



I am a legend

Celine & Elie Bursztein

<https://www.elie.net/hs>



Digital Collectible Card Game
Released by Blizzard in 2014
Based in the Warcraft
universe



Card **special abilities** are what make the game complex and interesting



Card **special abilities** are what make the game complex and interesting



Sometimes too interesting leads to
un-intended consequences



Game complexity generates exploitable biases

Outline

1. Finding undervalued cards
2. Predicting opponent's deck
3. Predicting game outcome





Your hero



Opponent's
hero



Your hero



Hero health



Decks



hand

hand





mana pool

Your Weapon



Minions



ipon

ightWind

1

17:57



ipon

ightWind

1

17:57







Mana Cost



Mana Cost



Attack



Mana Cost

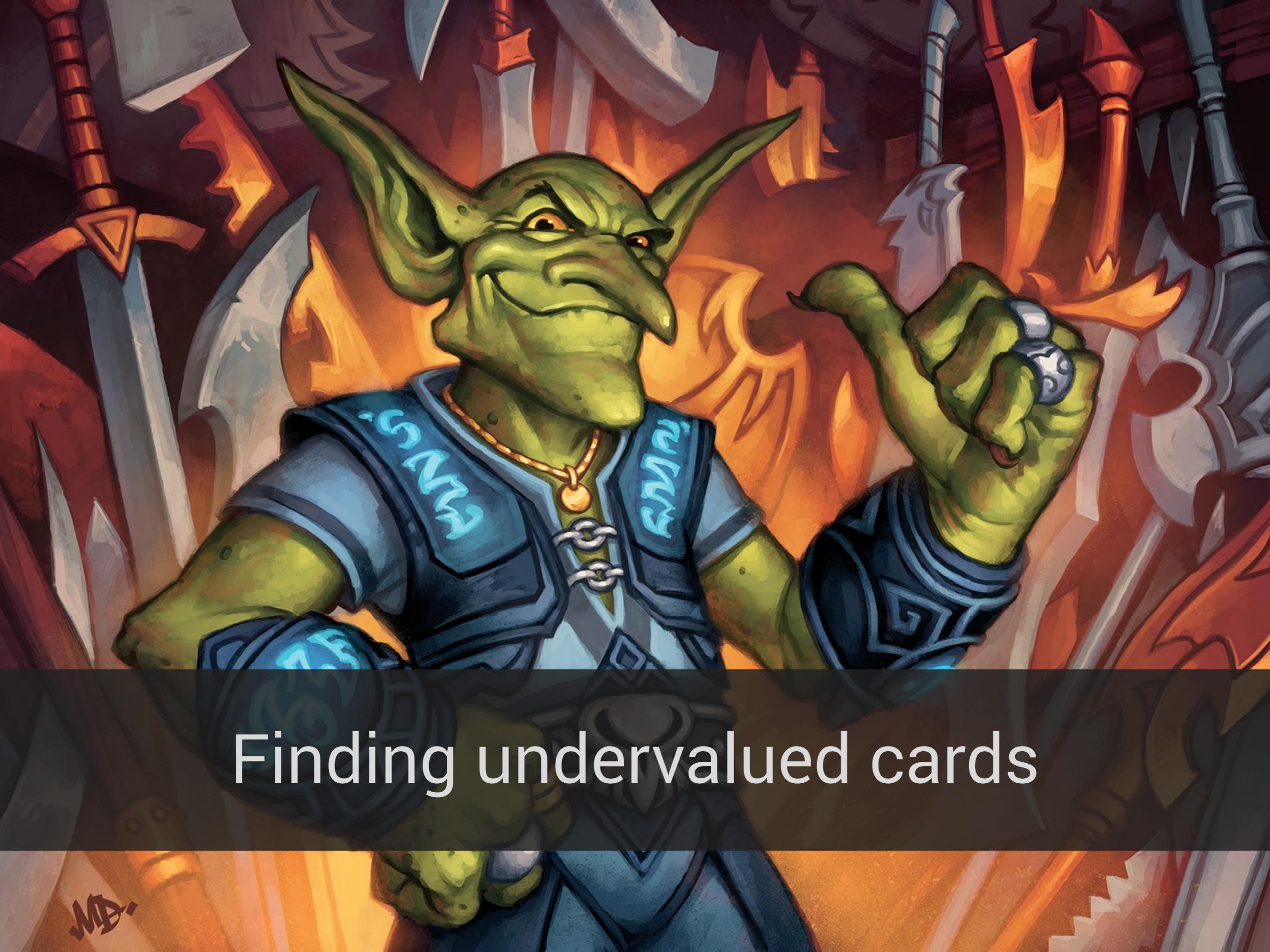


Attack

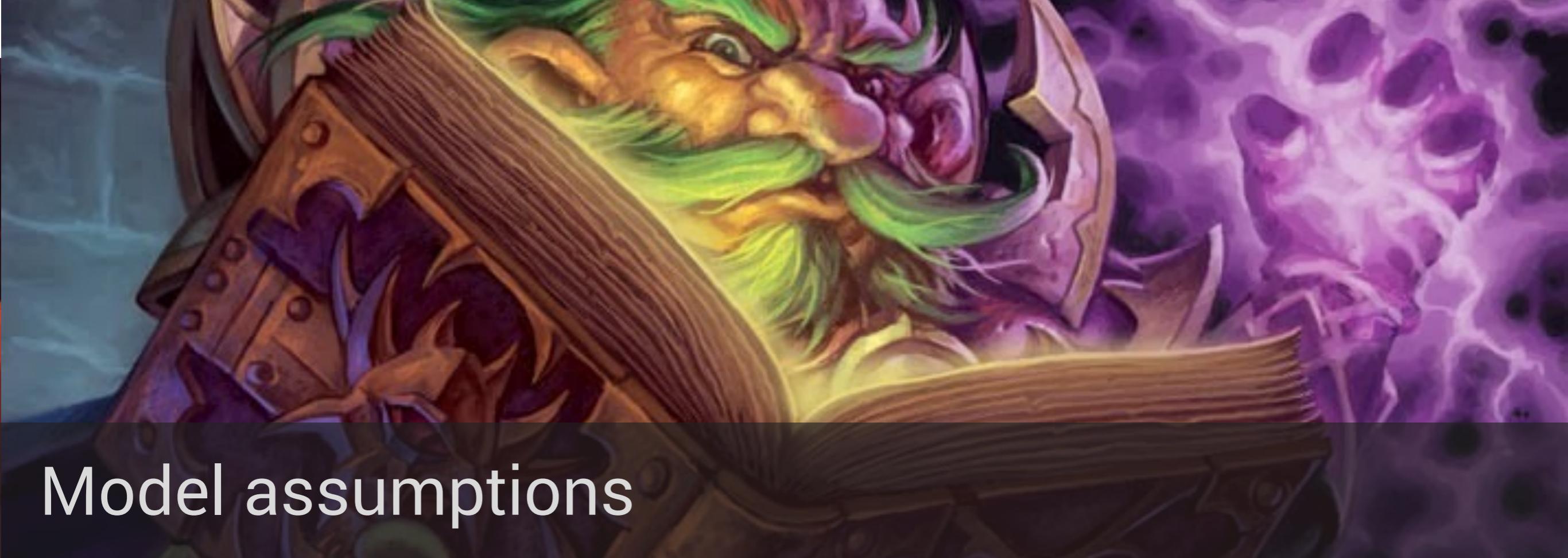


Health

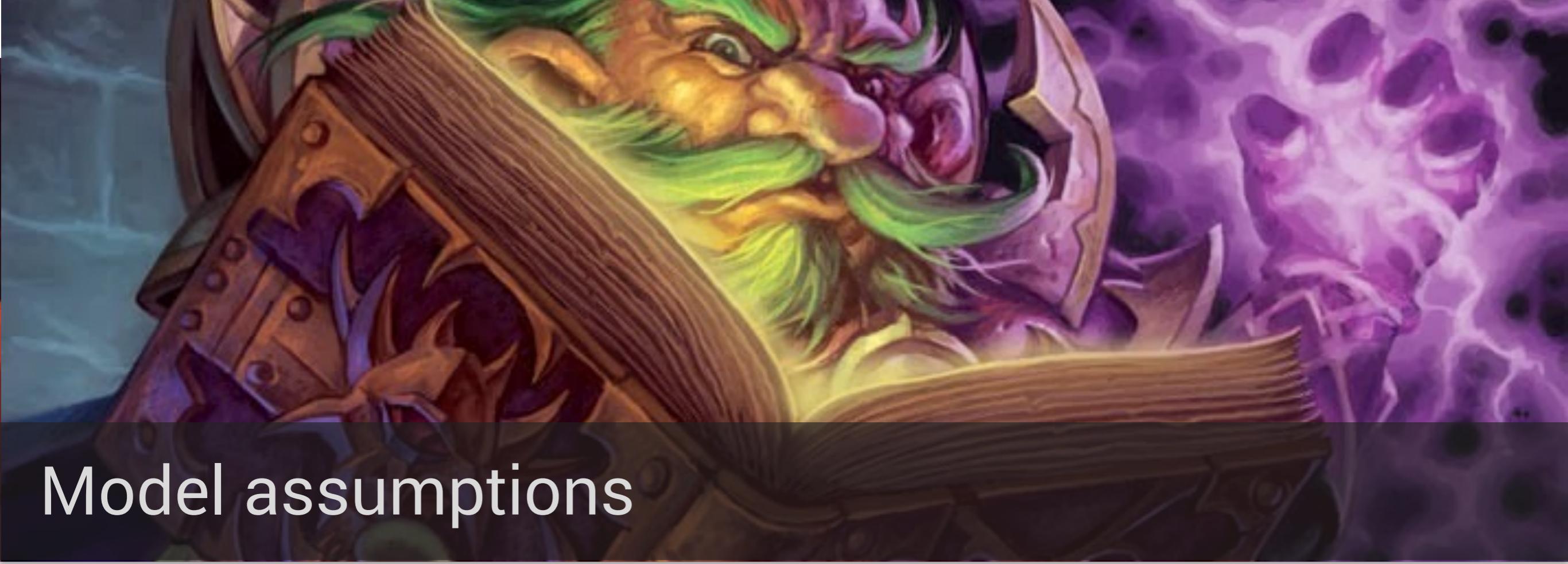




Finding undervalued cards

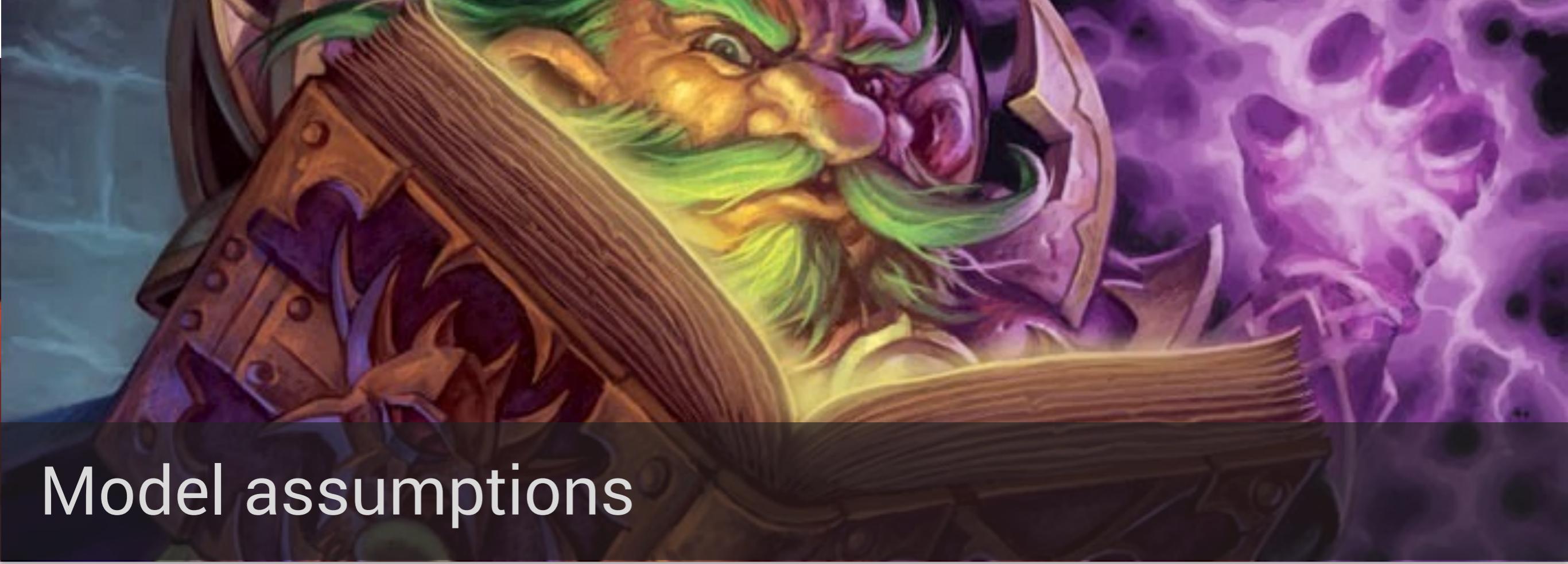


Model assumptions



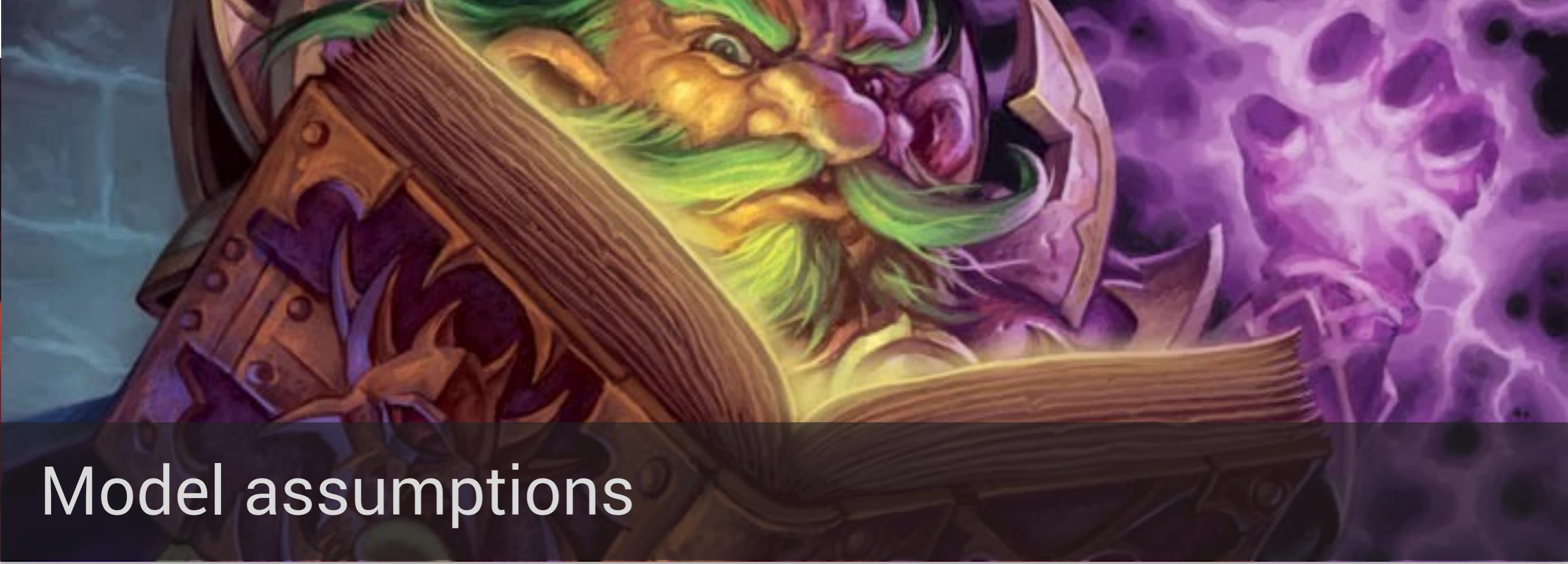
Model assumptions

1. Mana cost is proportional to card power



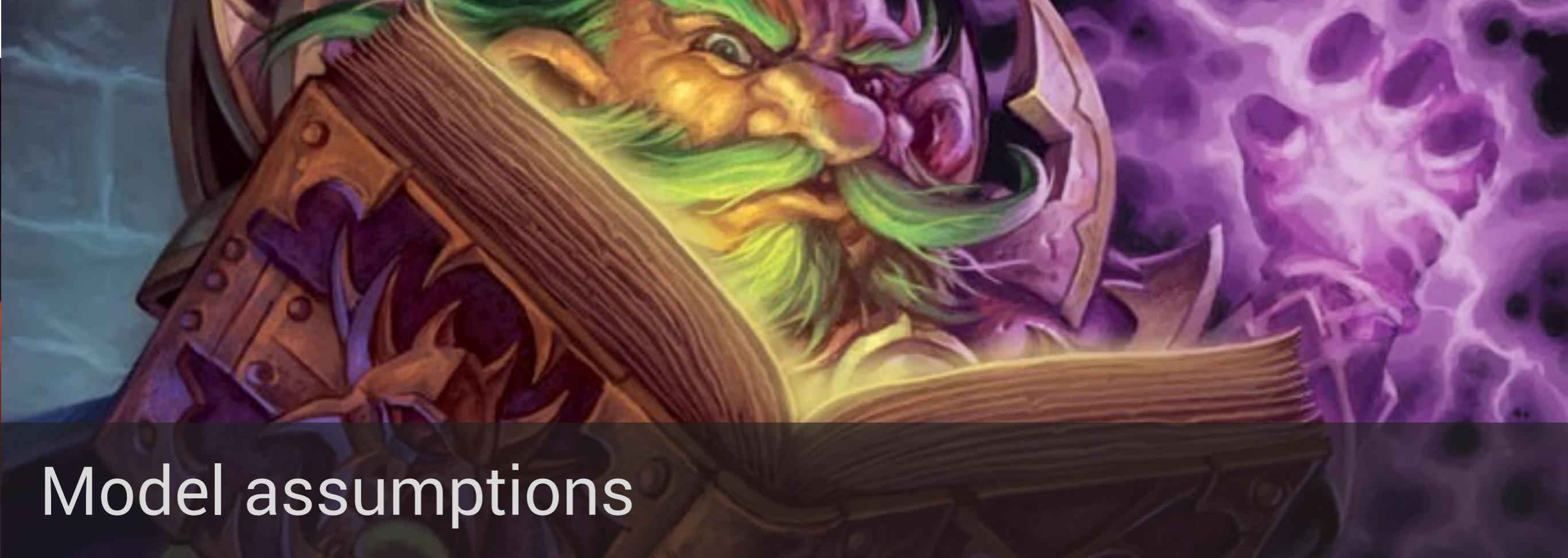
Model assumptions

1. Mana cost is proportional to card power
2. The power of cards increases roughly linearly



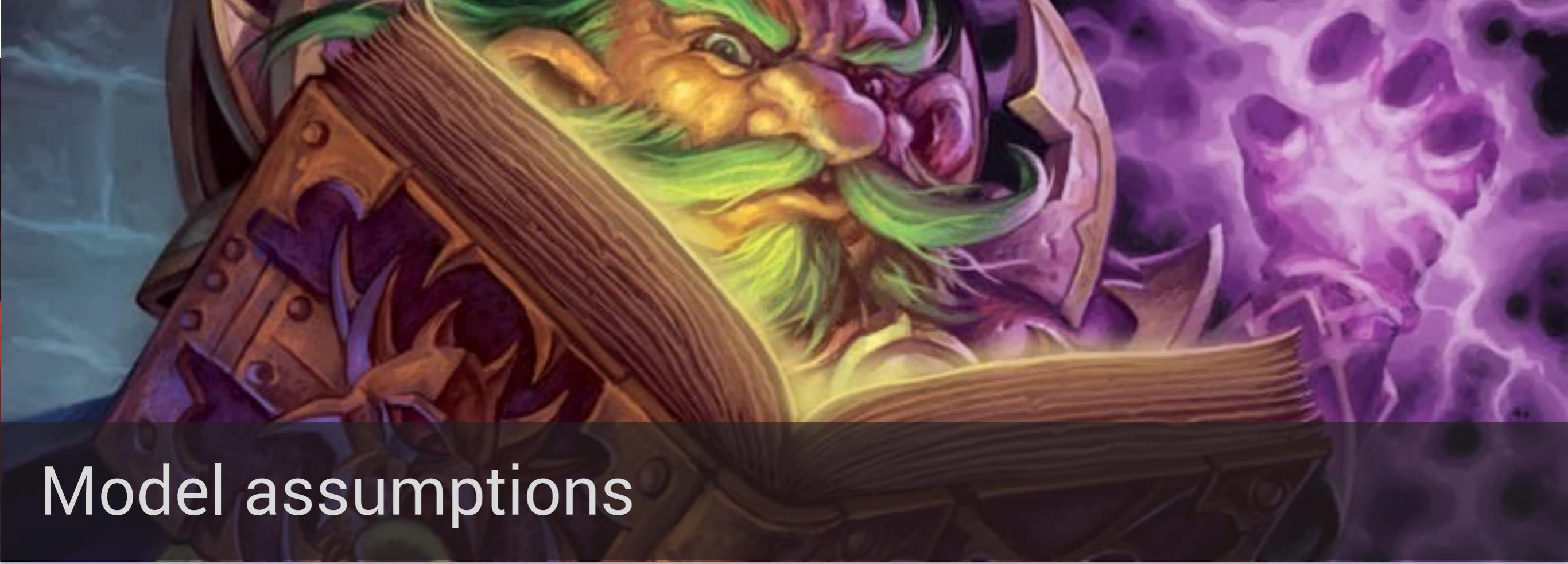
Model assumptions

1. Mana cost is proportional to card power
2. The power of cards increases roughly linearly
3. Card effects have constant prices



Model assumptions

1. Mana cost is proportional to card power
2. The power of cards increases roughly linearly
3. Card effects have constant prices
4. Cards have an intrinsic value



Model assumptions

1. Mana cost is proportional to card power
2. The power of cards increases roughly linearly
3. Card effects have constant prices
4. Cards have an intrinsic value
5. The value of a card is the sum of its attributes



mana = attack + health + intrinsic value



mana = attack + health + intrinsic value

$$4 = 4a + 5h + i$$

Thank you for the feedback!

The screenshot shows a blog post by Elie Bursztein. The title is "How to find automatically Hearthstone undervalued cards". The date is July, 2014. The post features a large image of Indiana Jones smiling. Below the image is a text block about the Black Lotus card in Hearthstone. A small image of the Black Lotus card is shown. The sidebar includes sections for "ABOUT ME" (with a photo of Elie), "LATEST BLOG POSTS" (listing several posts with thumbnails), and "POPULAR BLOG POSTS" (listing several posts with thumbnails).

Elie Bursztein

Follow me !

g+ t f in

Search

