THINKING LIKE A CEA EXPERT

An Intuition Guide
based on the following exercise:
LINK TO CASE STUDY

Bloomberg Philanthropies

DATA FOR HEALTH INITIATIVE

CDC Foundation
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VANDERBILT
Center for Health
Economic Modeling

Vital Strategies

Case Study Background:

Several years of teaching workshops has led to a new illness being observed among health economists. As revealed by new research from the pioneering decision scientist, Dr. Grooves, this new disease is a consequence of the enduring sadness that results from the workshop being over. This condition has come to be called the Brief Yearning Episode (commonly abbreviated to BYE). Our team has exclusive access to data on the natural history of BYE.

These data were gathered from an observational study that followed a cohort of 30-year old students for 3 years. At the start of the study, 60% have Mild BYE and 40% were healthy.

BYE is associated with reduced quality of life. The utility weight for Mild BYE is 0.88 and the utility weight for Severe BYE in 0.65, whereas individuals without BYE have a utility of 1.0.

Everyone represented in the model faces age-specific background mortality, which can be based on the provided life table. Individuals with BYE have a risk of dying from sadness. Mild cases have a 1.4% annual probability of dying from sadness and severe cases have a 4.21% annual probability of dying.

The data also suggested that healthy individuals that survive background mortality have a 40.71% chance of developing BYE within a year of the workshop. Among individuals newly developing BYE, 80% have Mild BYE and the rest have Severe BYE. It has been estimated that 30% of the individuals with Mild progressed to Severe over a 3-year period. Individuals with Mild BYE can fully recover and return to the Well state, with an annual probability of 7%, conditional on surviving to the end of the year.

Patients with Severe BYE have a 10.5% annual probability of returning to the Mild state. Individuals with Severe BYE cannot return directly to the Well state. Individuals who recover from previous episodes of BYE face the same risk of developing the condition again as those who have not yet had BYE.

To treat BYE, the only solution is a beach holiday. For mild cases, a $3,000 trip per year is required and for severe cases, a $9,000 trip is required. It is recommended that patients moving from mild to severe, have a one-time treatment at progression of upgrading to a private jet for $35,000.

A similar disease CYA that is seen in economic workshops but has slightly more expensive treatment and slightly worse outcomes has been found to cost about $100,00 per person and result in 10 QALYs.

Dr. Grooves develop a 5-state Markov model: (1) Well, (2) Mild, (3) Severe, (4) Disease Death and (4) [All Cause] Death based on the data provided above. He said he used a 3% discounting rate for both costs and QALYs, and half-cycle correction on the model. All costs were converted into the same year. He is hoping to find the life-time impacts of BYE.

He also provided you some results from other papers that he think you could use to help understand your results. (Added later)

This Guide's Style:

This guide is written as if you are in the brain of the expert and walks you through their thoughts. The goal is to help you build intuition for doing quality assurance on your own model as well as reviewing external resources. This is heavily focused on Amua but many of the concepts can be applied to other softwares.

I have the model open in Amua and the first thing that I want to use is Amua's "Check Model" feature this will show me any errors that can be quickly fixed

Check The ✓ Model

Okay so this tells us that me that the death node has probabilities that do not sum to 1. Let me look at that.

Treatment   23081.0559   1.614738517316E8   23081.0559   9.102

> 1 errors:
Node Death: Probabilities sum to 0.0!

Ah yes, I forgot to add the 100% probability that keeps all individuals in the "Death" end state. Well I am here, I also verified that the Death state has the end state of "Death"

Fix #1

Set p:1 for the "Death" node
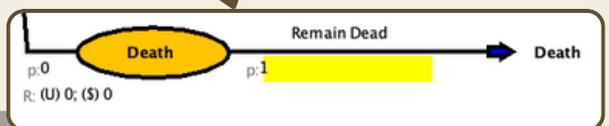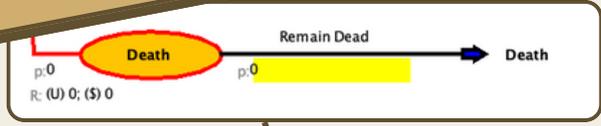
Remember that end states mean that no one can leave once they enter. Make sure there is an 100% chance that everyone stays in that state. (We don't zombies!)

Now that we have fixed that error, we can run the check again to see if there is anything else we missed.

Check The

Model
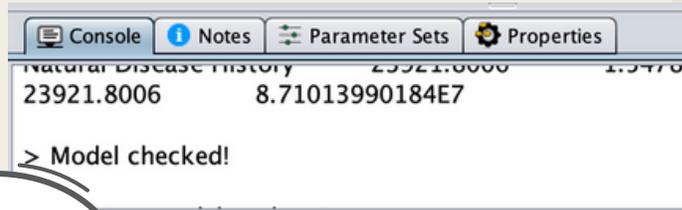
Okay, perfect. The "Model checked!" notification in the Console means that the model has code that will run. It does not mean that I have a perfect model.

Run The

Model

We should get two very important pieces of evidence on the model: the Markov trace (right) and outcomes (bottom)

Amua - Markov Trace: Natural Disease History

Export Copy

Cycle	Well	Mild	Severe	Disease ...	Death	Cycle_
0	0.0	0.0	1000.0	0.0	0.0	325.0
1	101.798	0.0	867.7071	13.7658	16.7291	665.8
2	148.1328	3.27	792.8426	25.7473	30.0073	666.3
3	168.2571	6.8496	748.0524	36.7742	40.0667	660.5
4	176.1869	9.8014	719.6652	47.2624	47.0842	652.5
5	178.627	11.9748	700.7736	57.4286	51.196	322.3

400
350
300
250

Console   Notes   Parameter Sets   Properties

Strategy	Utility	Cost	Utility (Dis)	Cost (Dis)	
Natural Disease History	3292.6128		3.67924017059E7	3292.6128	3.33266840

>

I want to start with the Markov trace because I already see an issue.

"He is hoping to find the life-time impacts of BYE."

Remember that a "Lifetime" model runs until everyone dies. The number of cycles varies based on the initial age. You can over estimate but each additional cycle does add run time to model.

