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
Opponent’s hero

Your hero
Hero health
Decks
hand
mana pool
Your Weapon
Minions
Celine & Elie Bursztein

I am a legend - Defcon 2014

https://www.elie.net/hs
Mana Cost

Chillwind Yeti

4

5
Mana Cost

Attack

Chillwind Yeti

Mana Cost: 4
Attack: 4

https://www.elie.net/hs
Mana Cost 4

Attack 4

Health 5

Chillwind Yeti
Finding undervalued cards
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!

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
4 = 4a + 5h + i
\[6 = 6a + 7h + i\]
\[= 1a + 1.16h + i\]
6 = 6a + 7h + i
\[\downarrow /6\]
1 = 1a + 1.16h + i

4 = 4a + 5h + i
\[\downarrow /4\]
6 = 6a + 7h + i

\[
\frac{1}{6}
\]

1 = 1a + 1.16h + i

4 = 4a + 5h + i

\[
\frac{1}{4}
\]

1 = 1a + 1.25h + i
Fireball
Deal 6 damage.

Pyroblast
Deal 10 damage.
$4 = 6d \\ \rightarrow 1 \text{ mana} = 1.5 \text{ dmg}$
4 = 6d  →  1 mana = 1.5 dmg

10 = 10d
4 = 6d  →  1 mana = 1.5 dmg

10 = 10d  →  1 mana = 1 dmg
\[
\begin{align*}
4 &= 6d & \Rightarrow & & 1 \text{ mana} &= 1.5 \text{ dmg} \\
10 &= 10d & \Rightarrow & & 1 \text{ mana} &= 1 \text{ dmg}
\end{align*}
\]

Pre nerf (8 mana)
4 = 6d  \rightarrow  1 \text{ mana} = 1.5 \text{ dmg}

10 = 10d  \rightarrow  1 \text{ mana} = 1 \text{ dmg}

Pre nerf (8 mana)
8 = 10d
Fireball
Deal 6 damage.

4 = 6d

1 mana = 1.5 dmg

Pyroblast
Deal 10 damage.

10 = 10d

Pre nerf (8 mana)
8 = 10d

1 mana = 1.25 dmg

1 mana = 1 dmg
Pyroblast

Deal 10 damage.

Fireball

Deal 6 damage.

10 damage → 4 damage
Pyroblast
Deal 10 damage.

Fireball
Deal 6 damage.
How to hunt for value cards
How to find undervalued cards?

Model cards
How to find undervalued cards?

- Model cards
- Reverse coefficients
How to find undervalued cards?

1. Model cards
2. Reverse coefficients
3. Compute card’s real value
How to find undervalued cards?

1. Model cards
2. Reverse coefficients
3. Compute card’s real value
4. Profit :)

Model cards

Reverse coefficients

Compute card’s real value

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

Kor'bron Elite

Argent Commander
Charge, Divine Shield

Reckless Rocketeer
Charge
Charge

Argent Commander
Charge, Divine Shield

Argent Squire
Divine Shield

Scarfia Crusader
Divine Shield

Kor'bron Elite
Charge

Reckless Rocketeer
Charge

Celine & Elie Bursztein
I am a legend - Defcon 2014
https://www.elie.net/hs
$4 = 4a + 3h + c + i$
$4 = 4a + 3h + c + i$

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

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

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

$1 = 1a + 1h + d + i$
Reversing attribute cost
Reversing attribute cost
Reversing attribute cost

<table>
<thead>
<tr>
<th>mana</th>
<th>Atk</th>
<th>Health</th>
<th>Charge</th>
<th>Divine</th>
<th>Intrinsic</th>
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Least square
Reversing attribute cost

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<th>Divine</th>
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</tbody>
</table>

Least square

Atk = 1
Health = -1
Charge = 2
Divine = 1
Intrinsic = 1
## Reversing attribute cost

<table>
<thead>
<tr>
<th>mana</th>
<th>Atk</th>
<th>Health</th>
<th>Charge</th>
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</table>

Least square:
- Atk = 1
- Health = -1
- Charge = 2
- Divine = 1
- Intrinsic = 1

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

\[ 4a + 2h + c + d + i \]
\[ 4*1 + 2*-1 + 2 + 1 + 1 = 6 \]

\[ 1a + 1h + d + i \]
\[ 1*1 + 1*-1 + 1 + 1 = 2 \]

Coeffs: Charge = 2  Atk = 1  Health = -1  Divine = 1  Intrinsic = 1
Modeling dependence between characteristics

Charge = $Atk \times \text{charge coeff}$

Windfury = $Atk \times \text{windfury coeff}$

Divine = ? (health related?)