Home About me Blog Publications Software

How to find automatically Hearthstone undervalued cards

July, 2014

Like 10 Tweet 4 g+ 14 Share 6

Indiana Jones

Hearthstone, like any collectible card game, has cards that are over-powered for their mana cost. Using them in a deck improves the odds of winning as they are more mana efficient than cards that have a fair mana cost or are over-priced. However given Blizzard's constant monitoring none of the Hearthstone under-valued cards are as drastically overpowered as the Black Lotus in Magic the Gathering which makes them hard to spot manually. This is why I wrote a little software utility that automatically finds a card's true value and spots good bargains. So far I was able to use my tool to evaluate the price of 134 cards (~30% of Hearthstone) and I've found quite a few cards that are undervalued.

Black Lotus

I also hadn't had a chance to model the Naxxramas cards yet as I have been focus on finishing the research on

ABOUT ME

LATEST BLOG POSTS

POPULAR BLOG POSTS

<https://www.elie.net/hs>





$$6 = 6a + 7h + i$$



$$6 = 6a + 7h + i$$



$$6 = 6a + 7h + i$$



$$4 = 4a + 5h + i$$



$$6 = 6a + 7h + i$$

↓ /6

$$4 = 4a + 5h + i$$



$$6 = 6a + 7h + i$$

↓ /6

$$1 = 1a + 1.16h + i$$

$$4 = 4a + 5h + i$$



$$6 = 6a + 7h + i$$

↓ /6

$$1 = 1a + 1.16h + i$$

$$4 = 4a + 5h + i$$

↓ /4



$$6 = 6a + 7h + i$$

↓ /6

$$1 = 1a + 1.16h + i$$

$$4 = 4a + 5h + i$$

↓ /4

$$1 = 1a + 1.25h + i$$





$$4 = 6d \longrightarrow$$





$$4 = 6d \longrightarrow 1 \text{ mana} = 1.5 \text{ dmg}$$





$$4 = 6d \longrightarrow 1 \text{ mana} = 1.5 \text{ dmg}$$



$$10 = 10d$$



$$4 = 6d \longrightarrow 1 \text{ mana} = 1.5 \text{ dmg}$$



$$10 = 10d \longrightarrow 1 \text{ mana} = 1 \text{ dmg}$$



$$4 = 6d \longrightarrow 1 \text{ mana} = 1.5 \text{ dmg}$$



$$10 = 10d \longrightarrow 1 \text{ mana} = 1 \text{ dmg}$$

Pre nerf (8 mana)



$$4 = 6d \longrightarrow 1 \text{ mana} = 1.5 \text{ dmg}$$



$$10 = 10d \longrightarrow 1 \text{ mana} = 1 \text{ dmg}$$

Pre nerf (8 mana)

$$8 = 10d$$



$$4 = 6d \longrightarrow 1 \text{ mana} = 1.5 \text{ dmg}$$



$$10 = 10d \longrightarrow 1 \text{ mana} = 1 \text{ dmg}$$

Pre nerf (8 mana)

$$8 = 10d \longrightarrow 1 \text{ mana} = 1.25 \text{ dmg}$$



10 damage



4 damage



10 damage



4 damage



15 damage

6 damage

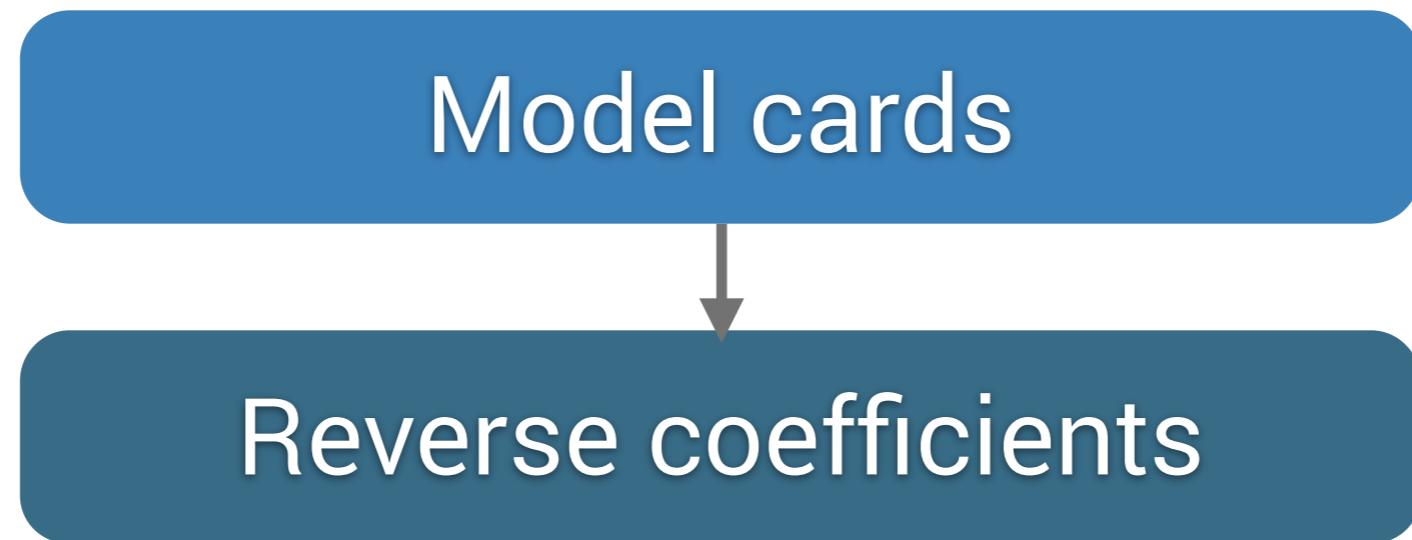


How to hunt for value cards

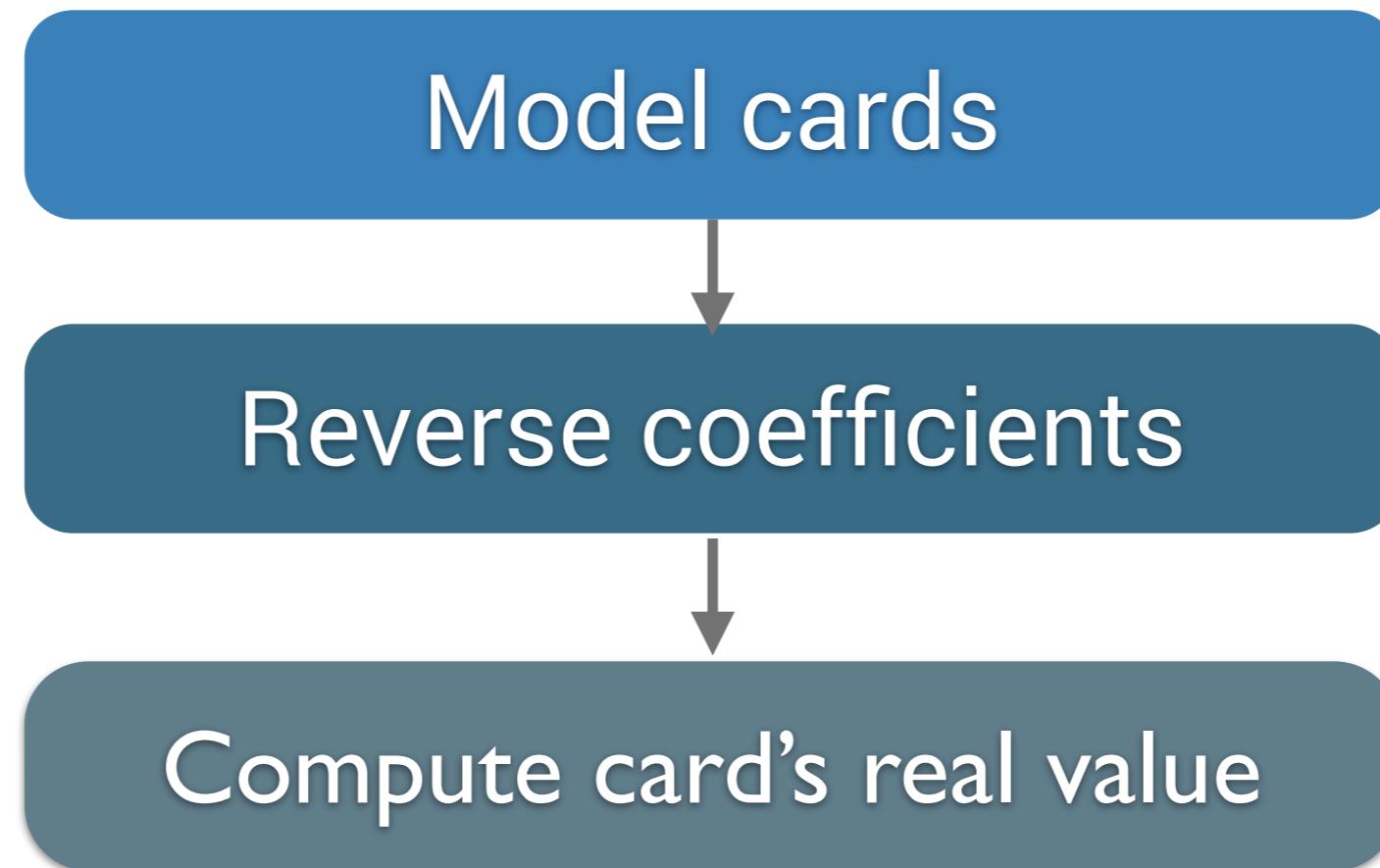
How to find undervalued cards?

Model cards

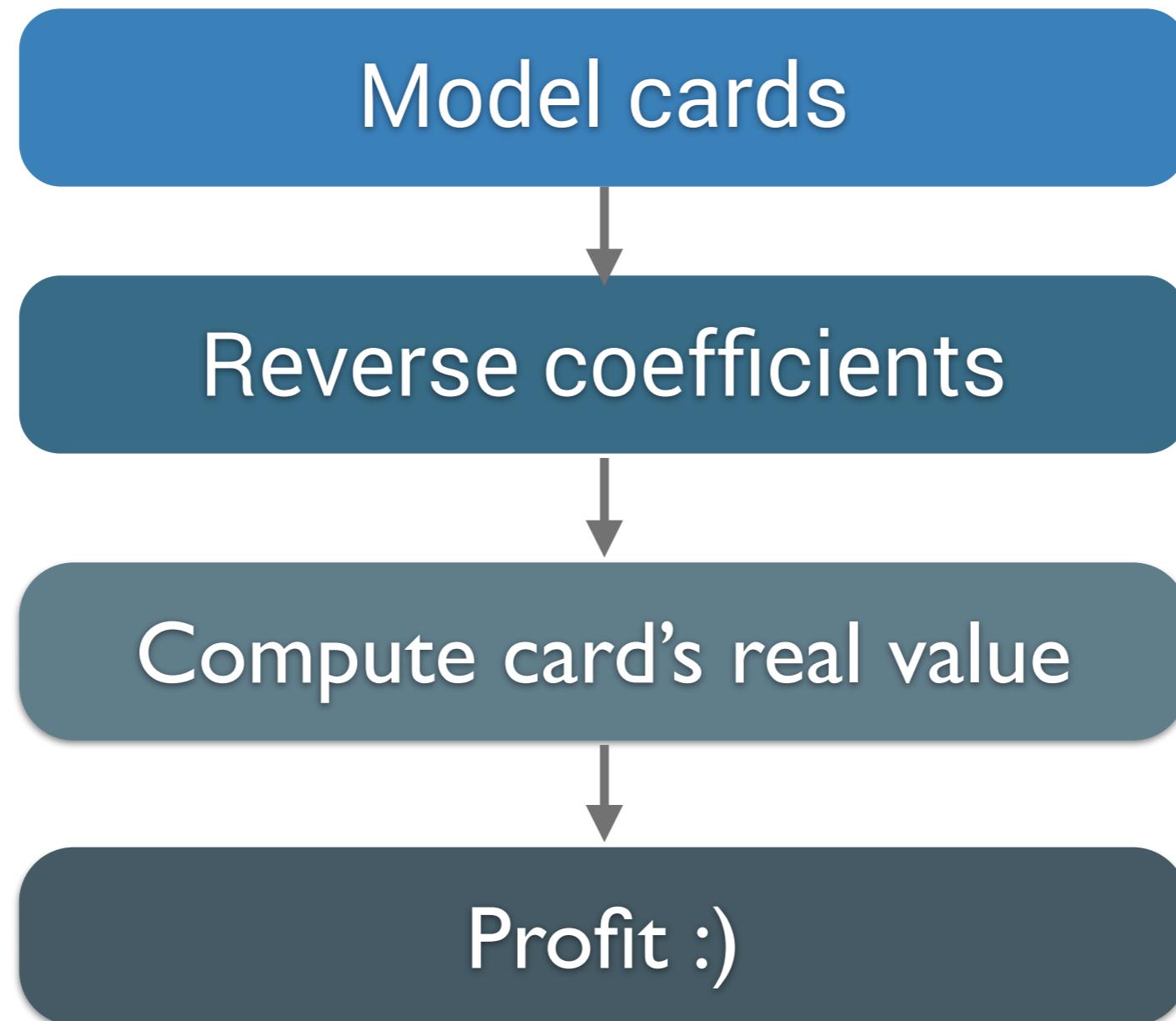
How to find undervalued cards?