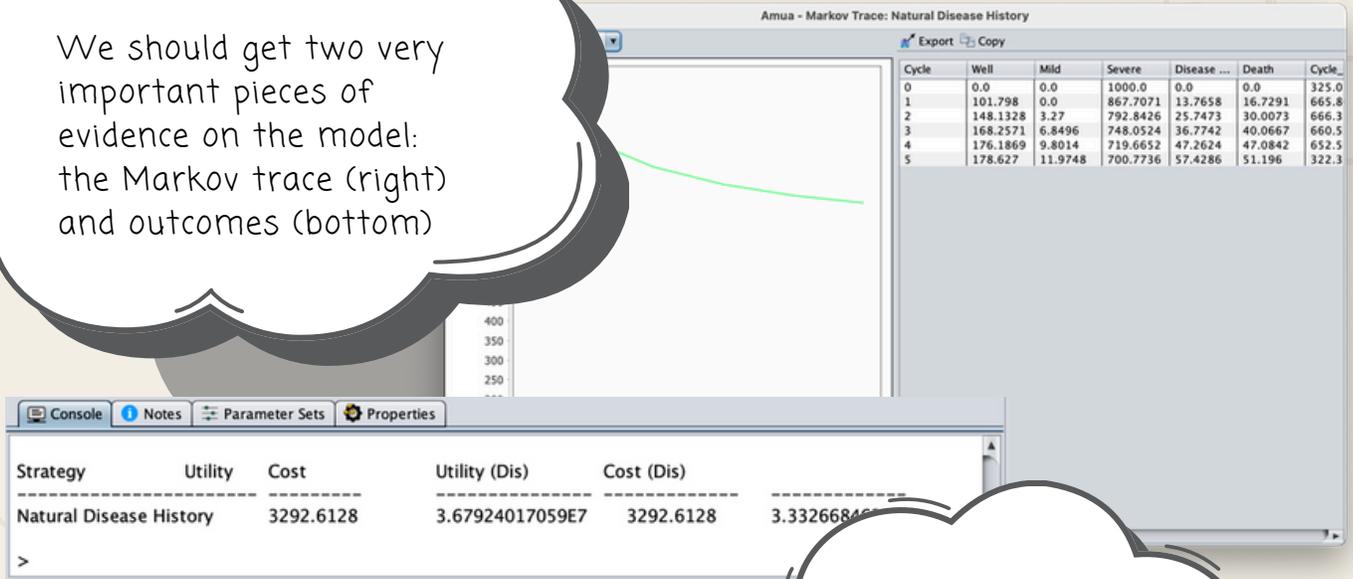The model needs to be a lifetime model but this only has 5 cycles in the Markov Trace

Fix #2
Set t==100 for the terminal condition

Natural Disease History
t == 5

Natural Disease History
t == 100

Cycle	Well					Cycle_
0	0.0	0.0	1000.0	0.0	0.0	325.0
1	101.798	0.0	867.7071	13.7658	16.7291	665.8
2	148.1328	3.27	792.8426	25.7473	30.0073	666.3
3	168.2571	6.8496	748.0524	36.7742	40.0667	660.5
4	176.1869	9.8014	719.6652	47.2624	47.0842	652.5
5	178.627	11.9748	700.7736	57.4286	51.196	322.3

Cycle	Well	Mild	Severe	Disease ...	Death	Cycl
70	64.2189	6.0276	242.8057	493.2825	193.6653	227
71	61.9044	5.8103	234.0546	496.6784	201.5523	219
72	59.5158	5.5861	225.0235	499.9433	209.9313	210
73	57.0683	5.3564	215.77	503.0739	218.7313	202
74	54.5772	5.1226	206.3511	506.0678	227.8813	193
75	52.057	4.8861	196.8226	508.9235	237.3108	184
76	49.5222	4.6481	187.2387	511.6402	246.9508	175
77	46.9393	4.4057	177.4733	514.2151	256.9665	166
78	44.3293	4.1607	167.6049	516.6469	267.2582	156
79	41.712	3.9151	157.7092	518.9351	277.7286	147
80	39.1064	3.6705	147.8577	521.0804	288.285	138
81	36.5302	3.4287	138.1171	523.0843	298.8397	129
82	33.968	3.1882	128.4298	524.9477	309.4662	120
83	31.4415	2.9511	118.8775	526.6725	320.0574	111
84	28.9703	2.7191	109.5338	528.2617	330.5151	102
85	26.5715	2.494	100.4644	529.7194	340.7508	94.
86	24.2602	2.2771	91.7257	531.0502	350.6868	85.
87	22.0376	2.0684	83.322	532.2591	360.3129	78.
88	19.9169	1.8694	75.304	533.3517	369.558	70.
89	17.909	1.6809	67.7121	534.3342	378.3639	63.
90	16.0217	1.5038	60.5765	535.2131	386.685	56.
91	14.2605	1.3385	53.9178	535.9954	394.4879	50.
92	12.63	1.1855	47.7529	536.6882	401.7434	44.
93	11.1304	1.0447	42.0832	537.2988	408.4429	39.
94	9.7603	0.9161	36.9026	537.8342	414.5868	34.
95	8.5163	0.7993	32.1993	538.3014	420.1837	30.
96	7.394	0.694	27.9561	538.707	425.2489	26.
97	6.3922	0.6	24.1684	539.0577	429.7817	22.
98	5.5026	0.5165	20.8048	539.3595	433.8166	19.
99	4.7166	0.4427	17.8329	539.6183	437.3896	16.
100	4.0255	0.3778	15.2202	539.8391	440.5373	7.1

Great the Markov Trace now has 100 cycles. Not everyone is dying though. This does not make sense. It is highly unlikely to have 20 people alive at 130 years old

First I want to check the structure of the model. We just fixed the Death node so let's check all branches that lead to death.
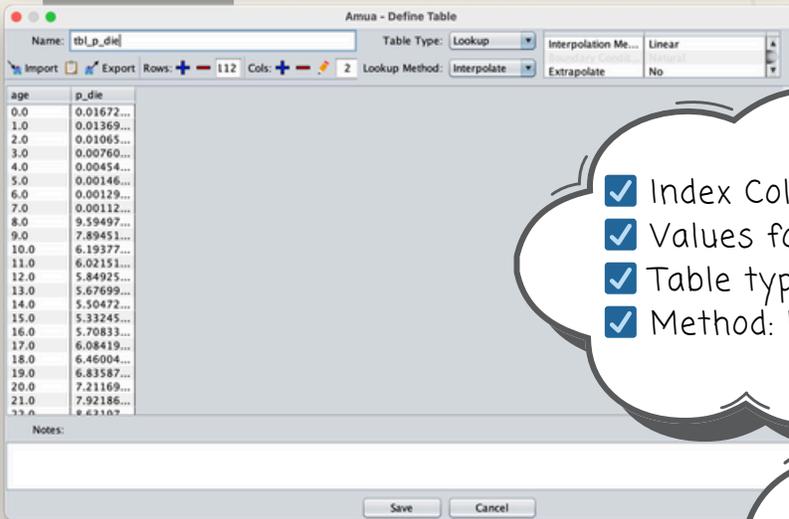
Well to Death:
☑ has branch
☑ p_die
☑ end state is Death

