a losing choice and also Monty's offer of the option to switch.
(3.1) I grab Monty's offer, withdraw/cancel my earlier choice of door-1.
(3.2) Then I re-evaluate the two choices available for me now, namely door-1 or door-2.
(3.3) I find that the chances of winning are exactly the same between the two available choices;
(4.1) Now that YOU enter the Hall, I seek YOUR recommendation. What is YOUR recommendation?
(4.2) TO SWITCH OR NOT TO SWITCH : THAT IS THE QUESTION!

Note that your answer must necessarily be independent of my initial-choice; although Monty's choice of opening a door to reveal a losing choice was dependent on my initial choice which he had to avoid as per the rules of the game. Hope your expert advice is *NEITHER* an exemplification of a well-known proverb "*the grass is always greener on the other side*" *NOR* any enticement to chase the proverbial mirage-waters wherein that perception itself vanishes, since the very conditions that caused such a perception are violated by the very action of moving towards it.

8. COOL-HEADED BRAVE-HEARTS PLAY WITH STRATEGIST HOST

This is somewhat *far from the so-called classical version* of the Monty-Hall Problem, wherein we allow the host to exercise whatever '*strategic game-playing*' that one wishes to play with the guest. The situation can be captured by the terms P[z3 | x1 & y1] and P[z3 | x2 & y2] that are fully under the control of the host. An extreme situation is when the host adopts a certain strategy that pulls down one of them to zero and pushes the other one to its maximum value of the restricted probability, namely 1/9. Then it turns out that the values of the two aposteriori(conditional) marginal probabilities P[x1 | z3] and P[x2 | z3] can't be the same anymore; in the *extreme case*, one will be 1/3 and the other will be 2/3; which then may lead to the two possibilities: One extreme case with a *specific strategy* wherein a *switched choice has a clear disadvantage*; and a second extreme case with a *specific strategy* wherein a *switched choice has a clear advantage*. This topic is *beyond the scope of the present paper*. It was left (refer: [12]) as an exercise to the cool-headed brave-hearts to figure out the two specific strategies that would lead to such extreme situations. To close this issue once for all, let us present the Monty-Hall Theorem for the case of strategist-host.

9. MONTY-HALL THEOREM : *STRATEGIST HOST*

There does not exist any strategy that can be adopted by a strategist-host in the Monty-Hall Problem, that would result in a situation wherein a *switched-choice* will *always* (*irrespective of the placement of the prize* and *irrespective of the initial-choice of the guest*) lead to an enhancement/diminishment in the chances of winning the prize.

The proof is left to the cool-headed brave-hearts. It is worth noting that this general version of the Monty-Hall Theorem subsumes the earlier specialized version for the classical case wherein the host randomly chooses between the two available doors to reveal a losing choice.

Note that there are *eight distinctly different possible extreme strategies* that can be adopted by a strategist-host in the Monty-Hall Problem; corresponding to the three situations that provide an option for the host to open one of the two available alternative doors to reveal a losing choice to the guest. That is, whenever the initial choice of the guest matches with the door behind which the prize is hidden, the host can open one specific chosen door from among the other two doors, each of which is a losing choice. Therefore, we can identify each of these eight distinct strategies by a *uniquely characteristic signature label* {x1y1zu, x2y2zv, x3y3zw} where $u \in \{2,3\}$; $v \in \{3,1\}$; $w \in \{1,2\}$; or simply by an equivalent label {11u22v33w}.

Referring back to Table-1, strategy S1 corresponds to the scenario that includes each of the three combined-triple-events [x1y1z3] and [x2y2z3] and [x3y3z1] with the joint probability of 1/9 for each of them, whereas the associated three combined-triple-events [x1y1z2] and [x2y2z1] and [x3y3z2] are eliminated from consideration; while the remaining six combined-triple-events [x1y2z3] and [x2y1z3] and [x1y3z2] and [x3y1z2] and [x2y3z1] and [x3y2z1] remain as such with the joint probability of 1/9 for each of them. It is exactly the same as deriving an Input Data Table S1 for the strategy S1 by appropriately eliminating the unwanted three rows from Table-1 and updating the joint probabilities for each of their corresponding complementary combined-triple-events therein. Similarly, we can derive the Input Data Table for each of the eight strategies mentioned above, using which the *required computations* can be carried out similar to what is presented in Section-4 for the proof of the Monty-Hall Theorem. The proof for this theorem (Monty-Hall Theorem : *Strategist-Host*) is exactly similar to that for the above theorem (Monty-Hall Theorem : *Classical Monty-Hall Problem*) wherein each of the eight strategies is associated with these modified Input Data Table entries.

Table-2 summarizes the results of the computations for each of these eight strategies, giving the probability of the prize being hidden behind one of the two doors corresponding to the case wherein the host reveals a losing choice.