How to find undervalued cards?



How to find undervalued cards?



Approach illustrated

Use mana cost instead of budget for clarity
Simple 5 card example to make it easy



Charge





Charge



Divine shield







$$4 = 4a + 3h + c + i$$





$$4 = 4a + 3h + c + i$$



$$3 = 3a + 1h + d + i$$



$$6 = 4a + 2h + c + d + i$$



$$6 = 5a + 2h + c + i$$



$$1 = 1a + 1h + d + i$$

Reversing attribute cost

Reversing attribute cost

Reversing attribute cost

mana Atk Health Charge Divine Intrinsic

Reversing attribute cost

mana	Atk	Health	Charge	Divine	Intrinsic
4	4	3	1	0	1

Reversing attribute cost

mana	Atk	Health	Charge	Divine	Intrinsic
4	4	3	1	0	1
6	5	2	1	0	1

Reversing attribute cost

mana	Atk	Health	Charge	Divine	Intrinsic
4	4	3	1	0	1
6	5	2	1	0	1
6	4	2	1	1	1

Reversing attribute cost

mana	Atk	Health	Charge	Divine	Intrinsic
4	4	3	1	0	1
6	5	2	1	0	1
6	4	2	1	1	1
3	3	1	0	1	1

Reversing attribute cost

mana	Atk	Health	Charge	Divine	Intrinsic
4	4	3	1	0	1
6	5	2	1	0	1
6	4	2	1	1	1
3	3	1	0	1	1
1	1	1	0	1	1

Reversing attribute cost

mana	Atk	Health	Charge	Divine	Intrinsic
4	4	3	1	0	1
6	5	2	1	0	1
6	4	2	1	1	1
3	3	1	0	1	1
1	1	1	0	1	1

Least
square

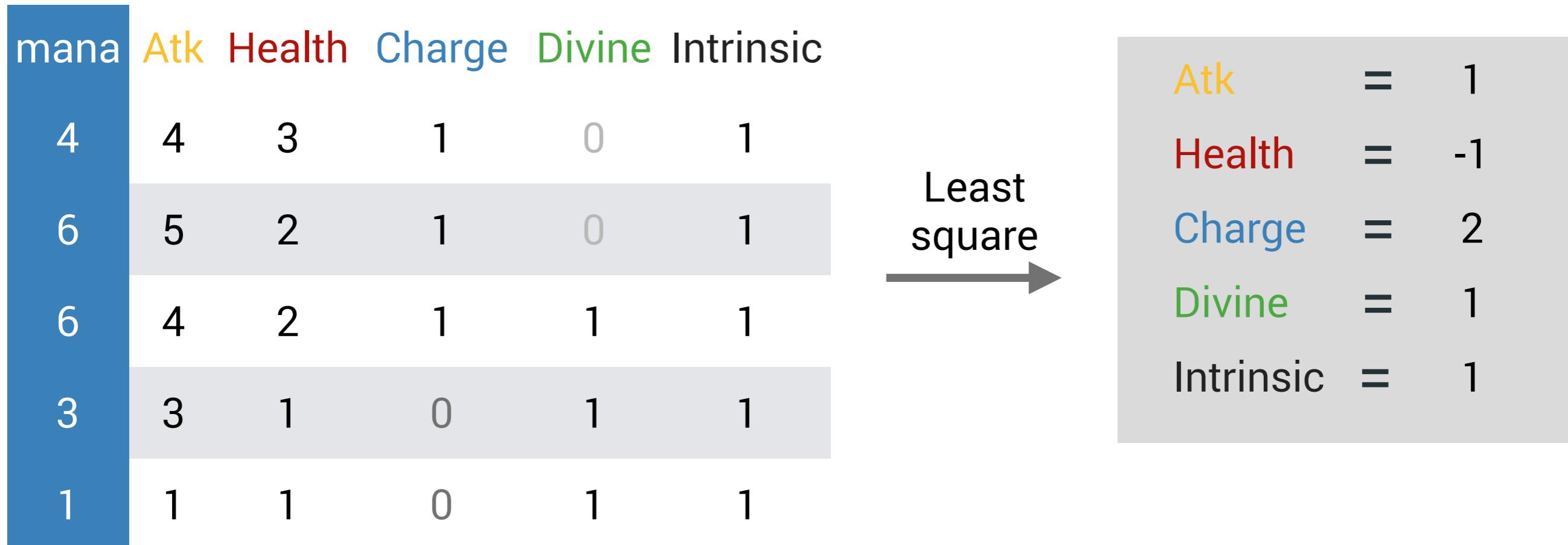
Reversing attribute cost

mana	Atk	Health	Charge	Divine	Intrinsic
4	4	3	1	0	1
6	5	2	1	0	1
6	4	2	1	1	1
3	3	1	0	1	1
1	1	1	0	1	1

Least
square

Atk	=	1
Health	=	-1
Charge	=	2
Divine	=	1
Intrinsic	=	1

Reversing attribute cost



Warning: These example attribute costs are bogus because we didn't use enough cards

Finding real prices using reversed coefficients



Coeffs: Charge = 2 Atk = 1 Health = -1 Divine = 1 Intrinsic = 1

Finding real prices using reversed coefficients



$$4a + 2h + c + d + i$$

Coeffs: Charge = 2 Atk = 1 Health = -1 Divine = 1 Intrinsic = 1

Finding real prices using reversed coefficients



$$4a + 2h + c + d + i$$

$$4*1 + 2*-1 + 2 + 1 + 1 = 6$$

Coeffs: Charge = 2 Atk = 1 Health = -1 Divine = 1 Intrinsic = 1

Finding real prices using reversed coefficients



$$4a + 2h + c + d + i$$

$$4*1 + 2*-1 + 2 + 1 + 1 = 6$$



Coeffs: Charge = 2 Atk = 1 Health = -1 Divine = 1 Intrinsic = 1

Finding real prices using reversed coefficients



$$4a + 2h + c + d + i$$

$$4*1 + 2*-1 + 2 + 1 + 1 = 6$$



$$1a + 1h + d + i$$

Coeffs: Charge = 2 Atk = 1 Health = -1 Divine = 1 Intrinsic = 1

Finding real prices using reversed coefficients



$$4a + 2h + c + d + i$$

$$4*1 + 2*-1 + 2 + 1 + 1 = 6$$



$$1a + 1h + d + i$$

$$1*1 + 1*-1 + 1 + 1 = 2$$

Coeffs: Charge = 2 Atk = 1 Health = -1 Divine = 1 Intrinsic = 1

Finding real prices using reversed coefficients



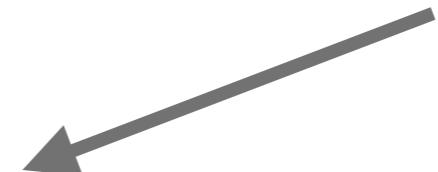
$$4a + 2h + c + d + i$$

$$4*1 + 2*-1 + 2 + 1 + 1 = 6$$



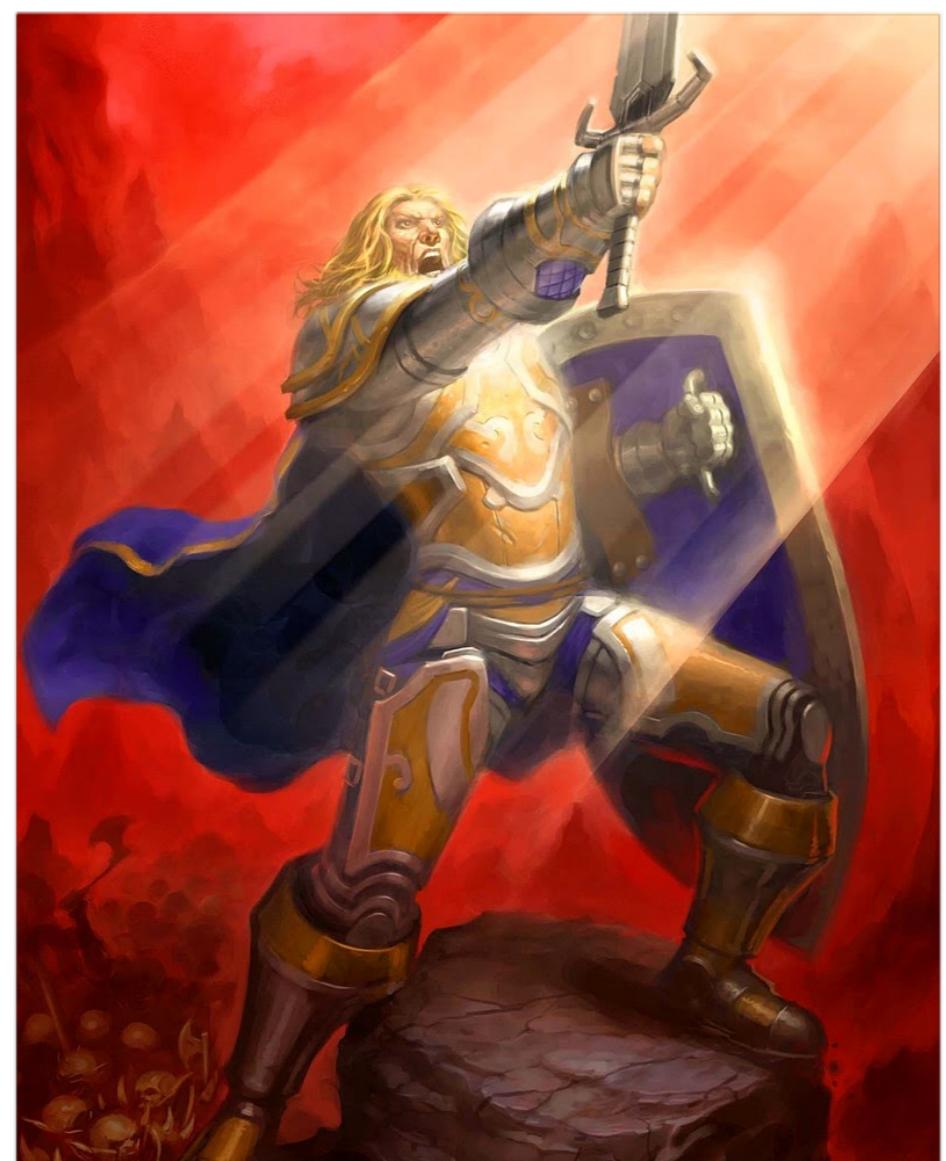
$$1a + 1h + d + i$$

$$1*1 + 1*-1 + 1 + 1 = 2$$



Under-valued
card!

Coeffs: Charge = 2 Atk = 1 Health = -1 Divine = 1 Intrinsic = 1



Modeling dependence between characteristics

Charge = Atk * charge coeff

Windfury = Atk * windfury coeff

Divine = ? (health related?)

Thanks to Niels for the idea



Et voila!

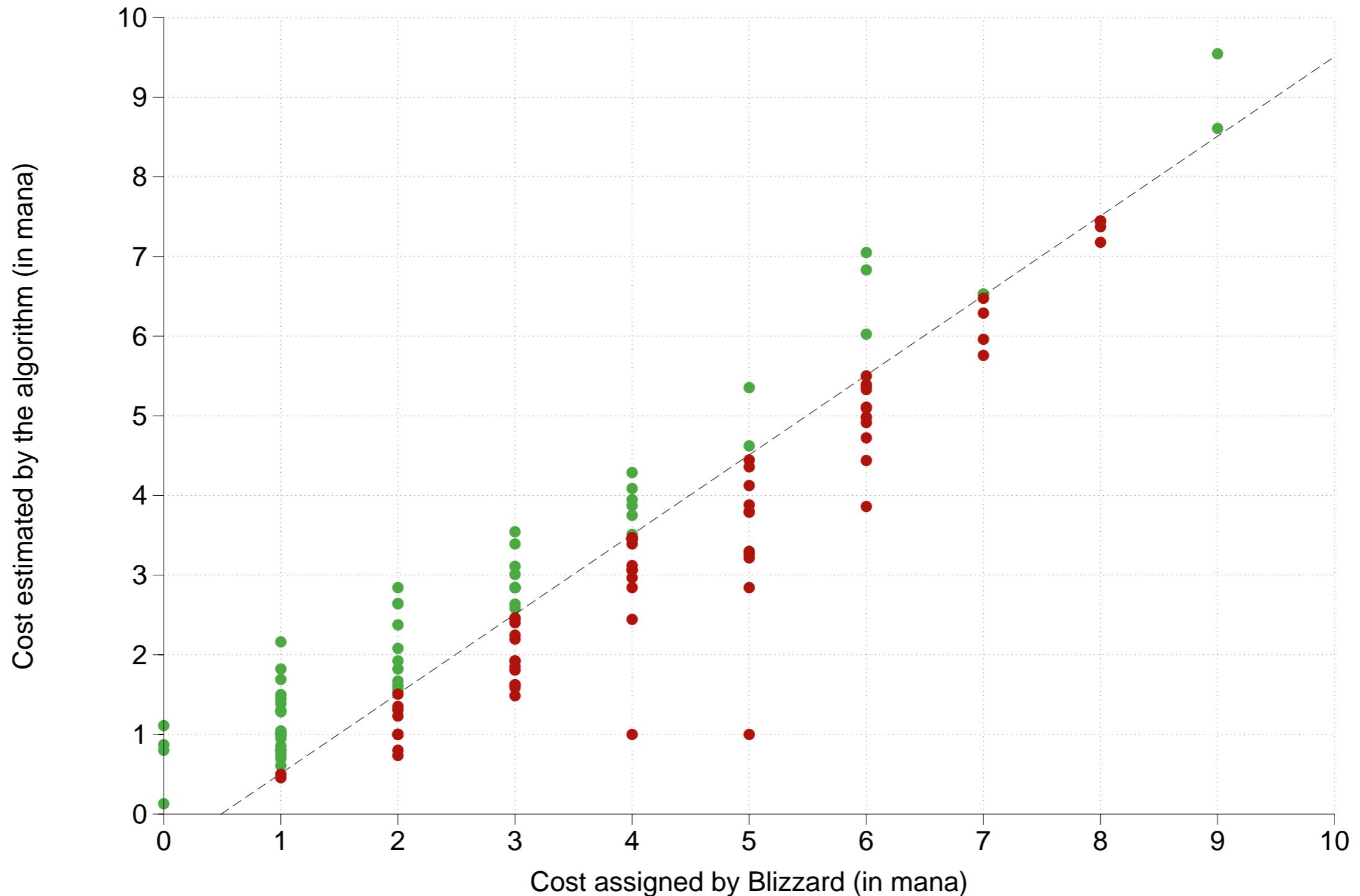
Reversed budget coefficients

Effect	cost per point
Destroy minion	10.63
Board damage	3.69
Draw card	3.68
Divine Shield	2.74
Freeze	2.04
Silence	1.66
Damage	1.64
Durability	1.22
Stealth	1.21
Attack	1.14
Taunt	1.02
WindFury	0.96
SpellPower	0.93
Health	0.81
Battlecry: heal	0.69
Battlecry: self hero heal	0.68
Charge	0.65
Intrinsic value	0.32