Severe to Death:
☑ has branch
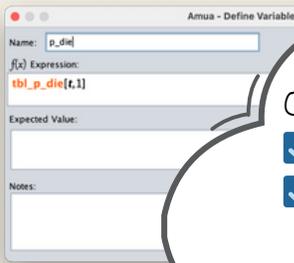☑ p_die
☑ end state is Death

Mild to Death:
☑ has branch
☑ p_die
☑ end state is Death

Okay the structure looks good, now I want to look at the table inputs

Amua - Define Table

Name: tbl_p_die Table Type: Lookup Interpolation Me... Linear

Import Export Rows: + − 112 Cols: + − 2 Lookup Method: Interpolate Extrapolate No

age	p_die
0.0	0.01672...
1.0	0.01369...
2.0	0.01065...
3.0	0.00760...
4.0	0.00454...
5.0	0.00146...
6.0	0.00129...
7.0	0.00112...
8.0	9.59497...
9.0	7.89451...
10.0	6.19377...
11.0	6.02151...
12.0	5.84925...
13.0	5.67699...
14.0	5.50472...
15.0	5.33245...
16.0	5.70833...
17.0	6.08419...
18.0	6.46004...
19.0	6.83587...
20.0	7.21169...
21.0	7.92186...

Notes:

Save Cancel

Index Column
Values for all indices
Table type: Lookup
Method: Interpolate

Not looking like a table issue. I will now go look at the variable for p_die.

Amua - Define Variable

Name: p_die

$f(x)$ Expression:
tbl_p_die[t,1]

Expected Value:

Notes:

Okay so:
Correct table name
Looking at the 1st column which is the p_die column
Using Amua time variable "t" to look up the index

Amua - Define Parameter

Name: i_age

$f(x)$ Expression:
30

Expected Value:

Notes:
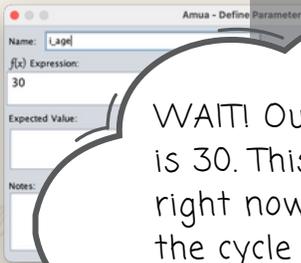
WAIT! Our initial age is 30. This means that right now "t" is using the cycle number not the age of the person to index the table.

Fix #3
Change "t" to include the initial age (t+i_age)

Remember that the Amua built in "t" variable is the cycle number or time in the model. It will be 1 for cycle 1, 2 for cycle 2, and so on.

Amua

Name: p_die

$f(x)$ Expression:
tbl_p_die[t,1]

Expected Value:

Amua

Name: p_die

$f(x)$ Expression:
tbl_p_die[t+i_age,1]

Expected Value:

Amua - Markov Trace: Natural Disease History

Plot: State Prevalence

Export Copy

Cycle	Well	Mild	Severe	Disease ...	Death	Cycl
70	6.0748	0.5702	22.9683	408.6244	561.7623	21.
71	5.1627	0.4846	19.5197	408.9076	565.9255	18.
72	4.3731	0.4105	16.5343	409.1475	569.5347	15.
73	3.6921	0.3465	13.9594	409.35	572.652	13.
74	3.1069	0.2916	11.7468	409.5204	575.3343	10.
75	2.6058	0.2446	9.8524	409.6634	577.6338	9.2
76	2.1784	0.2045	8.2363	409.7829	579.598	7.7
77	1.8168	0.1705	6.8693	409.8826	581.2608	6.4
78	1.5118	0.1419	5.7159	409.9655	582.665	5.3
79	1.255	0.1178	4.7451	410.0343	583.8478	4.4
80	1.0394	0.0976	3.93	410.0914	584.8416	3.6
81	0.8589	0.0806	3.2474	410.1385	585.6747	3.0
82	0.3429	0.0322	1.2963	410.1573	588.1714	1.2
83	0.1369	0.0128	0.5175	410.1648	589.168	0.4
84	0.0546	0.0051	0.2066	410.1678	589.5659	0.1
85	0.0218	0.002	0.0825	410.169	589.7247	0.0
86	0.0087	8.0E-4	0.0329	410.1695	589.7881	0.0
87	0.0035	3.0E-4	0.0131	410.1697	589.8134	0.0
88	0.0014	1.0E-4	0.0052	410.1697	589.8235	0.0
89	6.0E-4	1.0E-4	0.0021	410.1698	589.8275	0.0
90	2.0E-4	0.0	8.0E-4	410.1698	589.8292	8.0
91	1.0E-4	0.0	3.0E-4	410.1698	589.8298	3.0
92	0.0	0.0	1.0E-4	410.1698	589.83	1.0
93	0.0	0.0	1.0E-4	410.1698	589.8302	0.0
94	0.0	0.0	0.0	410.1698	589.8302	0.0
95	0.0	0.0	0.0	410.1698	589.8302	0.0
96	0.0	0.0	0.0	410.1698	589.8302	0.0
97	0.0	0.0	0.0	410.1698	589.8302	0.0
98	0.0	0.0	0.0	410.1698	589.8302	0.0
99	0.0	0.0	0.0	410.1698	589.8302	0.0
100	0.0	0.0	0.0	410.1698	589.8302	0.0

Prev(t)

Severe — Disease Death — Death

Perfect, now everyone is dead by the end of the model.

Now when I look at the graph i'm noticing something else.

"At the start of the study, 60% have Mild BYE and 40% were healthy."
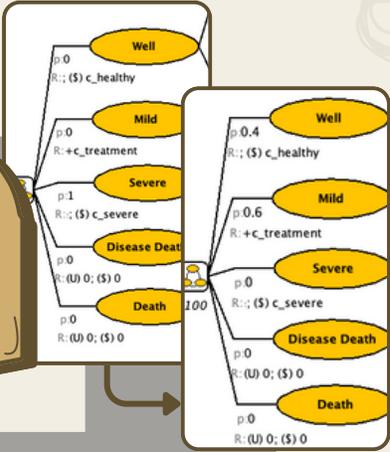
oc: State Pre

At cycle 0, all 1,000 people are in the severe state.

Remember the starting probabilities set the number of individuals that start in each state.
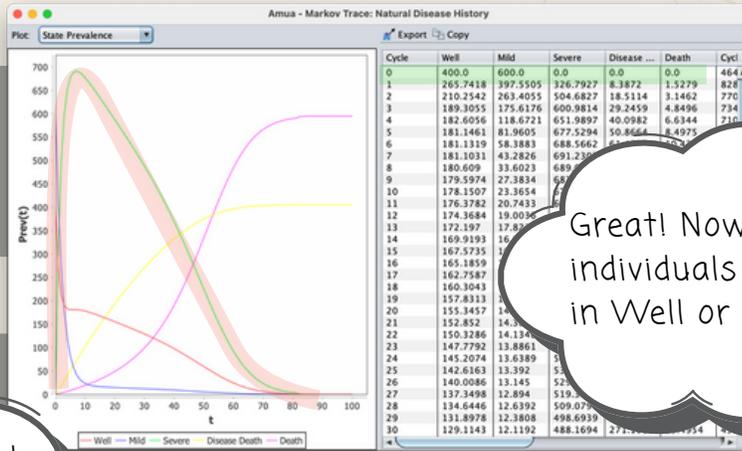
I need to check the starting probabilities.