Thanks to Niels for the idea
Et voila!
## Reversed budget coefficients

<table>
<thead>
<tr>
<th>Effect</th>
<th>cost per point</th>
</tr>
</thead>
<tbody>
<tr>
<td>Destroy minion</td>
<td>10.63</td>
</tr>
<tr>
<td>Board damage</td>
<td>3.69</td>
</tr>
<tr>
<td>Draw card</td>
<td>3.68</td>
</tr>
<tr>
<td>Divine Shield</td>
<td>2.74</td>
</tr>
<tr>
<td>Freeze</td>
<td>2.04</td>
</tr>
<tr>
<td>Silence</td>
<td>1.66</td>
</tr>
<tr>
<td>Damage</td>
<td>1.64</td>
</tr>
<tr>
<td>Durability</td>
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<td>Stealth</td>
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<tr>
<td>Attack</td>
<td>1.14</td>
</tr>
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<td>Taunt</td>
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<td>WindFury</td>
<td>0.96</td>
</tr>
<tr>
<td>SpellPower</td>
<td>0.93</td>
</tr>
<tr>
<td>Health</td>
<td>0.81</td>
</tr>
<tr>
<td>Battlecry: heal</td>
<td>0.69</td>
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<tr>
<td>Battlecry: self hero heal</td>
<td>0.68</td>
</tr>
<tr>
<td>Charge</td>
<td>0.65</td>
</tr>
<tr>
<td>Intrinsic value</td>
<td>0.32</td>
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# Reversed budget coefficients

<table>
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<th>Effect</th>
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</tr>
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<tbody>
<tr>
<td>Destroy minion</td>
<td>10.63</td>
<td>Opponent draw card</td>
<td>-3.97</td>
</tr>
<tr>
<td>Board damage</td>
<td>3.69</td>
<td>Discard cards</td>
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</tr>
<tr>
<td>Draw card</td>
<td>3.68</td>
<td>Overload</td>
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Model found several clearly **undervalued cards :)**
Model found several clearly **undervalued cards** :)
Model found several clearly **undervalued cards** :)
Model found several clearly undervalued cards :)

Cost estimated by the algorithm (in mana)

Cost assigned by Blizzard (in mana)

- undervalued cards
- overpriced 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
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

Twilight Drake

Battlecry: Gain +1 Health for each card in your hand.
Cards in hand
Cards in hand

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<thead>
<tr>
<th>Health</th>
<th>Real Value</th>
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<td>3.6</td>
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<td>4.7</td>
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<td>5.3</td>
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<td>9</td>
<td>5.9</td>
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Num of Twilight Drakes made

Drake Health

Overpriced
Fair
Undervalued
Average real value 3.7

Num of Twilight Drakes made

Drake Health
Twilight Drake’s price is **fair**
Edwin VanCleef

**Combo:** Gain +2/+2 for each card played earlier this turn.
Edwin VanCleef

**Combo:** Gain +2/+2 for each card played earlier 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

Cards played this turn

**Edwin VanCleef**

*Combo: Gain +2/+2 for each card played earlier this turn.*
Average real value 8.1

Num of VanCleef made

VanCleef size (atk/hp)

0 100 200 300 400 500 600 700 800

2/2 4/4 6/6 8/8 10/10 12/12 14/14 16/16 18/18 20/20 22/22 24/24 26/26 28/28

Average real value 8.1
VanCleef is **undervalued**, a fair price is probably between **6** and **8 mana**
Flamestrike

Deal 4 damage to all enemy minions.
Flamestrike

Deal 4 damage to all enemy minions.
Num Minions
Num Minions

Normal damage coeff

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Num Minions
Num Minions

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<td>16</td>
<td>28.6</td>
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<td>20</td>
<td>36.0</td>
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<tr>
<td>24</td>
<td>43.4</td>
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<tr>
<td>28</td>
<td>50.7</td>
</tr>
</tbody>
</table>

Board damage coeff
Flamestrike's price is **fair**

Don't **split** board damage and single damage coeff
Predicting opponent’s deck
Our tool :)
Real time dashboard
Real time dashboard

Game metrics
Real time dashboard

Game metrics

My deck with card tracking
Real time dashboard

Game metrics

My deck with card tracking

Opponent’s cards played so far

Game metrics

My deck with card tracking

Opponent’s cards played so far
Game Metrics

Dashboard

Started 03:13PM

Mana Advantage: Me 3

Draw Advantage: Me 1

Hand Advantage: Me 3

Opponent
My deck

<table>
<thead>
<tr>
<th>Card</th>
<th>T</th>
<th>P</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soulfire</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Abusive Sergeant</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Argent Squire</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Elven Archer</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Flame Imp</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Power Overwhelming</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Voidwalker</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Dire Wolf Alpha</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Haunted Creeper</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Knife Juggler</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Nerubian Egg</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Blood Knight</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Harvest Golem</td>
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<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Void Terror</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Dark Iron Dwarf</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Defender of Argus</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Leeroy Jenkins</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Doomguard</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