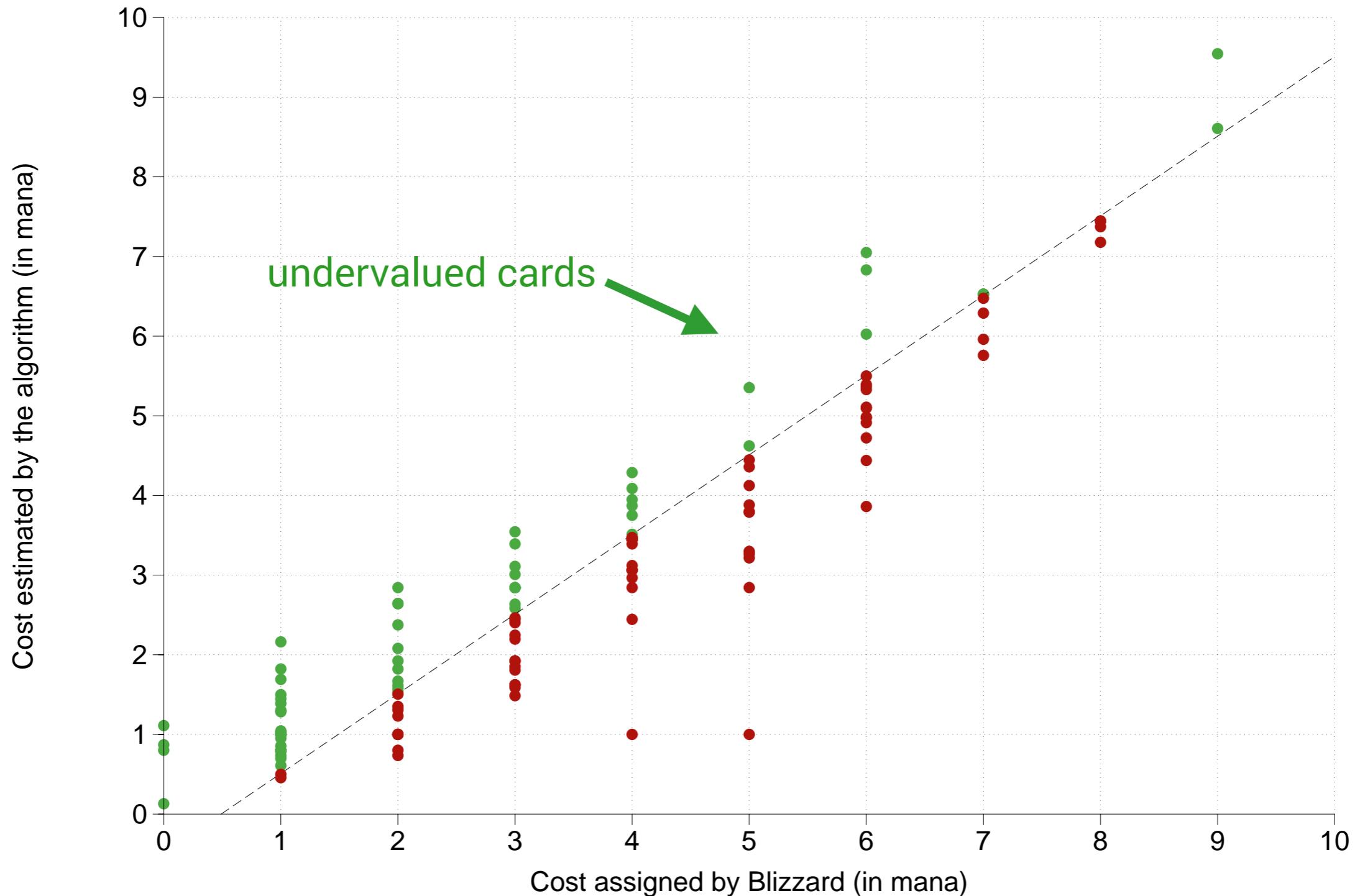
Reversed budget coefficients

Effect	cost per point
Destroy minion	10.63
Board damage	3.69
Draw card	3.68
Divine Shield	2.74
Freeze	2.04
Silence	1.66
Damage	1.64
Durability	1.22
Stealth	1.21
Attack	1.14
Taunt	1.02
WindFury	0.96
SpellPower	0.93
Health	0.81
Battlecry: heal	0.69
Battlecry: self hero heal	0.68
Charge	0.65
Intrinsic value	0.32

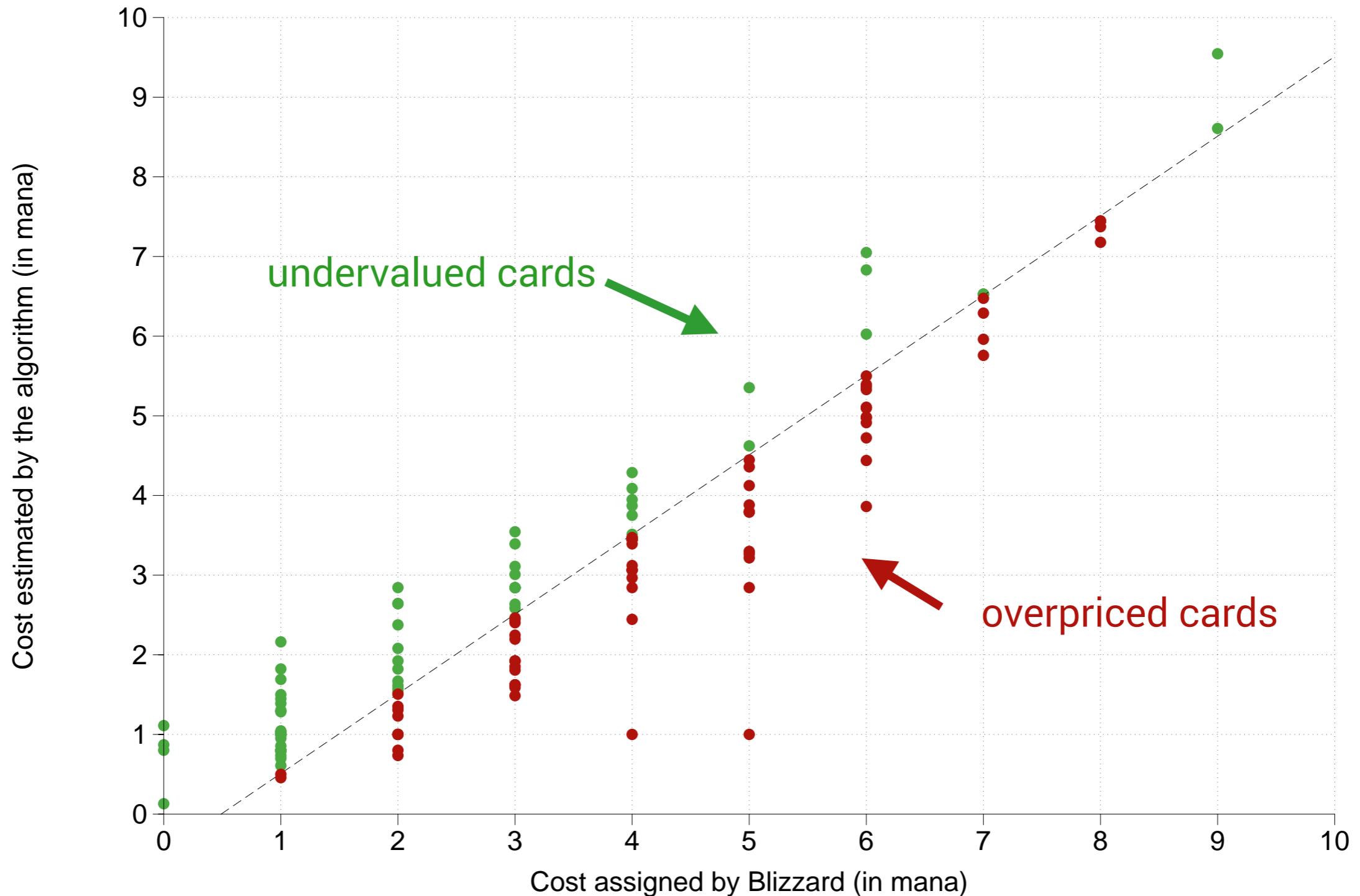
Effect	Cost per point
Opponent draw card	-3.97
Discard cards	-2.67
Overload	-1.68
Self hero damage	-0.54



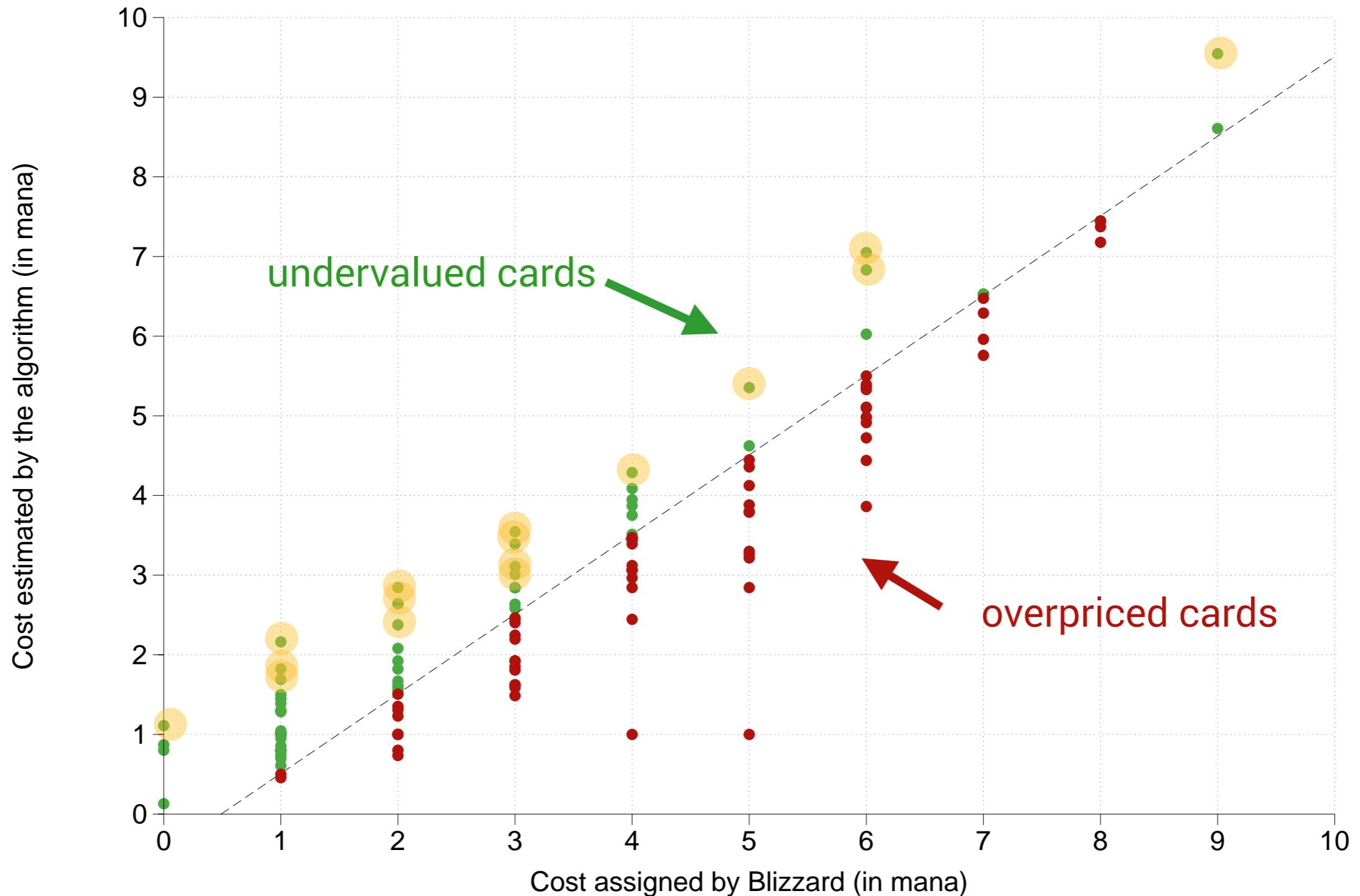
Model found several clearly undervalued cards :)



Model found several clearly undervalued cards :)



Model found several clearly undervalued cards :)



Model found several clearly undervalued cards :)

Most under-valued cards

1.3	0	Soulfire	
2.2	1	Light's Justice	
0.9	0	Backstab	
1.8	1	Mortal Coil	
1.7	1	Power Word: Shield	
0.7	0	Sacrificial Pact	
1.5	1	Argent Squire	
2.8	2	Explosive Trap	
1.4	1	Voidwalker	
2.7	2	Frostbolt	
2.7	2	Slam	
1.3	1	Worgen Infiltrator	
1.3	1	Shieldbearer	
1.3	1	Voodoo Doctor	
7.3	6	Fire Elemental	

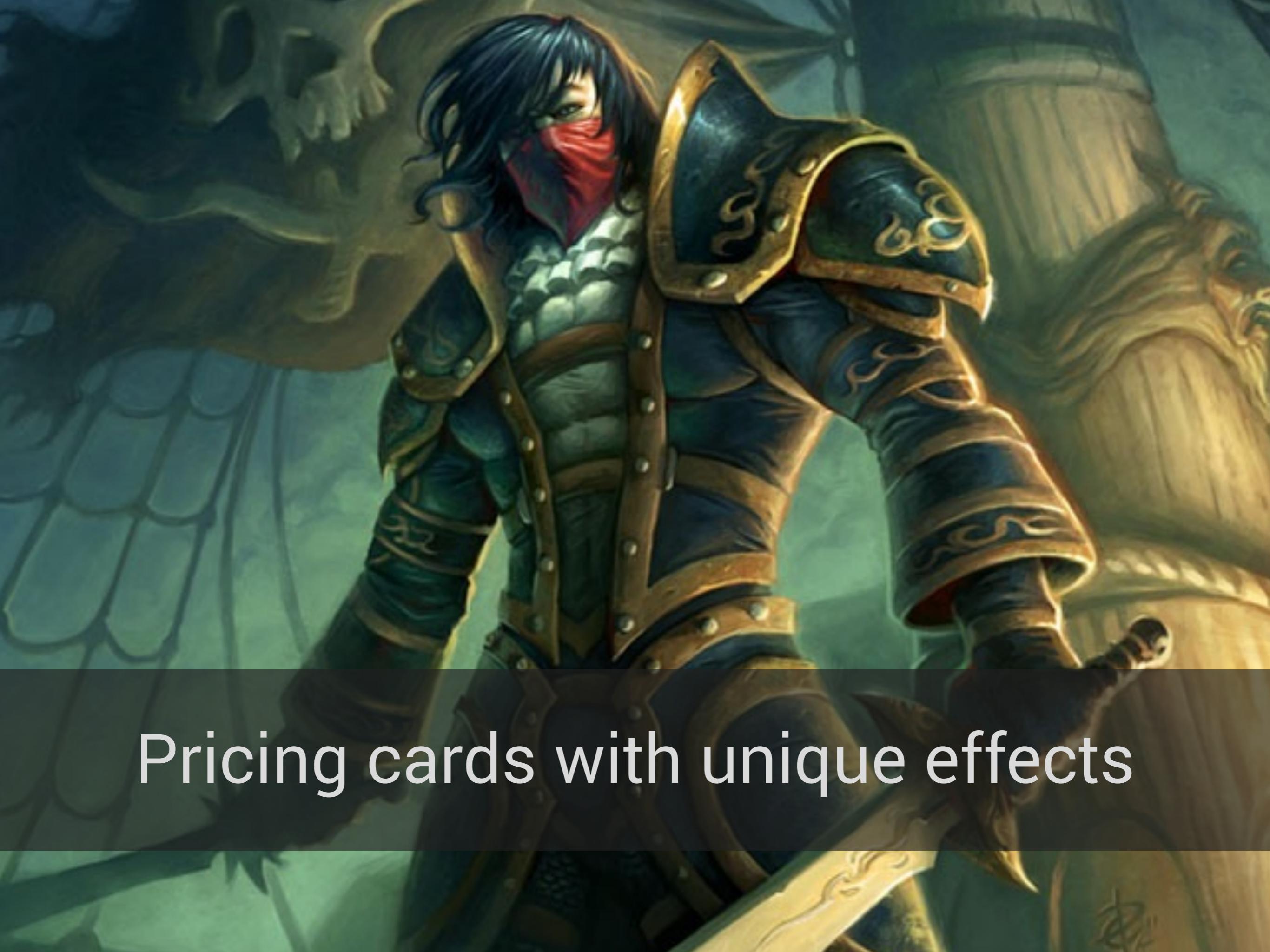
A dynamic illustration of a female character with blonde hair, wearing a dark, futuristic suit with glowing blue and green highlights. She is shouting with her mouth wide open, and a large, glowing yellow and orange energy shield surrounds her. The background is filled with bright, radial energy rays.