The starting probabilities are completely different than what we wanted to model.

Fix #4
Set
p: 0.4 for Well
p: 0.6 for Mild
p: 0 for Severe

Well
p:0
R:; ($) c_healthy

Mild
p:0
R:+c_treatment

Severe
p:1
R:; ($) c_severe

Disease Death
p:0
R:(U) 0; ($) 0

Death
p:0
R:(U) 0; ($) 0

Well
p:0.4
R:; ($) c_healthy

Mild
p:0.6
R:+c_treatment

Severe
p:0
R:; ($) c_severe

Disease Death
p:0
R:(U) 0; ($) 0

Death
p:0
R:(U) 0; ($) 0

Amua - Markov Trace: Natural Disease History

Plot: State Prevalence

Export Copy

Cycle	Well	Mild	Severe	Disease ...	Death	Cycl
0	400.0	600.0	0.0	0.0	0.0	464
1	265.7418	397.5505	326.7927	8.3872	1.5279	828
2	210.2542	263.4055	504.6827	18.5114	3.1462	770
3	189.3055	175.6176	600.9814	29.2459	4.8496	734
4	182.6056	118.6721	651.9897	40.0982	6.6344	710
5	181.1461	81.9605	677.5294	50.8664	8.4975	
6	181.1319	58.3883	688.5662	6		
7	181.1031	43.2826	691.230			
8	180.609	33.6023	689			
9	179.5974	27.3834	68			
10	178.1507	23.3654				
11	176.3782	20.7433				
12	174.3684	19.003				
13	172.197	17.83				
14	169.9193	16				
15	167.5735	1				
16	165.1859					
17	162.7587					
18	160.3043					
19	157.8313					
20	155.3457	14				
21	152.852	14.3				
22	150.3286	14.134				
23	147.7792	13.8861				
24	145.2074	13.6389	5			
25	142.6163	13.392	52			
26	140.0086	13.145	519.			
27	137.3498	12.894	519.			
28	134.6446	12.6392	509.079			
29	131.8978	12.3808	498.6939			
30	129.1143	12.1192	488.1694	271.		754

Legend: Well — Mild — Severe — Disease Death — Death

Great! Now we have individuals starting in Well or Mild.

Looking at the graph again, I notice there is a large spike in severe cases

Let me look at the background to see if this makes sense.

"Among individuals newly developing BYE, 80% have Mild BYE and the rest have Severe BYE."
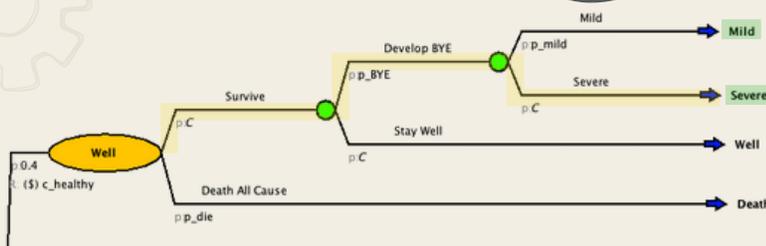
"30% of the individuals with Mild progressed to Severe over a 3-year period"

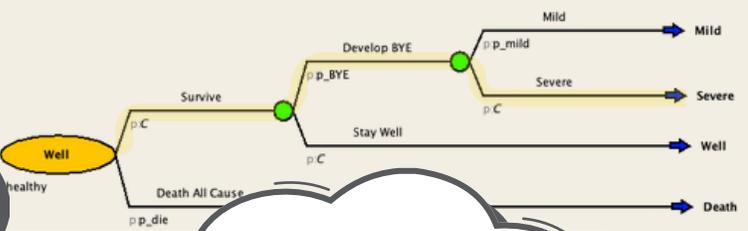Based on this, I would expect Mild to spike first then to see Severe grow over time.

Let's start by looking at the structure of the model. I should start with Well or Mild since everyone starts in these states

I'm going to look at the Well state, specifically the flow to Severe.

Looking at this I can see that the Well state correctly has Mild and Severe end states so that is not the issue.

Mild

Develop BYE

p p_mild

Mild

p p_BYE

Severe

Severe

Survive

p:C

p:C

Stay Well

Well

p:C

Well

p 0.4

t: ($) c_healthy

Death All Cause

Death

p p_die

Now I want to check the probability parameters.

I just fixed p_die so I know that is correct. and the Survive has the "C".

Remember that in Amua, using "C" allows the tool to automatically calculate the complementary probability.

I will start with p_BYE

"...healthy individuals that survive background mortality have a 40.71% chance of developing BYE within a year of the workshop

Since we have annual cycles. I know that p_BYE should be 0.4071.

Name	Expression
i_age	30
p_disease_death_mild	0.014
p_mild	0.08
r_mild2severe	0.3
p_mild2well	0.07
p_severe2mild	0.105
p_BYE	0.4071
u_mild	0.88
u_severe	0.65

Great it is correct!

Now let me check p_mild

"...developing BYE, 80% have Mild BYE and the rest have Severe BYE."

Based on the background p_mild = 0.8

Name	Expression
i_age	30
p_disease_death_mild	0.014
p_mild	0.08
r_mild2severe	0.3
p_mild2well	0.07
p_severe2mild	
p_BYE	
u_mild	

Oh no, a typo!

Fix #5
p_mild = 0.8

Name: p_mild
f(x) Expression:
0.08

Name: p_mild
f(x) Expression:
0.8

Run The Model Again

Mild — Mild
Develop BYE — p p_mild
p p_BYE
Survive — Severe — Severe
p C — p C
Well
Stay Well — Well
healthy — p C
Death All Cause — Death
p p_die

I finished checking the Well state so now I will check the Mild state specifically the flow to Severe.
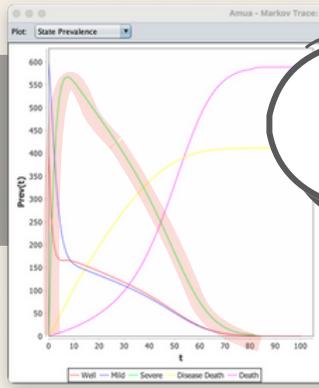
The spike in Severe got lower but it still feels high to me. I am going to do additional checks

I see that the Mild state has the correct end state for each branch.

Now I want to check the probability parameters.

