I am a legend

Celine & Elie Bursztein

https://www.elie.net/hs
Digital Collectible Card Game
Released by Blizzard in 2014
Based on World of Warcraft universe
Sometimes too interesting leads to un-intended consequences
Game complexity generates exploitable biases
Outline
1. Finding undervalued cards
Outline

1. Finding undervalued cards
2. Predicting opponent deck
Outline

1. Finding undervalued cards
2. Predicting opponent deck
3. Predicting the game outcome
Outline

1. Finding undervalued cards
2. Predicting opponent deck
3. Predicting the game outcome
4. Incoming alien invasion (or not)
You hero
Hero health
hand
mana pool
Minions
Celine & Elie Bursztein

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https://www.elie.net/hs
Chillwind Yeti

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

4

Chillwind Yeti

5
Card special abilities is what makes the game complex and interesting.
Card special abilities is what makes the game complex and interesting
Finding undervalued cards
Model assumptions
1. Mana cost is proportional to card power
Model assumptions

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2. The power of cards roughly increase linearly
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3. Card effects have constant price
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4. A card have an intrinsic value
Model assumptions

1. Mana cost is proportional to card power
2. The power of cards roughly increase linearly
3. Card effects have constant price
4. A card have an intrinsic value
5. The value of the card is the sum of its attribute
mana = attack + health + intrinsic value
mana = attack + health + intrinsic value

4 = 4a + 5h + i
6 = 6a + 7h + i
6 = 6a + 7h + i
6 = 6a + 7h + i

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

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

1 = 1a + 1.16h + i

4 = 4a + 5h + i
6 = 6a + 7h + i
1 = 1a + 1.16h + i

4 = 4a + 5h + i
6 = 6a + 7h + i

1 = 1a + 1.16h + i

4 = 4a + 5h + i

1 = 1a + 1.25h + i
4 = 6d

Deal 6 damage.
4 = 6d → 1 mana = 1.5 dmg

Deal 6 damage.
4 = 6d $\rightarrow$ 1 mana = 1.5 dmg
4 = 6d  ->  1 mana = 1.5 dmg

10 = 10d
4 = 6d  →  1 mana = 1.5 dmg

10 = 10d  →  1 mana = 1 dmg
4 = 6d \quad \rightarrow \quad 1 \text{ mana} = 1.5 \text{ dmg}

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

Pre nerf (8 mana)
4 = 6d  →  1 mana = 1.5 dmg

10 = 10d  →  1 mana = 1 dmg

Pre nerf (8 mana)
8 = 10d
4 = 6d → 1 mana = 1.5 dmg

Pre nerf (8 mana)
8 = 10d → 1 mana = 1.25 dmg
Pyroblast
Deal 10 damage.

Fireball
Deal 6 damage.
10 damages $\xrightarrow{\text{imply}}$ 4 damages
10 damages \ implies \ 4 damages

15 damages \ implies \ 6 damages
Hunting for under-valued 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 cards real value
How to find undervalued cards?

1. Model cards
2. Reverse coefficients
3. Compute cards real value
4. Profit :)
Approach illustrated
Charge
$4 = 4a + 3h + c + i$
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
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<table>
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<tr>
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Least square
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Least square

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

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Least square

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

Warning these example attribute costs are bogus as we didn’t use enough cards
Finding card real price using reversed coefficients

Coeffs: Charge = 2, Atk = 1, Health = -1, Divine = 1, Intrinsic = 1
Finding card real price using reversed coefficients

\[ 4a + 2h + c + d + i \]

**Coeffs:**  
Charge = 2  
Atk = 1  
Health = -1  
Divine = 1  
Intrinsic = 1
Finding card real price 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 card real price using reversed coefficients

\[4a + 2h + c + d + i\]

\[4 \times 1 + 2 \times -1 + 2 + 1 + 1 = 6\]

Coeffs: Charge = 2, Atk = 1, Health = -1, Divine = 1, Intrinsic = 1
Finding card real price 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 card real price 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 card real price 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

Under-valued card!
Thanks you for the feedback!

https://www.elie.net/hs
Modeling dependance between characteristics

Thanks to Niels for the idea
Modeling dependence between characteristics

\[
\text{Charge} = \text{Atk} \times \text{charge coeff}
\]

\[
\text{Windfury} = \text{Atk} \times \text{windfury coeff}
\]

\[
\text{Divine} = ? \quad \text{(health related?)}
\]

Thanks to Niels for the idea
Modeling dependance between characteristics

Charge \( = \text{Atk} \times \text{charge coeff} \)

Windfury \( = \text{Atk} \times \text{windfury coeff} \)

Divine \( = ? \) (health related?)