Taking it to the next level



Game replays

- 100,000 games from May to June
- Thanks to ... for them :)
- Need a longer term solution



Pricing cards with unique effects



Cards in
hand



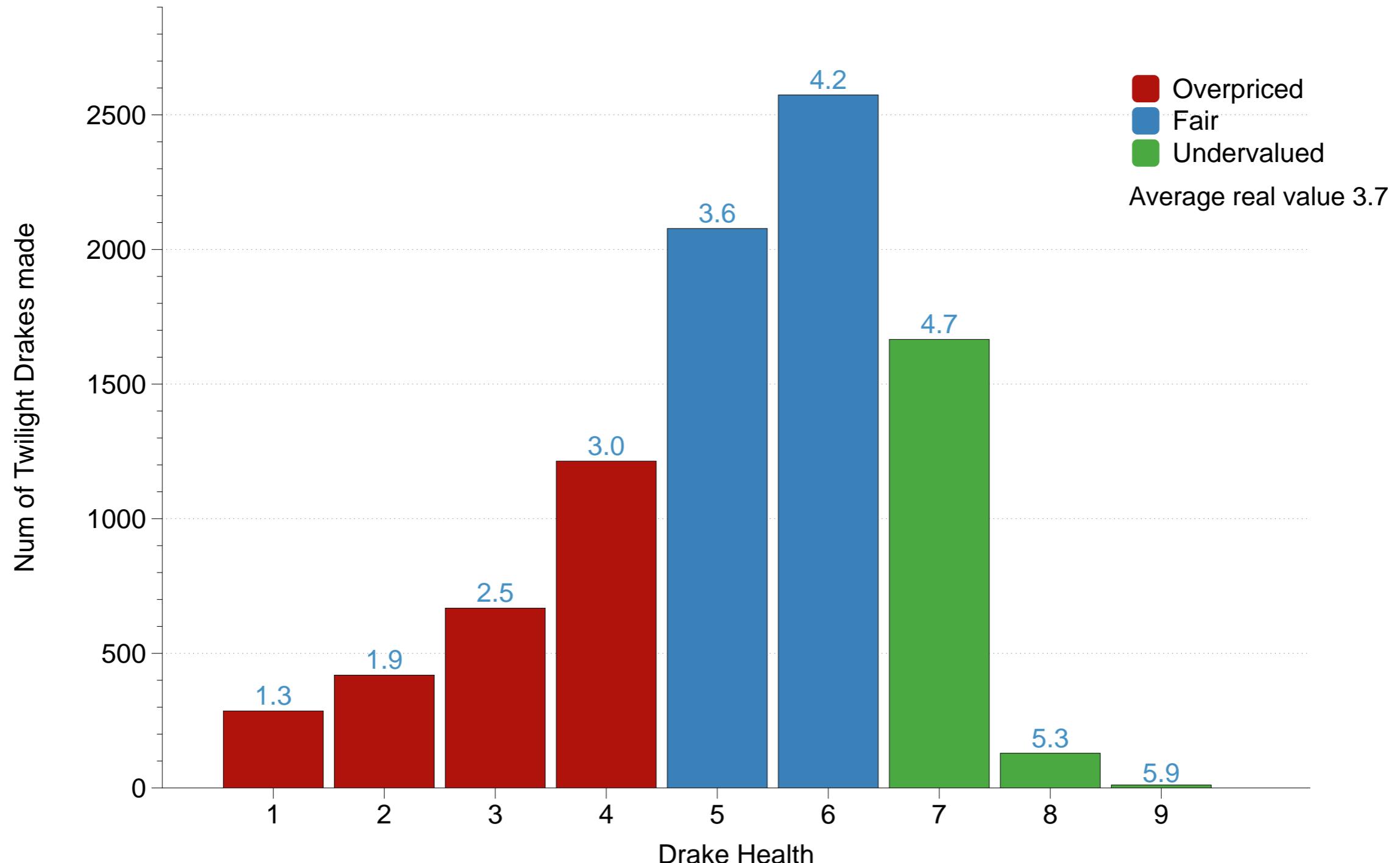
Cards in
hand

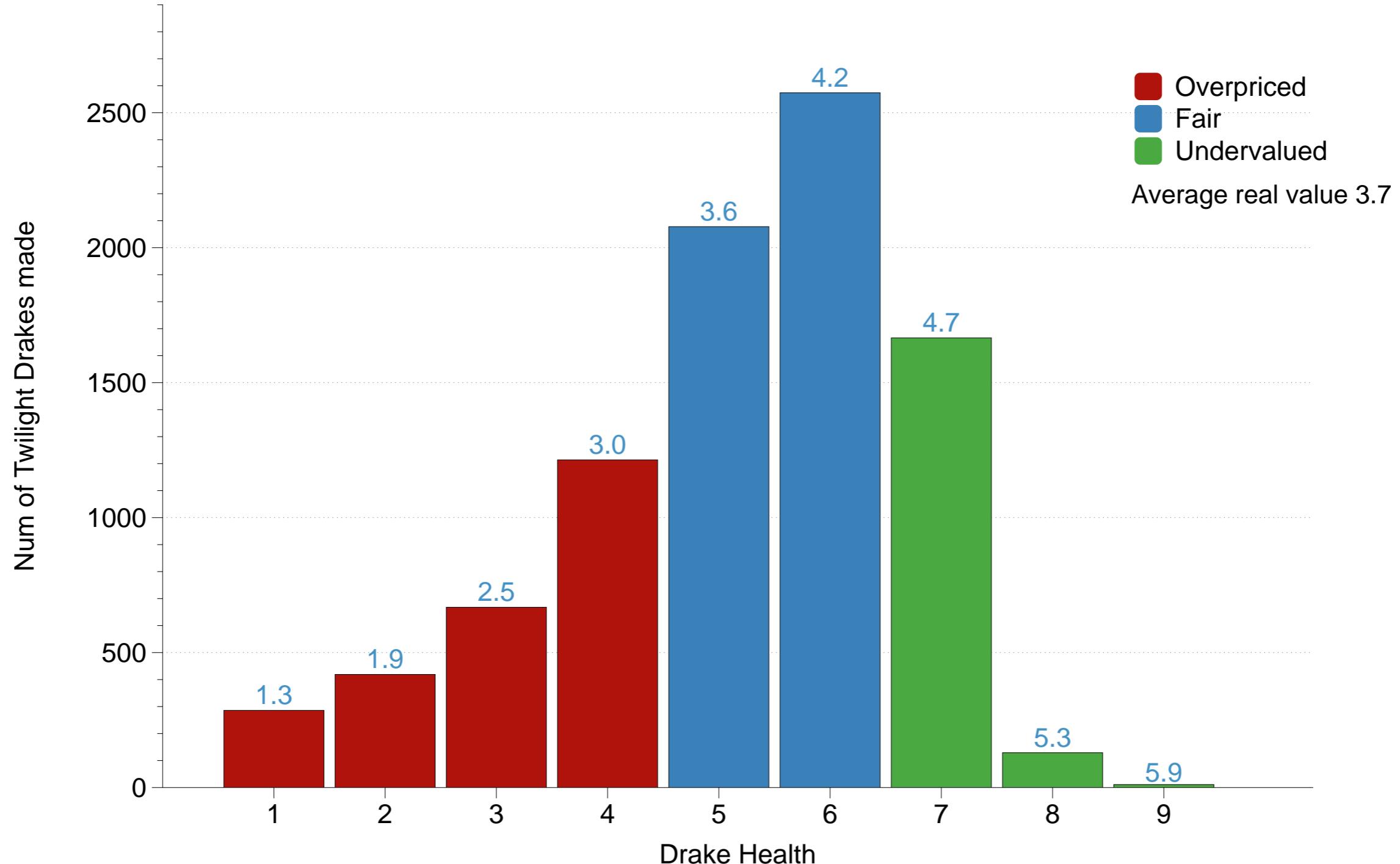


Cards in
hand



Health	Real Value
1	1.3
2	1.9
3	2.5
4	3
5	3.6
6	4.1
7	4.7
8	5.3
9	5.9





Twilight Drake's price is **fair**





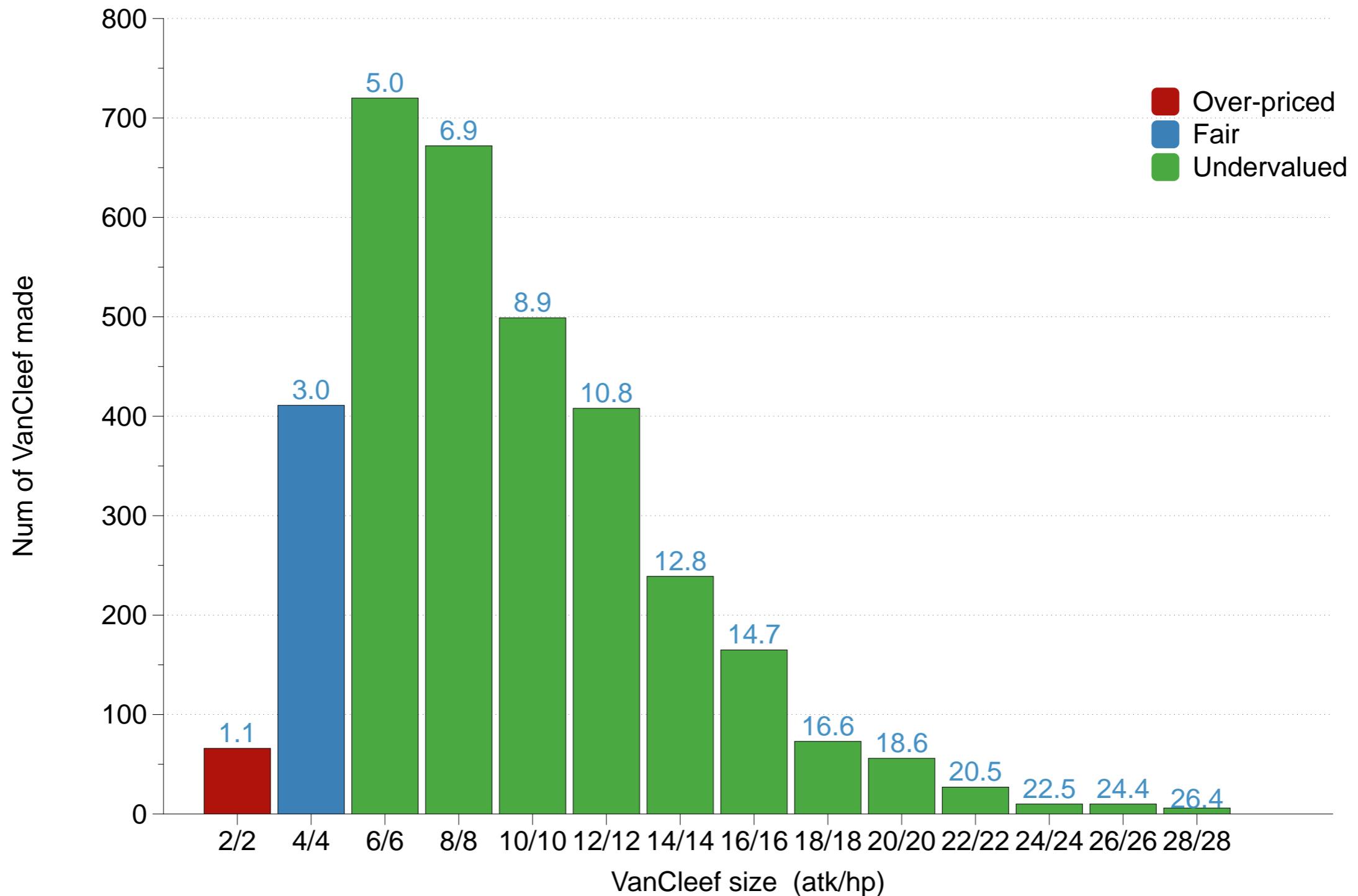


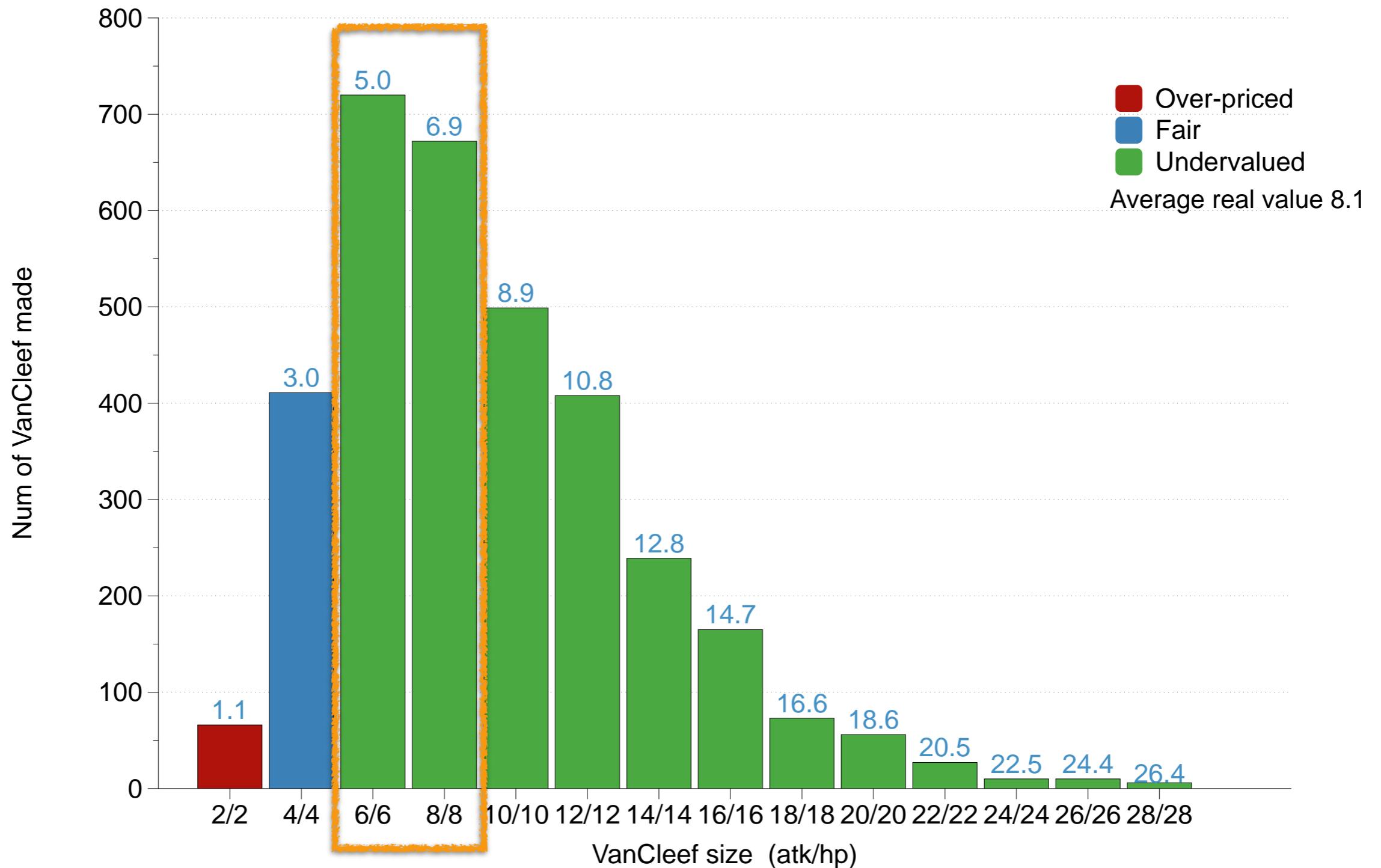
Cards
played
this turn

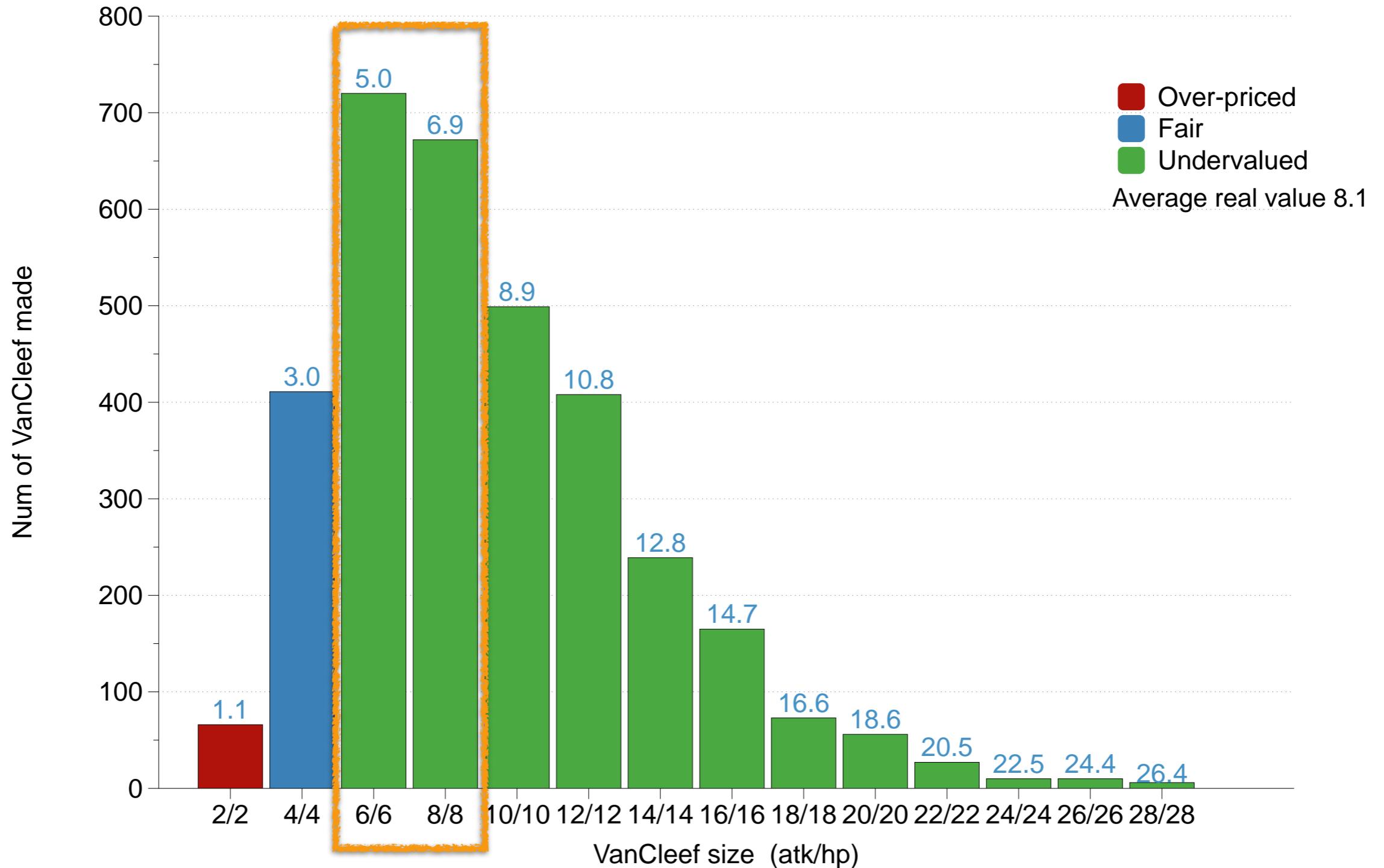


→
Cards
played
this turn

Edwin size	Real value
2/2	1.09
4/4	3.04
6/6	4.98
8/8	6.92
10/10	8.87
12/12	10.51
14/14	12.75
16/16	14.70
18/18	16.64
20/20	18.58
22/22	20.53