Progress
r_mild2severe → Severe

Survive
pC

Survive
pC

No Progression
pC

Stay → Mild

Improve → Well
p_mild2well

Mild
treatment

Disease Death
p_disease_death_mild → Disease Death

Death All Cause
p_die → Death
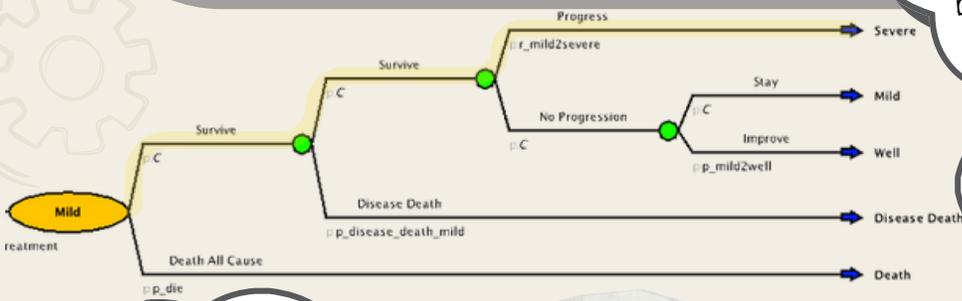
p_disease_death_mild is correct

"Mild cases have a 1.4% annual probability of dying"

Name	Expression
i_age	30
p_disease_death_mild	0.014
p_mild	0.8
r_mild2severe	0.3

Name	Expression
i_age	30
p_disease_death_mild	0.014
p_mild	0.8
r_mild2severe	0.3

"30% of the individuals with Mild progressed to Severe over a 3-year period"

This is a 3-year probability. I need to make sure this is an annual probability in the model

Yikes! this was entered into the model wrong

Remember that you cannot mix rates and probabilities. Additionally, all probabilities must be for the cycle length.

Fix #6
1. Change to Rate
2. Change to 1 year Prob.
3. Update Model

Name: p_mild2severe
f(x) Expression:
rateToProb(probToRate(0.3, 3, 1), 1, 1)

Progress
p_mild2severe

Run The Model Again

Amua - Markov Trace:

Plot: State Prevalence ▼
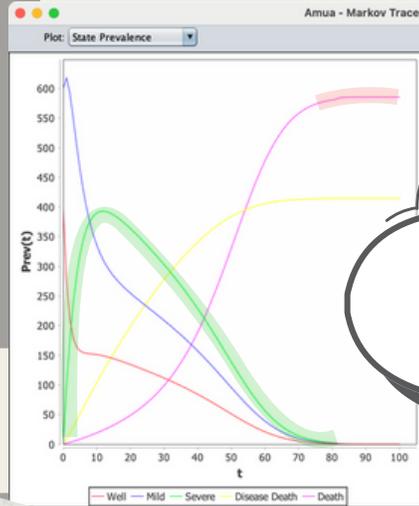
I remember from looking at Mild that p_disease_death_mild was higher than p_die for most ages

age	p_die
30.0	0.00152...
31.0	0.00163...
32.0	0.00174...
33.0	0.00184...
34.0	0.00195...
35.0	0.00206...
36.0	0.00219...
37.0	0.00232...
38.0	0.00245...
39.0	0.00259...
40.0	0.00272...
41.0	0.00290...
42.0	0.00309...
43.0	0.00327...
44.0	0.00346...
45.0	0.00364...
46.0	0.00392...
47.0	0.00420...
48.0	0.00447...
49.0	0.00475...
50.0	0.00503...
51.0	0.00547...
52.0	0.00591...

"Mild cases have a 1.4% annual probability of dying"

"Severe cases have a 4.21% annual probability of dying"

Knowing this, I am surprised to see more all cause deaths than disease deaths

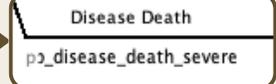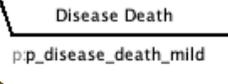I know that the Mild state is correct. So let me check the Severe state

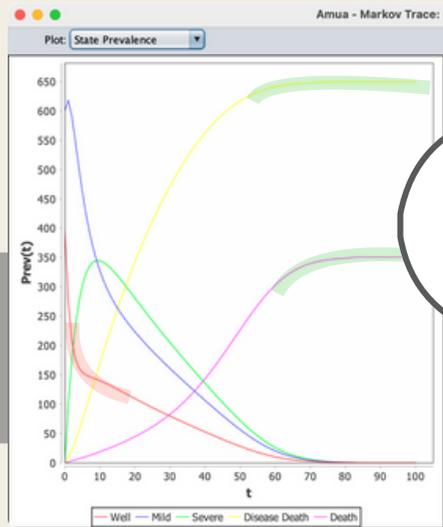Looking at the flow, I see that there is a branch correctly leading to the end state "Disease Death"
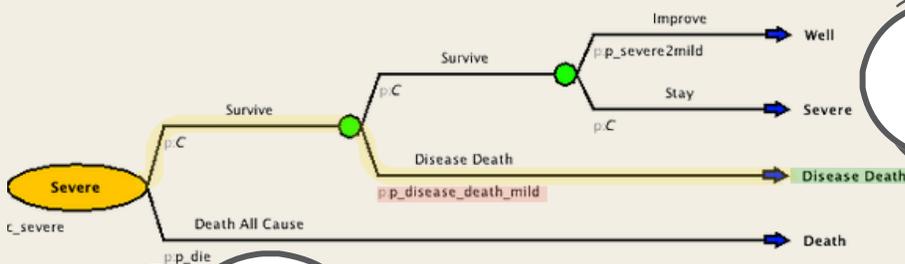
However, I noticed that the probability is p_disease_death_mild

Fix #7

Change mild to severe

Disease Death
p:p_disease_death_mild

Disease Death
p:p_disease_death_severe

Okay, this is looking really good. I'm making a mental note about the wiggle in Well but I want to move on to outcomes since i have reviewed a lot of the structure.
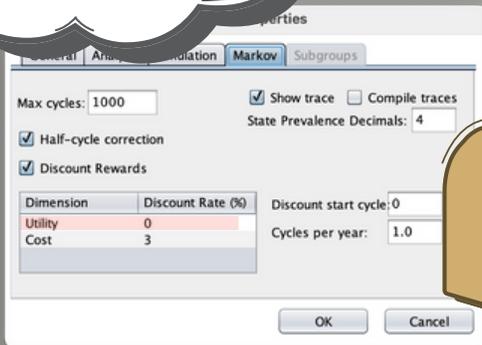
A quick look at the results shows me a glaring issue.