Model also use a card budget:
\( 2 \times \text{mana} + 1 \)

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

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<td>Divine Shield</td>
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2 coeff point ~ 1 mana point
Reversed budget coefficients

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<tr>
<td>Overload</td>
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<td>Self hero damage</td>
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2 coeff point ~ 1 mana point
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Effect Cost per point
- Opponent draw card: -3.97
- Discard cards: -2.67
- Overload: -1.68
- Self hero damage: -0.54

2 coeff point ~ 1 mana point
Cost estimated by the algorithm (in mana)

Cost assigned by Blizzard (in mana)

undervalued cards
Cost estimated by the algorithm (in mana)

Cost assigned by Blizzard (in mana)

undervalued cards

overpriced cards
Model found a couple of clearly **undervalued cards** :)
Most under-valued cards (~130 cards)

Full data https://www.elie.net/tools/hearthstone/cards_value
Taking it to the next level
Game replays

• 100 000 games from May to June
• Thanks to … for it :)
• Need a longer term solution
Pricing cards with unique effects
Twilight Drake

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

Dragon
**Twilight Drake**

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

Twilight Drake

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

Dragon
Cards in hand

<table>
<thead>
<tr>
<th>Health</th>
<th>Real Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.3</td>
</tr>
<tr>
<td>2</td>
<td>1.9</td>
</tr>
<tr>
<td>3</td>
<td>2.5</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>3.6</td>
</tr>
<tr>
<td>6</td>
<td>4.1</td>
</tr>
<tr>
<td>7</td>
<td>4.7</td>
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<tr>
<td>8</td>
<td>5.3</td>
</tr>
<tr>
<td>9</td>
<td>5.9</td>
</tr>
</tbody>
</table>
Overpriced
Fair
Undervalued
Average real value 3.7
Twilight drake 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
Cards played this turn

<table>
<thead>
<tr>
<th>Edwin size</th>
<th>Real value</th>
</tr>
</thead>
<tbody>
<tr>
<td>2/2</td>
<td>1.09</td>
</tr>
<tr>
<td>4/4</td>
<td>3.04</td>
</tr>
<tr>
<td>6/6</td>
<td>4.98</td>
</tr>
<tr>
<td>8/8</td>
<td>6.92</td>
</tr>
<tr>
<td>10/10</td>
<td>8.87</td>
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<tr>
<td>12/12</td>
<td>10.51</td>
</tr>
<tr>
<td>14/14</td>
<td>12.75</td>
</tr>
<tr>
<td>16/16</td>
<td>14.70</td>
</tr>
<tr>
<td>18/18</td>
<td>16.64</td>
</tr>
<tr>
<td>20/20</td>
<td>18.58</td>
</tr>
<tr>
<td>22/22</td>
<td>20.53</td>
</tr>
</tbody>
</table>
VanCleef is undervalued, a fair price is probably between 5 and 7 mana
Flamestrike

Deal 4 damage to all enemy minions.
Flamestrike

Deal 4 damage to all enemy minions.
Num Minions

Deal 4 damage to all enemy minions.
<table>
<thead>
<tr>
<th>Damage</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>6.5</td>
</tr>
<tr>
<td>8</td>
<td>13.9</td>
</tr>
<tr>
<td>12</td>
<td>21.3</td>
</tr>
<tr>
<td>16</td>
<td>28.6</td>
</tr>
<tr>
<td>20</td>
<td>36.0</td>
</tr>
<tr>
<td>24</td>
<td>43.4</td>
</tr>
<tr>
<td>28</td>
<td>50.7</td>
</tr>
</tbody>
</table>