Sl.No.	STRATEGY LABEL	P[x1|z3]	P[x2|z3]	P[x2|z1]	P[x3|z1]	P[x1|z2]	P[x3|z2]
S1	{113223331}	1/2	1/2	1/3	2/3	1/2	1/2
S2	{113223332}	1/2	1/2	1/2	1/2	1/3	2/3
S3	{113221331}	2/3	1/3	1/2	1/2	1/2	1/2
S4	{113221332}	2/3	1/3	2/3	1/3	1/3	2/3
S5	{112223331}	1/3	2/3	1/3	2/3	2/3	1/3
S6	{112223332}	1/3	2/3	1/2	1/2	1/2	1/2
S7	{112221331}	1/2	1/2	1/2	1/2	2/3	1/3
S8	{112221332}	1/2	1/2	2/3	1/3	1/2	1/2

Table-2: Eight Extreme Strategies -
each with three pairs of aposteriori probabilities for comparison

The symmetry in the results as shown in Table-2 above is indeed very intriguing.

Note that Table-2 presents three pairs of values for aposteriori probabilities comparison corresponding to each of the eight strategies, thus having a total of 24 pairs of values for comparison. For six of the eight strategies, there are two pairs of values (1/2, 1/2) and one pair of values (2/3, 1/3). The two pairs (1/2, 1/2) indicate the two scenarios wherein a switched-choice doesn't affect the chances of winning the prize; whereas the one pair (2/3, 1/3) indicates a scenario wherein a switched-choice affects the chances of winning the prize - an enhancement from 1/3 to 2/3 or a diminishment from 2/3 to 1/3 based on the initial-choice of the guest. For the two strategies S4 & S5, there are three pairs of values (2/3, 1/3).

Corresponding to each scenario of an enhancement there is a complementary scenario of diminishment, and these are distributed symmetrically among the eight distinctly different extreme strategies as can be observed from the Table entries.

For example, in strategy S1 since P[x2 | z1] is 1/3 and P[x3 | z1] is 2/3 it is clear that if the initial-choice is door-2 [y2] then a switched-choice [y3] yields an enhancement in the chances of winning the prize, whereas if the initial-choice is door-3 [y3] then a switched-choice [y2] yields a diminishment in the chances of winning the prize.

Therefore, it is established that there is no strategy which presents any scenario wherein a switched-choice *always* (*irrespective of the placement of the prize* and *irrespective of the initial-choice of the guest*) yields a clear advantage or a clear disadvantage (enhancement or diminishment) in the chances of winning the prize.

10. CONCLUSION

The Monty-Hall Theorem establishes the correct approach in formulating and solving the *classical* Monty-Hall Problem. It establishes the fact that the probability of winning the prize is indeed unaffected by a switched choice.

The most prevalent and widely accepted position held by the Leading Subject Matter Experts seems to have arisen from either some *erroneous problem formulation* giving rise to an *erroneous mathematical model* and/or *erroneous problem-solving approach*, possibly also riddled with some *Logical Fallacy*, leading to an *erroneous result*, that seems to have been justified by some *erroneous computer simulation* studies, etc.

The clearly partitioned *triple-event* space, with the twelve *mutually-exclusive together-exhaustive* possible alternatives, as represented in the Table, is a fail-safe framework to study, analyze & solve the problem – no possibility of missing any relevant (and/or including any irrelevant) component terms while going through the required calculations in order to derive whatever desired results.

11. RECOMMENDED READING

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12. ACKNOWLEDGEMENT

Let us acknowledge that, looking back, it seems as if Marilyn cast an enchantingly deep spell over the Frequentists who in turn pushed the Probabilists to mistake Bayes-Price, paying the price through errors of commission and/or errors of omission, riddled with some Logical Fallacy as well. We need to come out of that long drawn intellectual hibernation of over six decades, and wake up to reality.

I must necessarily confess here that the *core idea behind this analysis is so stunningly & elusively simple*, that one may simply be taken aback in a profound wonder-struck jaw-drop-silence, maybe

with an after-thought: "*oh my goodness, how could it be that it never flashed on me any time earlier*"! as was also the case in an earlier research work reported in [13] by this author.

On this most auspicious vidyaa(vijaya)daSami day [2025OCT02] I was blessed with the vision to formulate the *Monty-Hall Theorem* and its *proof* - as a *concise* & *precise* approach - the preferred style of presentation for the target audience consisting of Mathematicians, Statisticians, Logicians, eminent scientists etc.

13. DEDICATION

To my ಅಜ್ಜ(ajja) Karinja Halemane Keshava Bhat & ಅಜ್ಜಿ(ajji) Thirumaleshwari, ಅಪ್ಪ(appa) Shama Bhat & ಅಮ್ಮ(amma) Thirumaleshwari, for their *teachings through love*, that *quality matters more than quantity*; to my wife Vijayalakshmi for her *ever consistent love & support*; to my daughter Sriwidya.Bharati and my twin sons Sriwidya.Ramana & Sriwidya.Prawina for their *love & affection*.

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To all the *cool-headed brave-hearts*, eagerly awaited but probably yet to be visible among the world professionals, especially the *Subject-Matter-Experts*, who would be attracted to and certainly capable of effectively understanding without any prejudice and appreciating the deeper insights enshrined in this short research report, who may opt for innate rational-&-intellectual common-sense and simple creativity over any sophisticated and/or complex theory in problem-solving to resolve any seemingly paradoxical scenarios possibly arising therefrom.

ॐतत्सत्