"3% discounting rate for both costs and QALYs"

Strategy	QALYs	Cost	QALYs (Dis)	Cost (Dis)
Treatment	23348.0	5.58E8	23348.0	3.37E8

The cost is being discounted but "QALYs" and "QALYs (Dis)" are the same

Remember that discounting should be applied to both to QALYs and costs. They do not have to be the same percentage though.
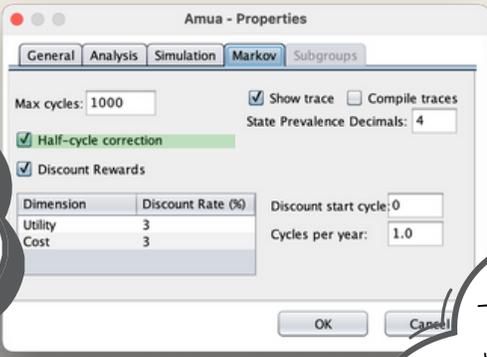
Let me check the model properties
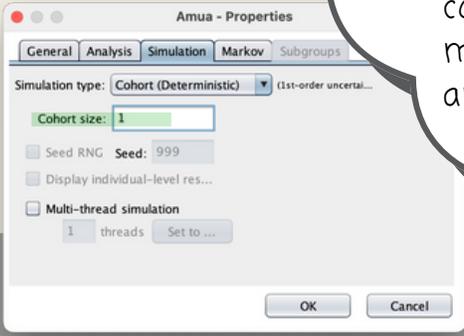
Fix #8
Discount QALYs

Well here, I also confirmed that half-cycle correction was used

Amua - Properties

General | Analysis | Simulation | Markov | Subgroups

Max cycles: 1000 ☑ Show trace ☐ Compile traces
State Prevalence Decimals: 4
☑ Half-cycle correction
☑ Discount Rewards

Dimension	Discount Rate (%)
Utility	3
Cost	3

Discount start cycle: 0
Cycles per year: 1.0

OK | Cancel

To help make the results more understandable to me, I am going to use a cohort size = 1. This gives me individual-level cost and QALYs

Amua - Properties

General | Analysis | Simulation | Markov | Subgroups

Simulation type: Cohort (Deterministic) ▾ (1st-order uncertai...
Cohort size: 1
☐ Seed RNG **Seed:** 999
☐ Display individual-level res...
☐ Multi-thread simulation
1 threads | Set to ...

OK | Cancel

Run The ▶ Model Again

Strategy	QALYs	Cost	QALYs (Dis)	Cost (Dis)
Treatment	23.35	$557,760	13.74	$336,917

Looking at the numbers on the individual-level gives me a much better understanding of how realistic they seem

QALYs tells me the additional quality-adjusted life years that a person will have.

With an initial age of 30. Having 14 QALYs on average feels good to me.

I would be concerned if they were super high (like 30) or super low (like 2).

Now I want to look at the cost.

| Strategy	QALYs	Cost	QALYs (Dis)	Cost (Dis)
Treatment	23.35	$557,760	13.74	$336,917

"Severe cases, a $9,000 trip per year"

"Patients moving from mild to severe, have a one-time treatment at progression of ... $35,000."

"Mild cases, a $3,000 trip per year"

Knowing that most costs are low, I want to see in the trace if a lot of people are in severe

Looking at this, I see that around cycle 20 there are a lot more deaths than illness. I would expect costs to be around c_sick * 20. Expecting like $150,000 – $200,000.
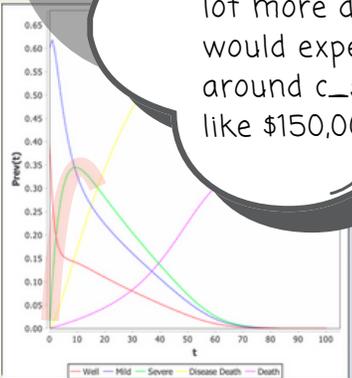
I am going to check the costs on each state.

Since you are already looking at costs. It's a good time to just quickly check the utility values as well, even if the results feel realistic

A quick check of the death states
☑QALYs are 0
☑Cost is 0

Death
p:0
R:QALY) 0; ($) 0

Disease Death
p:0
R:QALY) 0; ($) 0

Well
☑Utility is u_healthy
☑u_healthy = 1
☑Cost is c_healthy
☑c_healthy = 0

"Utility weight for Mild BYE is 0.88 "

Mild
☑Utility is u_mild
☑u_mild = 0.88
☒Cost is c_mild
☑c_mild = 3,000

Healthy
(QALY): u_healthy
($): c_healthy

The cost of treatment is being applied EVERY CYCLE to ALL individuals in the Mild state

Sick
(QALY): u_mild
($): c_mild + c_treatment

Patients moving from mild to severe, have a one-time treatment at progression of ... $35,000."

Severe
(QALY): u_severe
($): c_severe

But we want a one-time cost at progression

Fix #9
Move cost of treatment
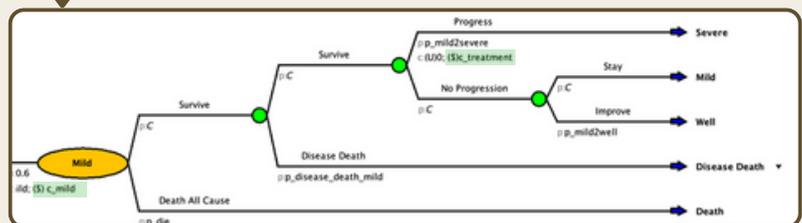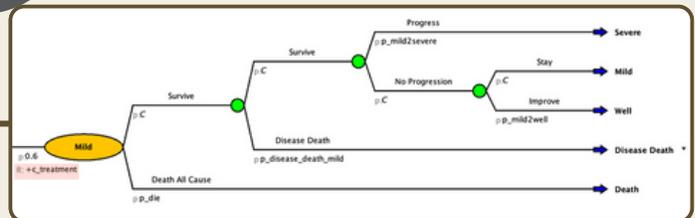
Severe
☑Utility is u_severe
☑u_mild = 0.65
☑Cost is c_severe
☑c_severe = $9,000

"Utility weight for Severe BYE is 0.65 "

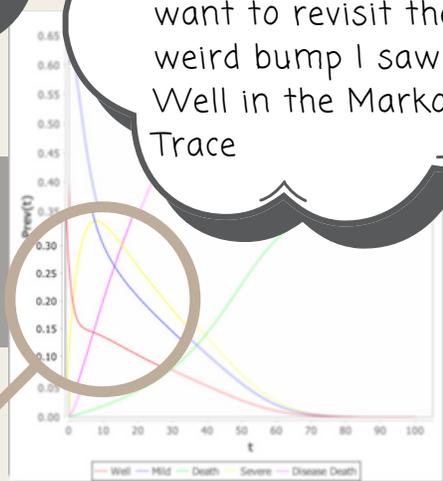| Strategy	QALYs	Cost	QALYs (Dis)	Cost (Dis)
Treatment	23.35	$855,503	13.74	$106,646

This price seems more reasonable based on most people getting sick and living to around 50.