VanCleef is **undervalued**, a fair price is probably between 6 and 8 mana







→
Num
Minions



Num
Minions

Damage	Real Value
4	2.43835
8	5.71835
12	8.99835
16	12.27835
20	15.55835
24	18.83835
28	22.11835

Normal damage coeff



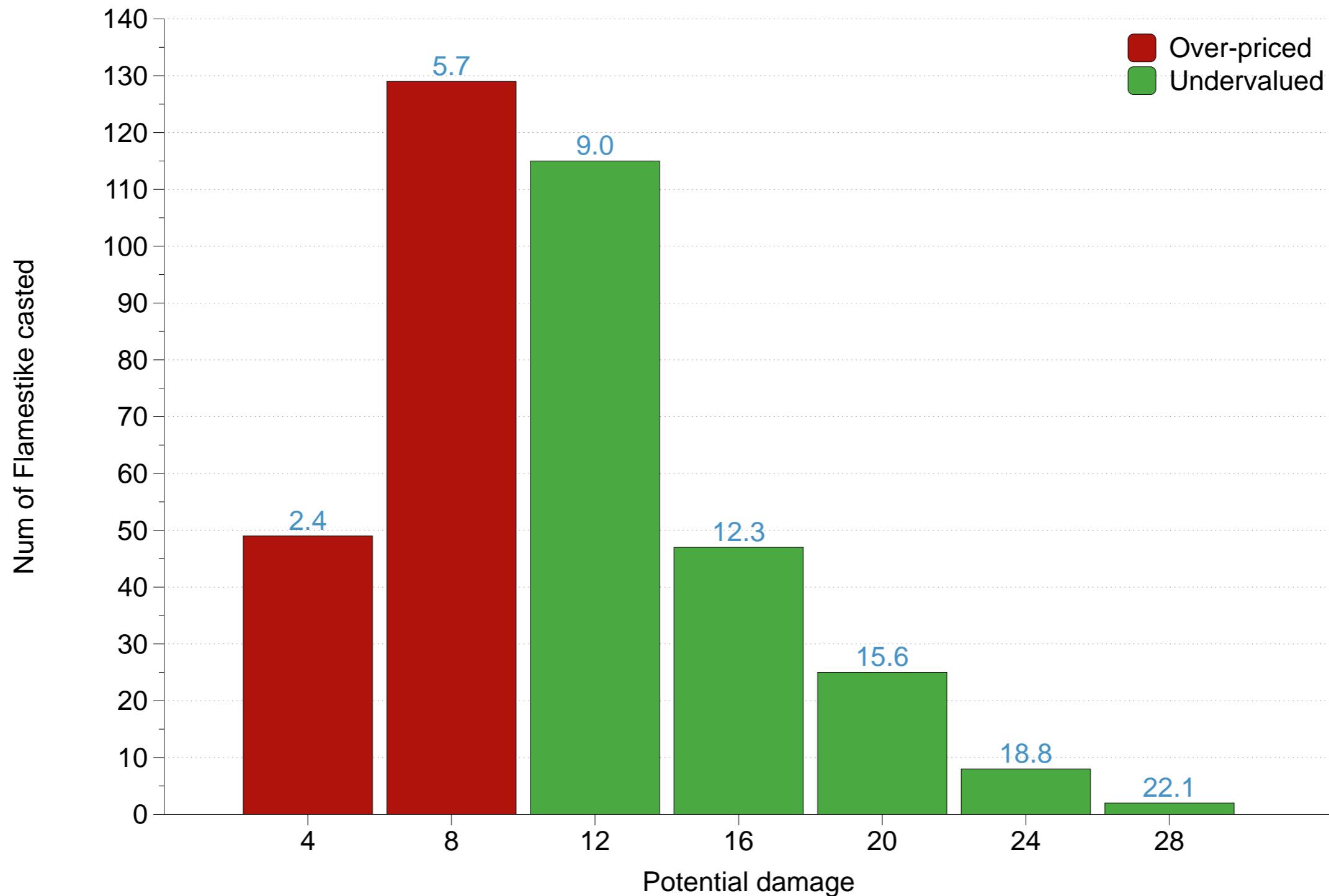
→
Num
Minions



Num
Minions

Damage	Value
4	6.5
8	13.9
12	21.3
16	28.6
20	36.0
24	43.4
28	50.7

Board damage coeff



Flamestrike's price is **fair**
Don't split board damage and single damage coeff



Predicting opponent's deck

Dashboard

Started 03:13PM

MANA ADVANTAGE 3

DRAW ADVANTAGE 1

HAND ADVANTAGE 3

Me - ZOO NAXX

	T	P	D
0 Soulfire	2	0	0
1 Abusive Sergeant	2	0	0
1 Argent Squire	2	1	0
1 Elven Archer	1	0	0
1 Flame Imp	2	1	0
1 Power Overwhelming	1	0	0
1 Voidwalker	2	1	0
2 Dire Wolf Alpha	2	0	0
2 Haunted Creeper	2	0	0
2 Knife Juggler	2	0	0
2 Nerubian Egg	2	0	0
3 Blood Knight	1	0	0
3 Harvest Golem	2	0	0
3 Void Terror	1	0	0
4 Dark Iron Dwarf	1	0	0
4 Defender of Argus	2	0	0
4 Leeroy Jenkins	1	0	0
5 Doomguard	2	0	0

My opponent - Cealtea

	T	P	D
0 Backstab	1	0	1

Predicted deck

0 Backstab	66.67	
1 Deadly Poison	20.86	
2 Eviscerate	4.19	
2 Betrayal	1.14	
1 Sinister Strike	1.05	
6 Holy Fire	0.67	

The screenshot shows a Hearthstone game interface. On the left, the player's dashboard displays statistics: Started at 03:13PM, Mana Advantage 3, Draw Advantage 1, Hand Advantage 3. Below this is the player's deck list for 'Me - ZOO NAXX' with columns T P D. The predicted deck for the opponent 'Cealtea' is also shown. The main board view shows the player's turn. A 'Backstab' card is played, dealing 2 damage to an undamaged minion. The board includes cards like Soulfire, Dire Wolf Alpha, and various minions like Flame Imp, Voidwalker, and Nerubian Egg. The player has 29 health and 3 mana, while the enemy has 27 health and 0 mana.

Our tool :)



Dashboard

Started 03:13PM

MANA ADVANTAGE 3

DRAW ADVANTAGE 1

HAND ADVANTAGE 3

Me - ZOO NAXX

	T	P	D
0 Soulfire	2	0	0
1 Abusive Sergeant	2	0	0
1 Argent Squire	2	1	0
1 Elven Archer	1	0	0
1 Flame Imp	2	1	0
1 Power Overwhelming	1	0	0
1 Voidwalker	2	1	0
2 Dire Wolf Alpha	2	0	0
2 Haunted Creeper	2	0	0
2 Knife Juggler	2	0	0
2 Nerubian Egg	2	0	0
3 Blood Knight	1	0	0
3 Harvest Golem	2	0	0
3 Void Terror	1	0	0
4 Dark Iron Dwarf	1	0	0
4 Defender of Argus	2	0	0
4 Leeroy Jenkins	1	0	0
5 Doomguard	2	0	0

My opponent -

	T	P	D
0 Backstab	1	0	1

Predicted deck

0 Backstab	66.67
1 Deadly Poison	20.86
2 Eviscerate	4.19
2 Betrayal	1.14
1 Sinister Strike	1.05
6 Holy Fire	0.67

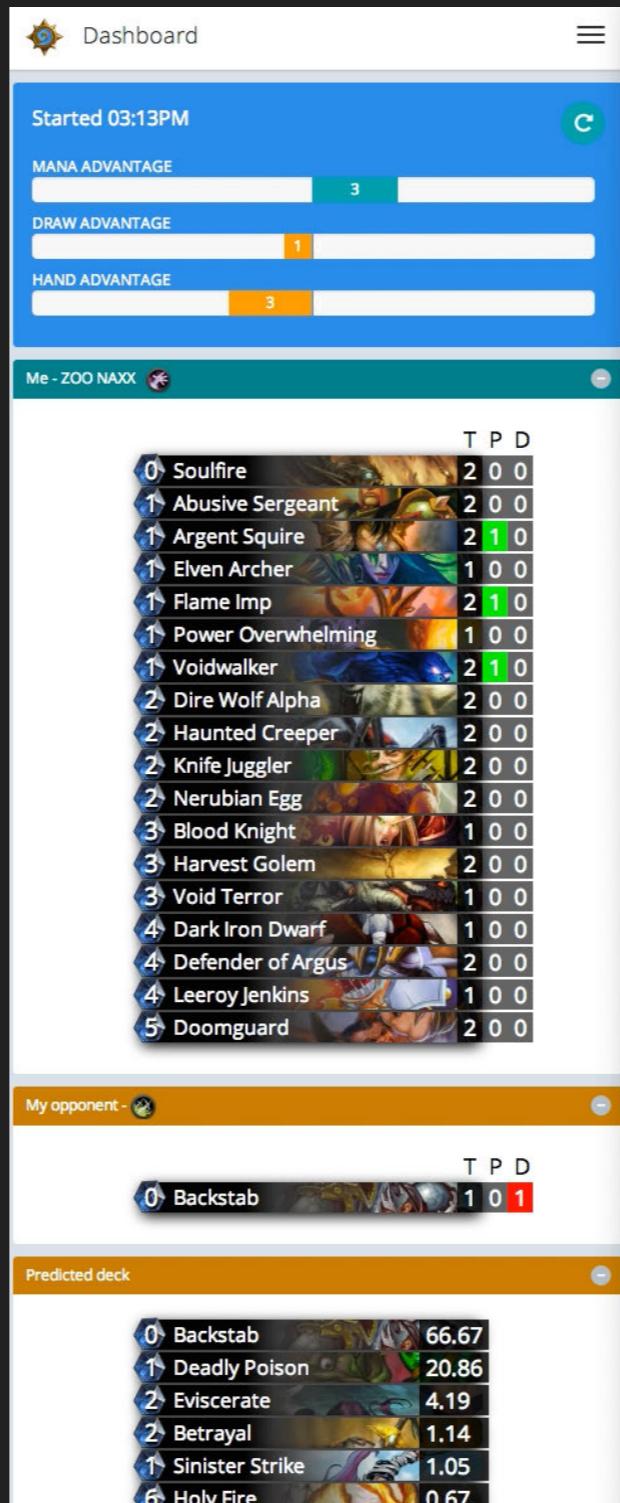


Real time dashboard



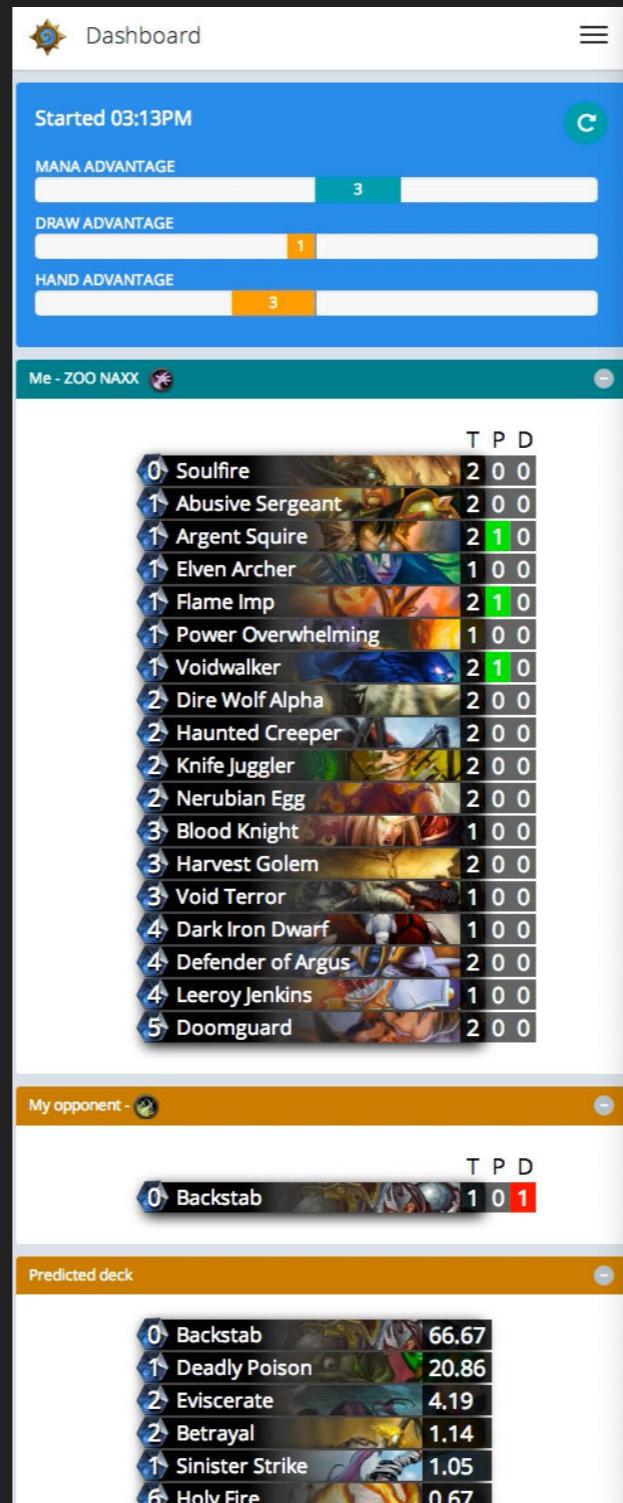
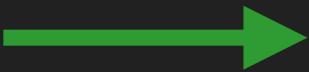
Real time dashboard