T = Total
P = Played
D = Dead
Opponent played cards

- T = Total
- P = Played
- D = Dead
Predictions

Predicted deck

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Backstab</td>
<td>66.67</td>
</tr>
<tr>
<td>1</td>
<td>Deadly Poison</td>
<td>20.86</td>
</tr>
<tr>
<td>2</td>
<td>Eviscerate</td>
<td>4.19</td>
</tr>
<tr>
<td>2</td>
<td>Betrayal</td>
<td>1.14</td>
</tr>
<tr>
<td>1</td>
<td>Sinister Strike</td>
<td>1.05</td>
</tr>
<tr>
<td>6</td>
<td>Holy Fire</td>
<td>0.67</td>
</tr>
</tbody>
</table>
Game data from
Packet Sniffing

Game data from
Game data from OCR

Packet Sniffing
Game data from

Packet Sniffing
OCR
Debug logs

https://www.elie.net/hs
Packet Sniffing
OCR
Debug logs

Game data from

Real logs from Blizzard like in WoW?
video demo
Turn by Turn History
Available on Github

LightWind/hearthstone-dashboard
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

Model card affinities

Evaluate affinities
How the prediction algorithm works

1. Model card affinities
2. Evaluate affinities
3. Learn from replays
How the prediction algorithm works

1. Model card affinities
2. Evaluate affinities
3. Learn from replays
4. Profit :)
Modeling card affinities
Card bigrams

1. Armorsmith
   Whenever a friendly minion takes damage, gain 1 Armor.

2. Cruel Taskmaster
   Battlecry: Deal 1 damage to a minion and give it +2 Attack.

3. Acolyte of Pain
   Whenever this minion takes damage, draw a card.
Card bigrams

- **Armorsmith**: Whenever a friendly minion takes damage, gain 1 Armor.
- **Cruel Taskmaster**: Battlecry: Deal 1 damage to a minion and give it +2 Attack.
- **Acolyte of Pain**: Whenever this minion takes damage, draw a card.

Connections:
- Armorsmith → Cruel Taskmaster
- Cruel Taskmaster → Acolyte of Pain
Card bigrams
Un-ordered bigrams
Evaluate card affinities
Played

Deadly Poison

Give your weapon +2 Attack.
Played

1st

**Deadly Poison**
Give your weapon +2 Attack.

2nd

**Shiv**
Deal 1 damage. Draw a card.
Played

Bi-grams

1. **Deadly Poison**
   - Give your weapon +2 Attack.

2. **Shiv**
   - Deal 1 damage. Draw a card.
Played

Bi-grams

500

Deadly Poison
Give your weapon +2 Attack.

Fan of Knives
Deal 1 damage to all enemy minions. Draw a card.

Shiv
Deal 1 damage. Draw a card.
Played

Bi-grams

500

350

1. Deadly Poison
   - Give your weapon +2 Attack.

2. Deadly Poison
   - Give your weapon +2 Attack.

3. Fan of Knives
   - Deal 1 damage to all enemy minions. Draw a card.

4. Blade Flurry
   - Destroy your weapon and deal its damage to all enemies.

5. Shiv
   - Deal 1 damage. Draw a card.
Played

Bi-grams

Ranked Predictions

500

350

400

400

750
Played

<table>
<thead>
<tr>
<th>Bi-grams</th>
<th>Ranked Predictions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Deadly Poison</td>
<td>2. Blade Flurry</td>
</tr>
<tr>
<td>Give your weapon +2</td>
<td>Destroy your weapon</td>
</tr>
<tr>
<td>Attack.</td>
<td>and deal its</td>
</tr>
<tr>
<td></td>
<td>damage to all</td>
</tr>
<tr>
<td></td>
<td>enemy minions.</td>
</tr>
<tr>
<td></td>
<td>Draw a card.</td>
</tr>
<tr>
<td>3. Fan of Knives</td>
<td>2. Fan of Knives</td>
</tr>
<tr>
<td>Deal 1 damage to all</td>
<td>Deal 1 damage to</td>
</tr>
<tr>
<td>enemy minions. Draw a</td>
<td>all enemy minions.</td>
</tr>
<tr>
<td>card.</td>
<td>Draw a card.</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Shiv</td>
<td>2. Shiv</td>
</tr>
<tr>
<td>Deal 1 damage. Draw a</td>
<td>Deal 1 damage.</td>
</tr>
<tr>
<td>card.</td>
<td>Draw a card.</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Shiv</td>
<td>3. Amanti Berserber</td>
</tr>
<tr>
<td></td>
<td>Enrage: +3 Attack</td>
</tr>
</tbody>
</table>

Celine & Elie Bursztein

I am a legend - Defcon 2014

https://www.elie.net/hs
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