Now that the results are looking good. I want to revisit the weird bump I saw in Well in the Markov Trace
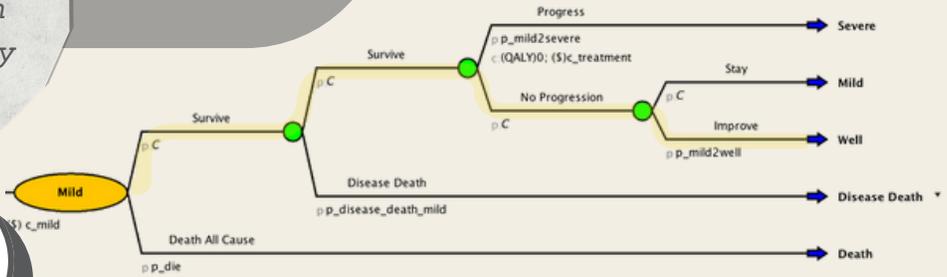
I think I want to start by checking all the arms that lead to Well since I have already checked everything in the Well branch

This should only be from the Mild State

I have already checked the two death probabilities and p_mild2severe

"Mild BYE can fully recover and return to the Well state, with an annual probability of 7%"
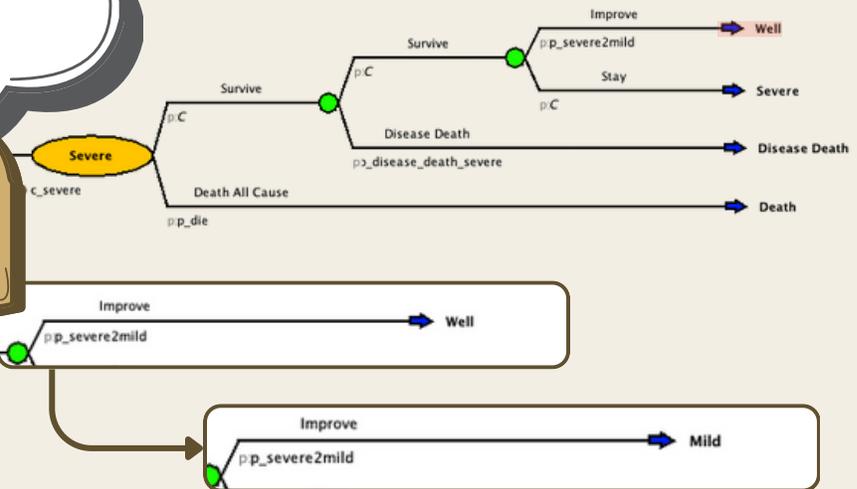
☑ p_mild2well = 0.07

This all looks correct so now I need to figure out why this bump is happening

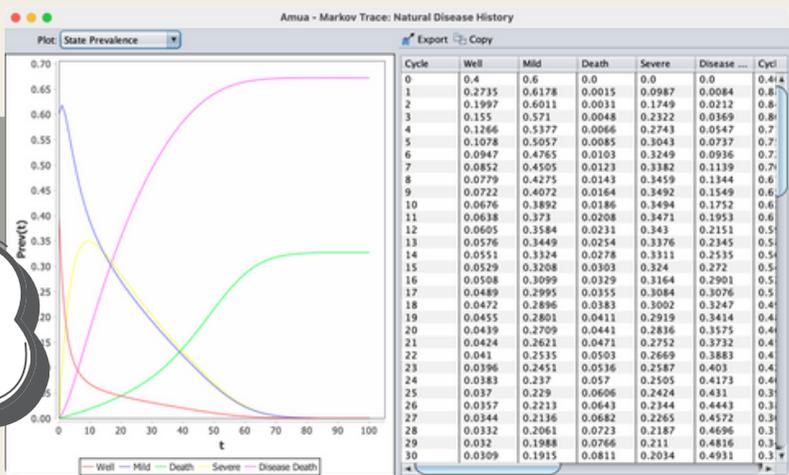Let me just see if the Severe state somehow leads into Well.

Ahhhh, there is the issue. When I look at "Improve" it is going to well instead of "Mild"

Fix #10

Change Well to Mild

Survive

p:C

Improve

p:p_severe2mild → Well

Stay → Severe

p:C

Disease Death

p:p_disease_death_severe → Disease Death

Survive

p:C

Death All Cause

p:p_die → Death

Severe

p:c_severe

Improve

p:p_severe2mild → Well

Improve

p:p_severe2mild → Mild

Run The Model Again

We're looking great!

Amua - Markov Trace: Natural Disease History

Plot: State Prevalence

Export Copy

Cycle	Well	Mild	Death	Severe	Disease ...	Cycl
0	0.4	0.6	0.0	0.0	0.0	0.4
1	0.2735	0.6178	0.0015	0.0987	0.0084	0.8
2	0.1997	0.6011	0.0031	0.1749	0.0212	0.8
3	0.155	0.571	0.0048	0.2322	0.0369	0.8
4	0.1266	0.5377	0.0066	0.2743	0.0547	0.7
5	0.1078	0.5057	0.0085	0.3043	0.0737	0.7
6	0.0947	0.4765	0.0103	0.3249	0.0936	0.7
7	0.0852	0.4505	0.0123	0.3382	0.1139	0.7
8	0.0779	0.4275	0.0143	0.3459	0.1344	0.6
9	0.0722	0.4072	0.0164	0.3492	0.1549	0.6
10	0.0676	0.3892	0.0186	0.3494	0.1752	0.6
11	0.0638	0.373	0.0208	0.3471	0.1953	0.6
12	0.0605	0.3584	0.0231	0.343	0.2151	0.5
13	0.0576	0.3449	0.0254	0.3376	0.2345	0.5
14	0.0551	0.3324	0.0278	0.3311	0.2535	0.5
15	0.0529	0.3208	0.0303	0.324	0.272	0.5
16	0.0508	0.3099	0.0329	0.3164	0.2901	0.5
17	0.0489	0.2995	0.0355	0.3084	0.3076	0.5
18	0.0472	0.2896	0.0383	0.3002	0.3247	0.4
19	0.0455	0.2801	0.0411	0.2919	0.3414	0.4
20	0.0439	0.2709	0.0441	0.2836	0.3575	0.4
21	0.0424	0.2621	0.0471	0.2752	0.3732	0.4
22	0.041	0.2535	0.0503	0.2669	0.3883	0.4
23	0.0396	0.2451	0.0536	0.2587	0.403	0.4
24	0.0383	0.237	0.057	0.2505	0.4173	0.4
25	0.037	0.229	0.0606	0.2424	0.431	0.3
26	0.0357	0.2213	0.0643	0.2344	0.4443	0.3
27	0.0344	0.2136	0.0682	0.2265	0.4572	0.3
28	0.0332	0.2061	0.0723	0.2187	0.4696	0.3
29	0.032	0.1988	0.0766	0.211	0.4816	0.3
30	0.0309	0.1915	0.0811	0.2034	0.4931	0.3

Well — Mild — Death — Severe — Disease Death

Strategy	QALYs	Cost	QALYs (Dis)	Cost (Dis)
Treatment	22.37	$197,154	13.32	$113,410

Now i'm going to look at the resources that were provided to see if I got similar results

Strategy	Cost (Dis)	QALYs (Dis)	Inc. Cost	Inc. QALYs	ICER
No Treatment	$78,620	11.56	-	-	-
Screen then Treat	$103,245	10.18	$24,625	-1.38	-$17,844.20
Treatment	$107,989	13.45	$4,744	3.27	$1,450.76

Oh No! Right away I notice a negative ICER.