Game metrics



Real time dashboard

Game metrics

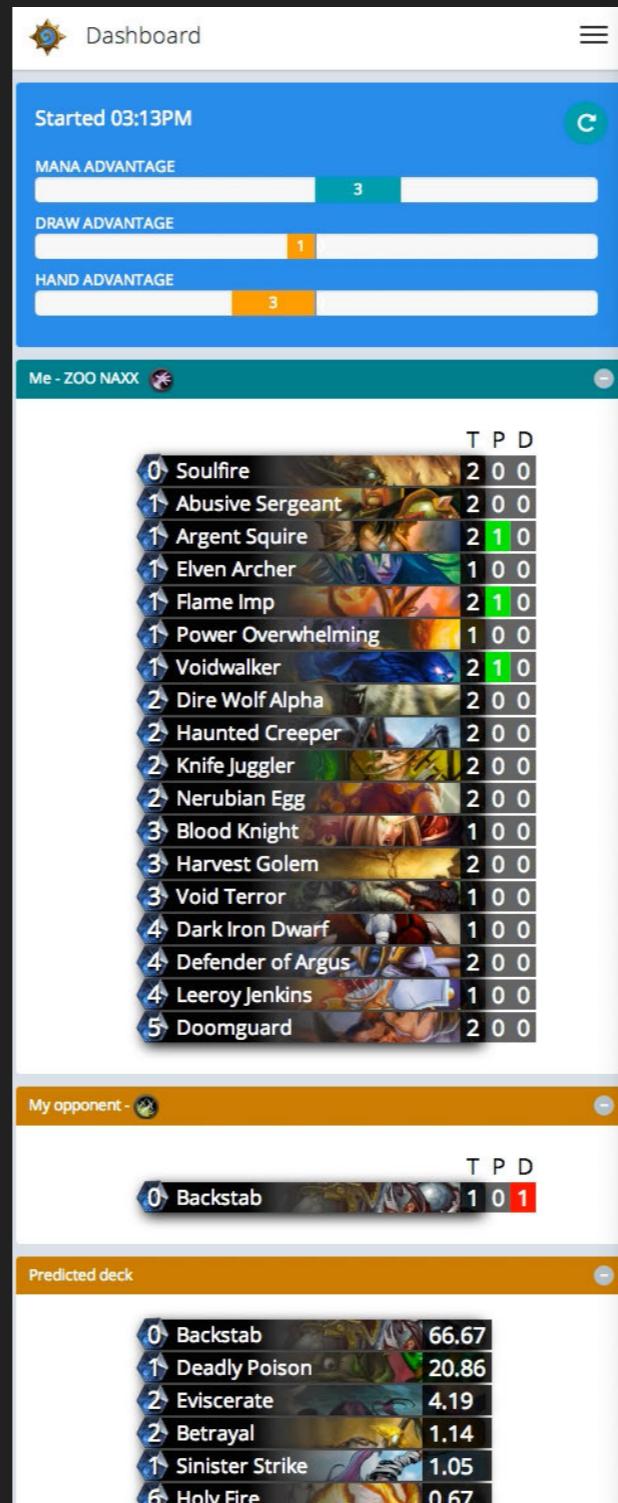


My deck with
card tracking

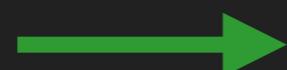


Real time dashboard

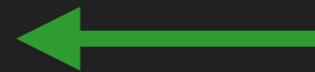
Game metrics



Opponent's cards
played so far

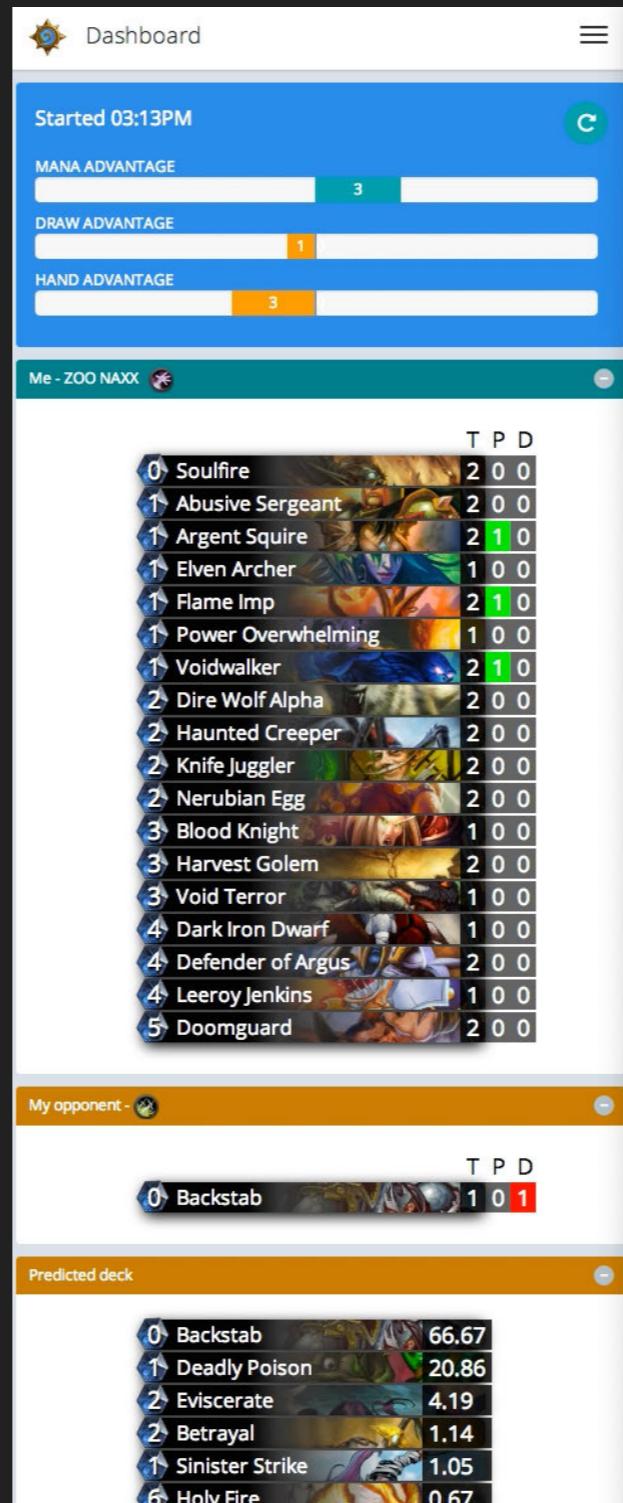


My deck with
card tracking

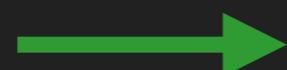


Real time dashboard

Game metrics



Opponent's cards
played so far



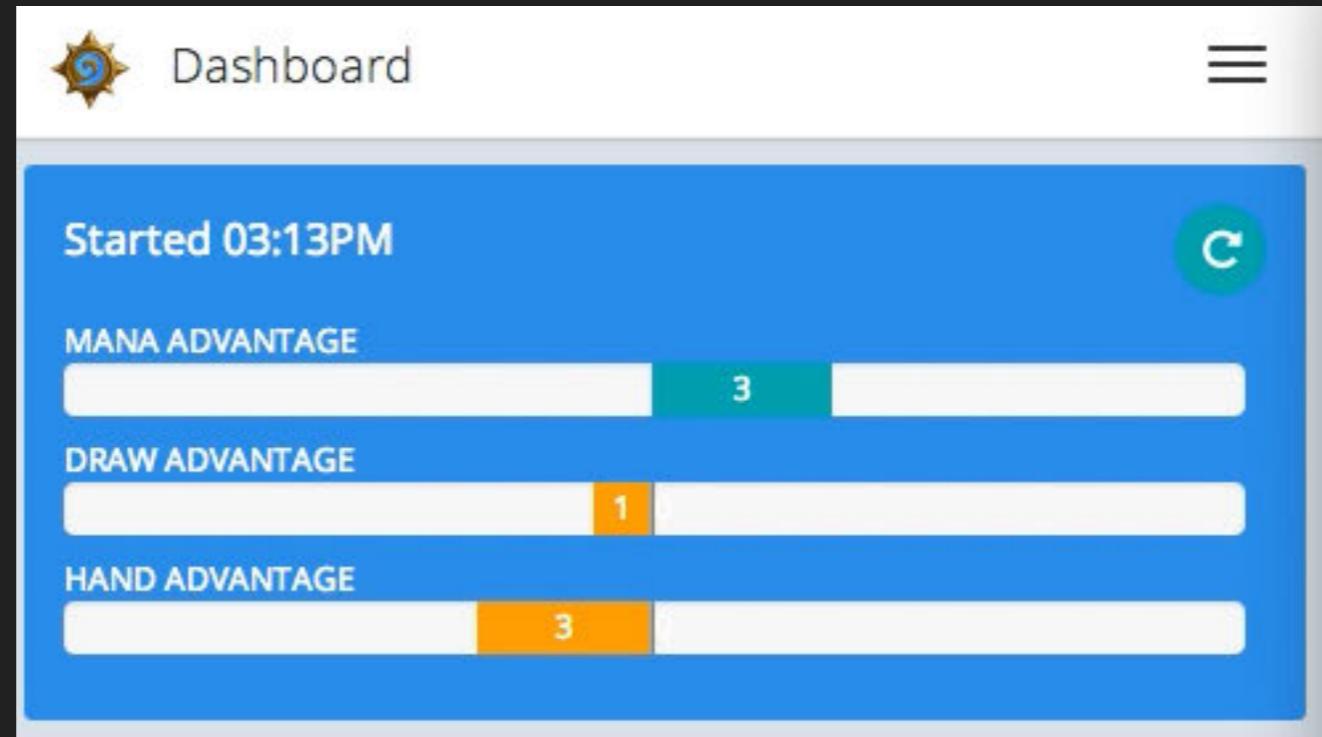
My deck with
card tracking



Opponent's next
card prediction



Game Metrics



Me

Opponent

My deck

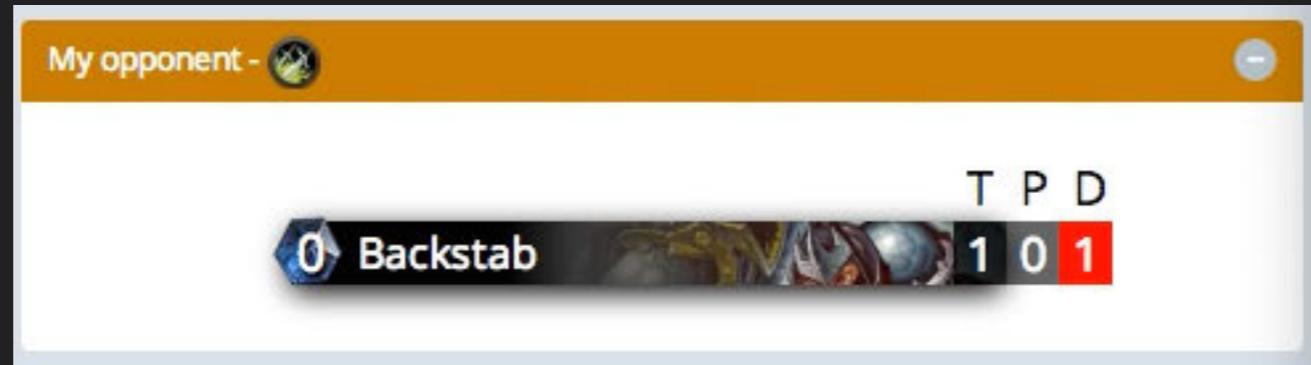
		T	P	D
0	Soulfire	2	0	0
1	Abusive Sergeant	2	0	0
1	Argent Squire	2	1	0
1	Elven Archer	1	0	0
1	Flame Imp	2	1	0
1	Power Overwhelming	1	0	0
1	Voidwalker	2	1	0
2	Dire Wolf Alpha	2	0	0
2	Haunted Creeper	2	0	0
2	Knife Juggler	2	0	0
2	Nerubian Egg	2	0	0
3	Blood Knight	1	0	0
3	Harvest Golem	2	0	0
3	Void Terror	1	0	0
4	Dark Iron Dwarf	1	0	0
4	Defender of Argus	2	0	0
4	Leeroy Jenkins	1	0	0
5	Doomguard	2	0	0

T = Total

P = Played

D = Dead

Opponent played cards

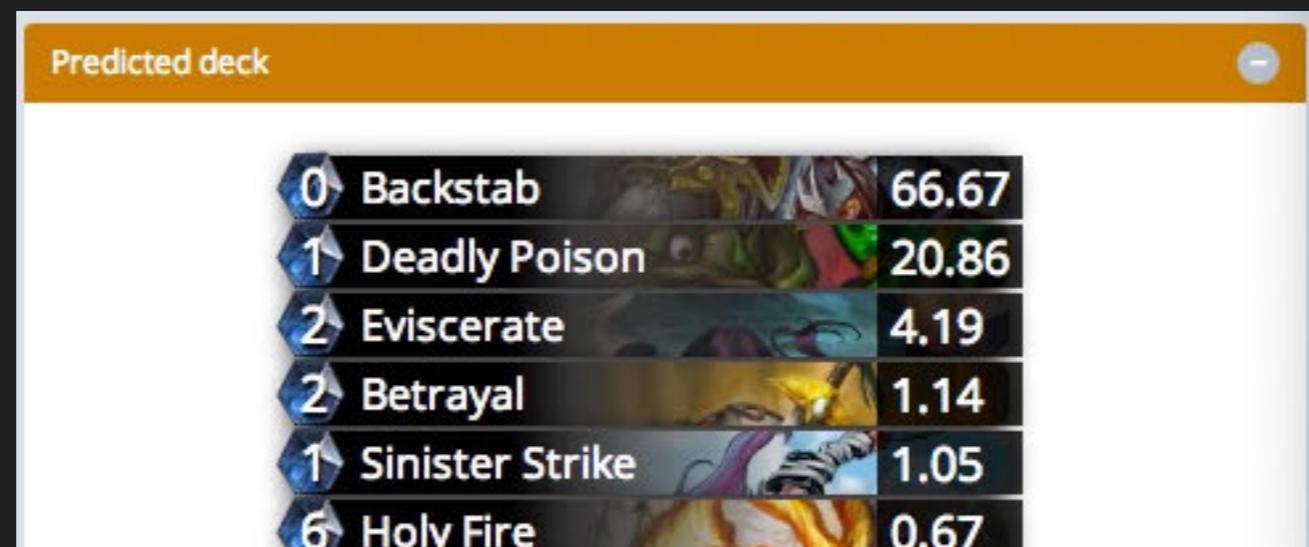


T = Total

P = Played

D = Dead

Predictions



Game data from

Game data from

Packet Sniffing

Game data from

Packet Sniffing
OCR

Game data from

Packet Sniffing
OCR
Debug logs

Game data from

Packet Sniffing
OCR
Debug logs

Real logs from Blizzard like in WoW ?

Video

video demo

Turn by Turn History

The screenshot shows a turn-by-turn history interface for a card game, likely Hearthstone. The interface is divided into two main sections: "Me" (left) and "My opponent" (right), each showing a timeline of turns.

Me (Left Side):

- Turn 1:** No action.
- Turn 2:** Card: Dire Wolf Alpha (drawn). Card: Argent Squire (drawn). Card: Flame Imp (drawn).
- Turn 3:** Card: Voidwalker (drawn). Card: Argent Squire (played).
- Turn 4:** Card: Soulfire (drawn). Card: Flame Imp (played). Card: Voidwalker (played).
- Turn 5:** Card: Flame Imp (killed).
- Turn 6:** Card: Voidwalker (killed).
- Turn 7:** (No visible actions)

My opponent (Right Side):

- Turn 1:** Card: ? (drawn). Card: ? (drawn). Card: ? (drawn). Card: ? (drawn).
- Turn 2:** Card: ? (drawn). Card: ? (mulligan). Card: ? (drawn). Card: ? (mulligan).
- Turn 3:** Card: ? (drawn).
- Turn 4:** Card: ? (drawn). Card: Backstab (played with ability).
- Turn 5:** Card: Preparation (played with ability). Card: Eviscerate (played with ability).
- Turn 6:** Card: Edwin VanCleef (played).



Available on Github
LightWind/hearthstone-dashboard



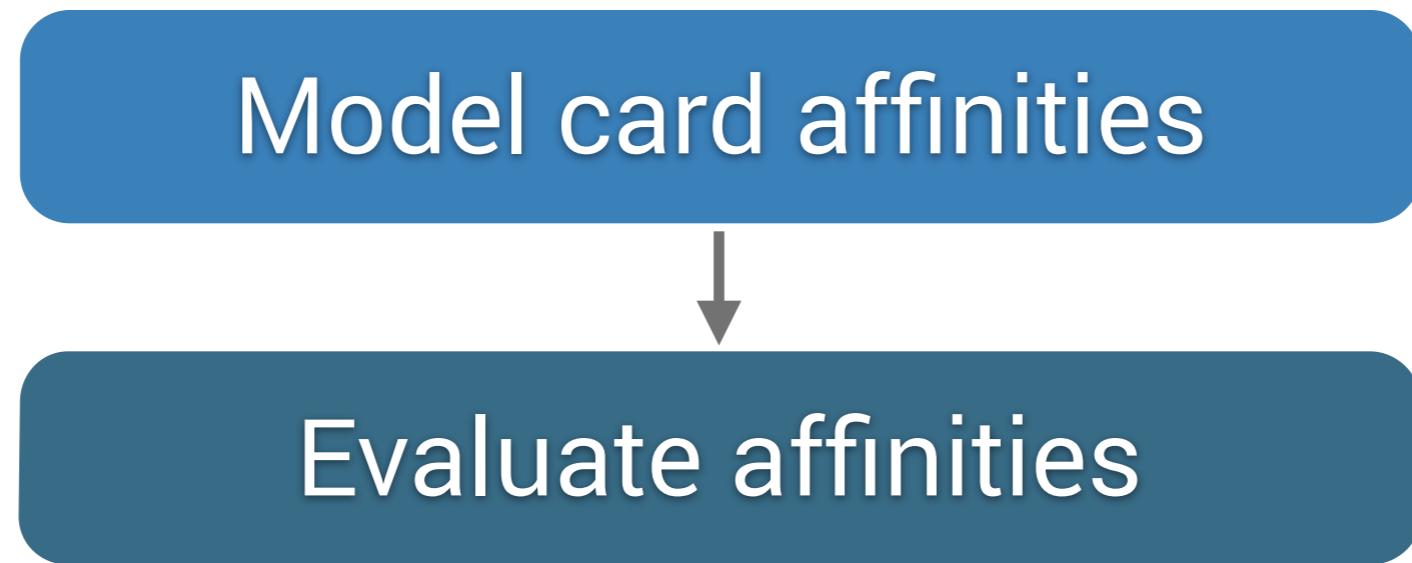
©2014 Blizzard Entertainment, Inc. All Rights Reserved.