**Flamestrike**

Deal 4 damage to all enemy minions.
Num Minions

Deal 4 damage to all enemy minions.
<table>
<thead>
<tr>
<th>Damage</th>
<th>Real Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>2.43835</td>
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<tr>
<td>8</td>
<td>5.71835</td>
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<tr>
<td>12</td>
<td>8.99835</td>
</tr>
<tr>
<td>16</td>
<td>12.27835</td>
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<tr>
<td>20</td>
<td>15.55835</td>
</tr>
<tr>
<td>24</td>
<td>18.83835</td>
</tr>
<tr>
<td>28</td>
<td>22.11835</td>
</tr>
</tbody>
</table>
Flamestrike price is fair
Don’t split board damage and single damage coeff
Predicting opponent deck
Deal 2 damage to an undamaged minion.
Our tool :)
Real time dashboard

- Game metrics
- My deck with card tracking
- Opponent cards played so far
- Opponent next cards prediction
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>Name</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>
<td>2</td>
<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  

---

Celine & Elie Bursztein  
I am a legend - Defcon 2014  
https://www.elie.net/hs
My opponent

T = Total
P = Played
D = Dead
Predictions

Predicted deck

1. Backstab 66.67
2. Deadly Poison 20.86
2. Eviscerate 4.19
2. Betrayal 1.14
1. Sinister Strike 1.05
6. Holy Fire 0.67
Game data from
Sniff packets

Game data from
Game data from

Sniff packets

OCR
Game data from

Sniff packets
OCR
Debug log
Game data from

Sniff packets
OCR
Debug log

Real logs from Blizzard like in WoW?
Turn by Turn History

**Turn 1**
Card: Dire Wolf Alpha, Action: drawn
Card: Argent Squire, Action: drawn
Card: Flame Imp, Action: drawn

**Turn 2**
Card: Voidwalker, Action: drawn
Card: Argent Squire, Action: played

**Turn 3**
Card: Soulfire, Action: drawn
Card: Flame Imp, Action: played
Card: Voidwalker, Action: played

**Turn 4**
Card: Flame Imp
Card: Voidwalker

**Turn 5**
Card: Flame Imp, Action: killed

**Turn 6**
Card: Voidwalker

**Turn 7**
Card: Edwin VanCleef, Action: played
Available on Github
LightWind/hearthstone-dashboard
Naxx new cards made the meta to unstable to be predicted accurately for now
Anatomy of our prediction system

Model card affinities
Anatomy of our prediction system

Model card affinities

Evaluate affinities
Anatomy of our prediction system

1. Model card affinities
2. Evaluate affinities
3. Learn from replays
Anatomy of our prediction system

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

https://www.elie.net/hs
Modeling cards affinities
Cards 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.
Cards bigrams

Armormith
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.
Cards bigrams
Cards un-ordered bigrams
Evaluate cards affinities
Played

![Card Image]

Deadly Poison

Give your weapon +2 Attack.
Played

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

2. **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 500 Bi-grams

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

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

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

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I am a legend - Defcon 2014

Played

500

350

Bi-grams
Played

Bi-grams

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.

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

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

500

350

400

https://www.elie.net/hs
Played

Bi-grams

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

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

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

4. **Bladebasher**
   - Destroy your weapon and deal its damage to all enemies.

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

6. **Amani Berserker**
   - Enrage: +3 Attack

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

8. **Bladebasher**
   - Destroy your weapon and deal its damage to all enemies.

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

10. **Bladebasher**
    - Destroy your weapon and deal its damage to all enemies.
Bi-grams

Played

Ranked Predictions

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

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

2. Blade Hurry
   - Destroy your weapon and deal its damage to all enemies.

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

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

2. Amani Berserker
   - Emerge; +3 Attack

500

350

400

400
Played

Bi-grams

Ranked Predictions

500

350

400

400

750
Played

Bi-grams

Ranked Predictions

Celine & Elie Bursztein

https://www.elie.net/hs
Training and evaluation

Training: 45000 replays
Testing: 5000 replays
1 model per class
Suspense is killing me
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 decks types
Thank you!

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