Do not report negative ICERs. They are ambiguous; the strategy can be dominated or dominant. Report the status instead.

Strategy	Cost (Dis)	QALYs (Dis)	Inc. Cost	Inc. QALYs	ICER	Status
No Treatment	$78,620	11.56	-	-	-	
Treatment	$107,989	13.45	$29,369	1.89	$15,539.15	
Screen then Treat	$103,245	10.18	$24,625	-1.38	--	Dominated

Now, I can actually compare.

My results are similar and it makes sense that we did not consider screening.

"Treatment: Cost (Dis) = $108,127 QALYs(Dis) = 13.65"

The second resource also has an Incremental CEA table for me to review.

Strategy	Cost (Dis)	QALYs (Dis)	Inc. Cost	Inc. QALYs	ICER
No Treatment	$86,340	12.35	-	-	-
Screen then Treat	$107,650	13.79	$21,310	1.44	$14,799
Treatment	$109,145	14.08	$22,805	1.73	$13,182

Seems like they also found "Screen then treat to be a viable strategy. Let me look at this closer.

Huh, the incremental cost from "Screen then Treat" to "Treat is wrong. I need to look into this.

Seems like both strategies are compared to "No Treat"

Strategy	Cost (Dis)	QALYs (Dis)	Inc. Cost	Inc. QALYs	ICER
No Treatment	$86,340	12.35	-	-	-
Screen then Treat	$107,650	13.79	$21,310	1.44	$14,799
Treatment	$109,145	14.08	$1,495	0.29	$5,155

! Economic evaluation uses marginal (not absolute) contribution. This helps remove dominated strategies and allows us to identify the best value for cost.

Okay, now when I correctly calculate the incremental CEA, I see the screening strategy dominated again.

Strategy	Cost (Dis)	QALYs (Dis)	Inc. Cost	Inc. QALYs	ICER	Status
No Treatment	$86,340	12.35	-	-	-	
Treatment	$109,145	14.08	$22,805	1.73	$13,182	
Screen then Treat	$107,650	13.79				Dominated

"Treatment:
Cost (Dis) = $108,127
QALYs(Dis) = 13.65"

Once again, we have similar findings.

Key takeaways

Effective model QA:
- **Run automated checks** - Use software validation features first
- **Review Markov trace visually** - Look for unexpected patterns
- **Examine outputs** - Check if results are in plausible range
- **Trace backwards from anomalies** - When something looks wrong, follow the logic chain back to find the error
- **Verify against source materials** - Cross-check key parameters and structure against background documents
- **Double check your model** - Check structure, settings, parameters, costs, AND interpretation

1. Model Structure Integrity
Absorbing States Must Absorb
- Key Learning: End states (like death) should have a 100% probability of remaining in that state
- Why it matters: Without this, your model suggests people can leave death or other terminal states
- How to check: Absorbing state populations should never decrease in the Markov trace

Verify All State Transitions Match Inputs (& Reality)
- Key Learning: Every pathway between states should reflect actual transitions
- Why it matters: Impossible transitions create unrealistic health trajectories
- How to check: Look for unexpected spikes or drops in Markov trace

Use Causal (Not Predictive) Parameters
- Key Learning: Model parameters should represent causal effects of interventions, not observational associations
- Why it matters: Treating a predictor of disease doesn't prevent disease unless that predictor is on the causal pathway
- How to check: Ask "Does this parameter capture the causal effect of the intervention?" not "Is this parameter associated with better outcomes?"

2. Time Horizon and Model Settings
Match Model Horizon to Research Question
- Key Learning: Termination conditions should allow the model to answer your research question fully
- Why it matters: Cutting off too early underestimates long-term costs and benefits
- How to check: For lifetime models, ensure nearly all cohort reaches absorbing states; verify cycle count in the Markov trace matches intended time period

Apply Discounting to All Relevant Outcomes
- Key Learning: Both costs and health outcomes typically need discounting
- Why it matters: Missing discounting on any dimension biases your cost-effectiveness estimates
- How to check: Confirm that discounted and undiscounted columns differ.

3. Parameter Values and Data Inputs
Verify Table Lookups Use Correct Index Variables
- Key Learning: When using lookup tables (e.g., mortality, utility), ensure the index matches what you intend (age vs. cycle number)
- Why it matters: Wrong indexing applies inappropriate values throughout the model
- How to check: Trace a few values manually; check if time-varying parameters behave as expected

Watch for Data Entry Errors
- Key Learning: Simple typos, misattributed values, and misplacement in models can dramatically change results
- Why it matters: Small input errors cascade into large output errors
- How to check: Double check every parameter in your model.

Never Mix Rates and Probabilities
- Key Learning: Rates and probabilities are different mathematical constructs requiring conversion
- Why it matters: Rates and probabilities can not be mathematically combined.
- How to check: Confirm conversions applied when needed

4. Cost and Benefit Assignments
Distinguish Between State Costs and Event Costs
- Key Learning: Ongoing state costs (per cycle) differ from one-time event costs (at transition)
- Why it matters: Misclassification dramatically inflates or deflates total costs
- How to check: Verify costs align with clinical practice (annual treatment vs one-time intervention)

5. Results Interpretation and Reporting
Never Report Negative ICERs
- Key Learning: Negative ICERs are ambiguous; they could mean "dominant" or "dominated"
- Why it matters: Readers cannot interpret cost-effectiveness.
- How to check: When ICER is negative, determine if more costly/less effective (dominated) or less costly/more effective (dominant) and report that status.

Always Use Incremental (Not Absolute) Analysis
- Key Learning: Compare each strategy to the next-best alternative, not all to baseline
- Why it matters: Absolute comparisons miss dominated strategies and don't show marginal value
- How to check: Verify incremental costs/effects calculated sequentially after ranking by cost

Remember: Models that "run" are not necessarily correct. Verification requires multiple forms of evidence that your implementation matches your conceptual model.