Naxx's new cards made the meta too unstable to be predicted accurately for now

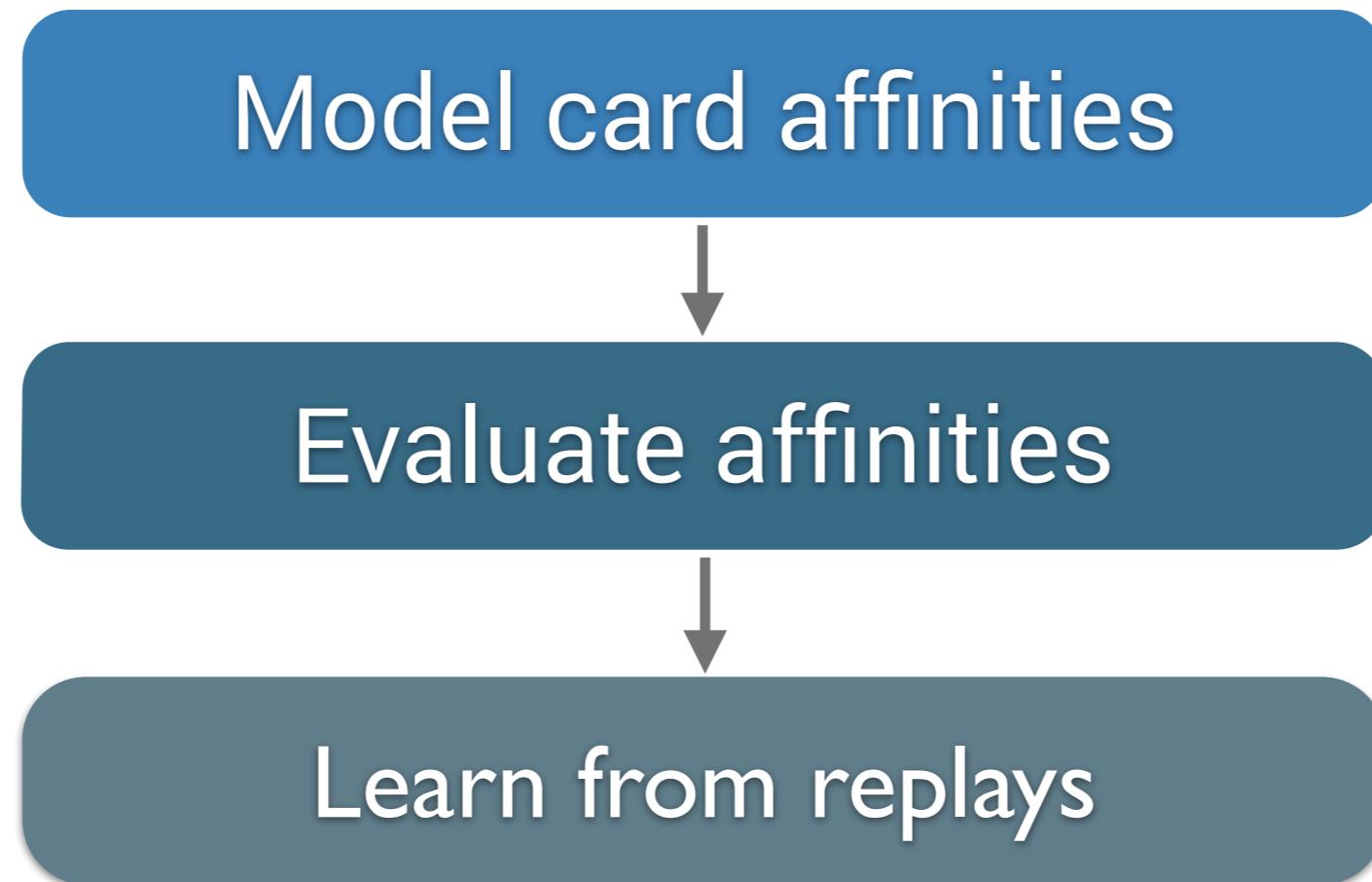
How the prediction algorithm works

Model card affinities

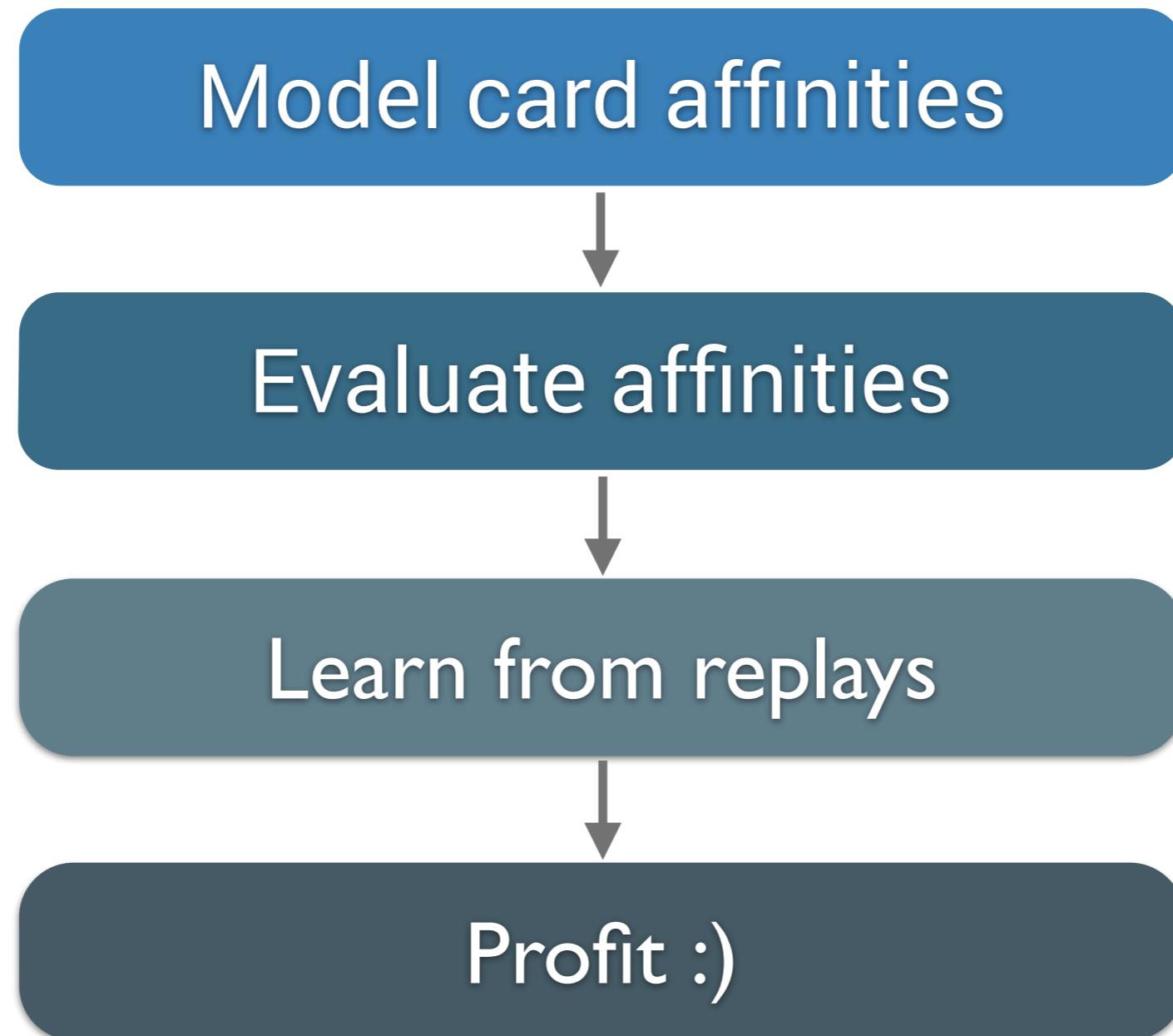
How the prediction algorithm works



How the prediction algorithm works



How the prediction algorithm works





Modeling card affinities

Card bigrams



Card bigrams



Card bigrams



Un-ordered bigrams





Evaluate card affinities

Played



Played



Played Bi-grams

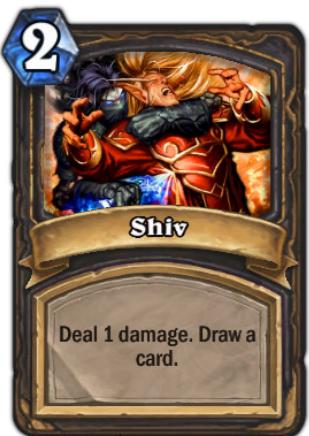


Played

Bi-grams



500



Played

Bi-grams



Played

Bi-grams



500

350

400

Played

Bi-grams



Played

Bi-grams

Ranked Predictions



500

350

400

400

Played

Bi-grams

Ranked Predictions



Played

Bi-grams

Ranked Predictions

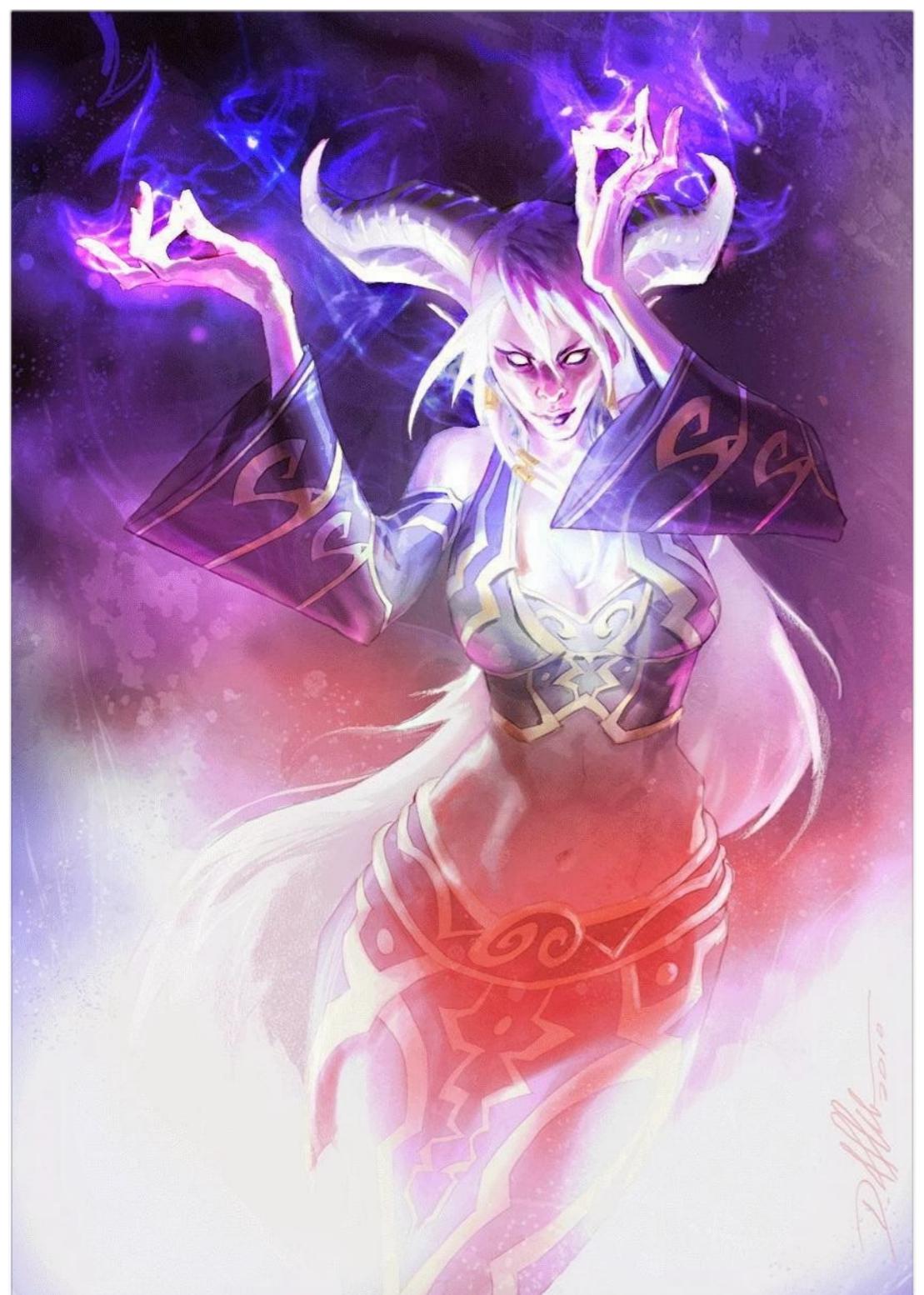


Played

Bi-grams

Ranked Predictions



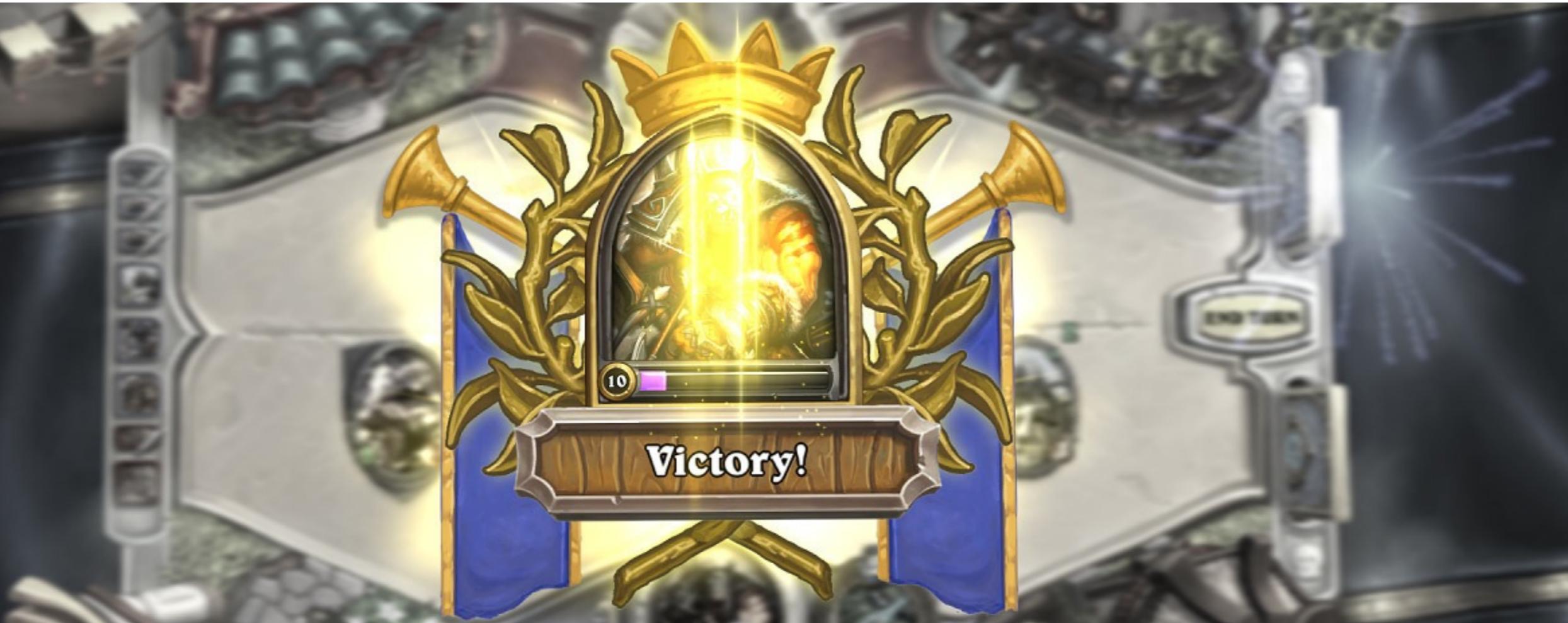


Training and evaluation

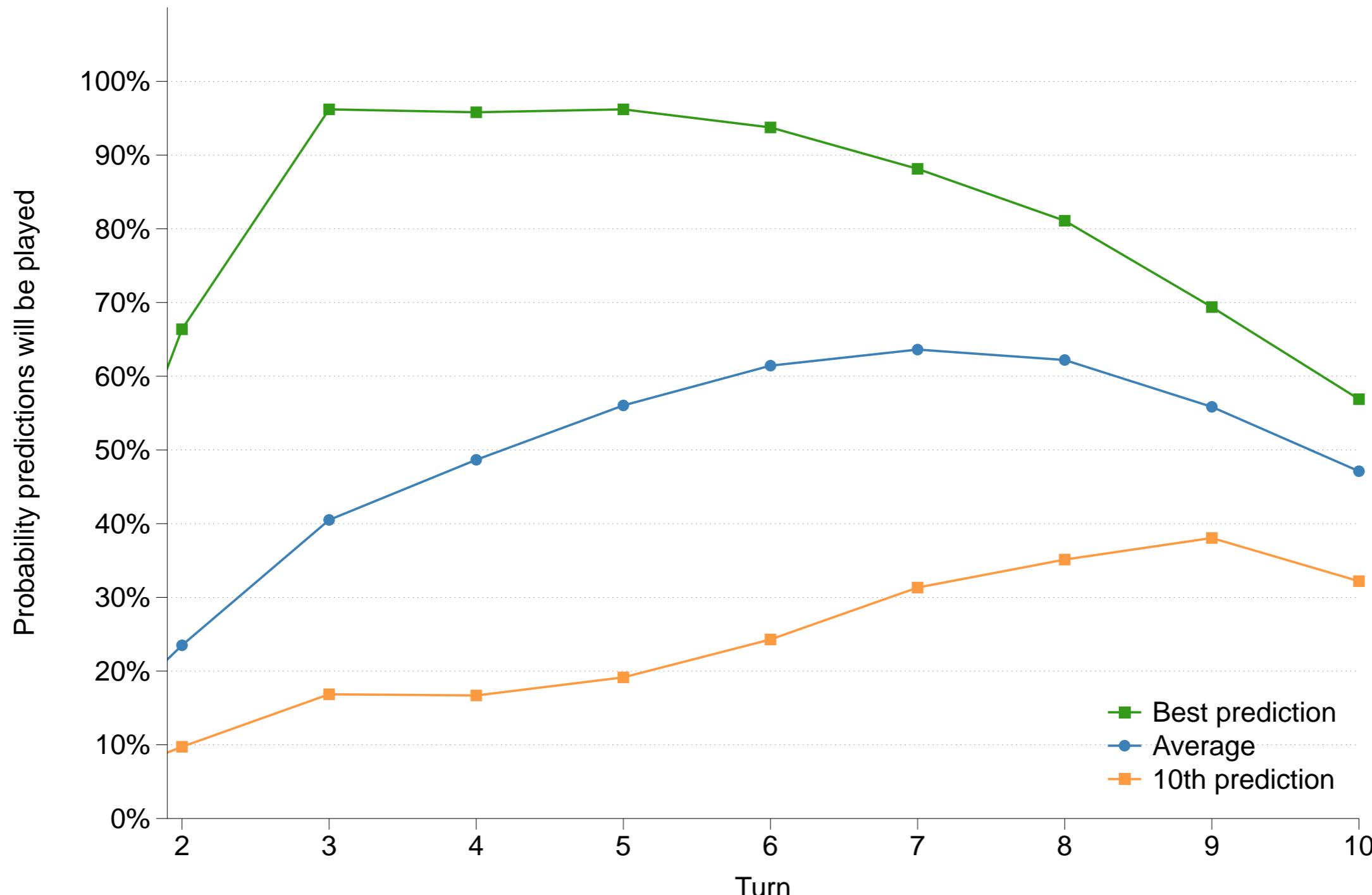
Training: 45000 replays

Testing : 5000 replays

1 model per class



97% success rate for best prediction by turn 3





What's next?

- Predicting game outcome
- How to optimize deck for mana-throughput
- Hero powers comparison
- Comparing deck types



Thank you!

<https://www.elie.net/hs> & @elie/@cealtea on Twitter