Risks in networked world

Galina Schwartz*

*UC Berkeley

Moral Hazard

(Cyber)-Insurance under asymmetric information

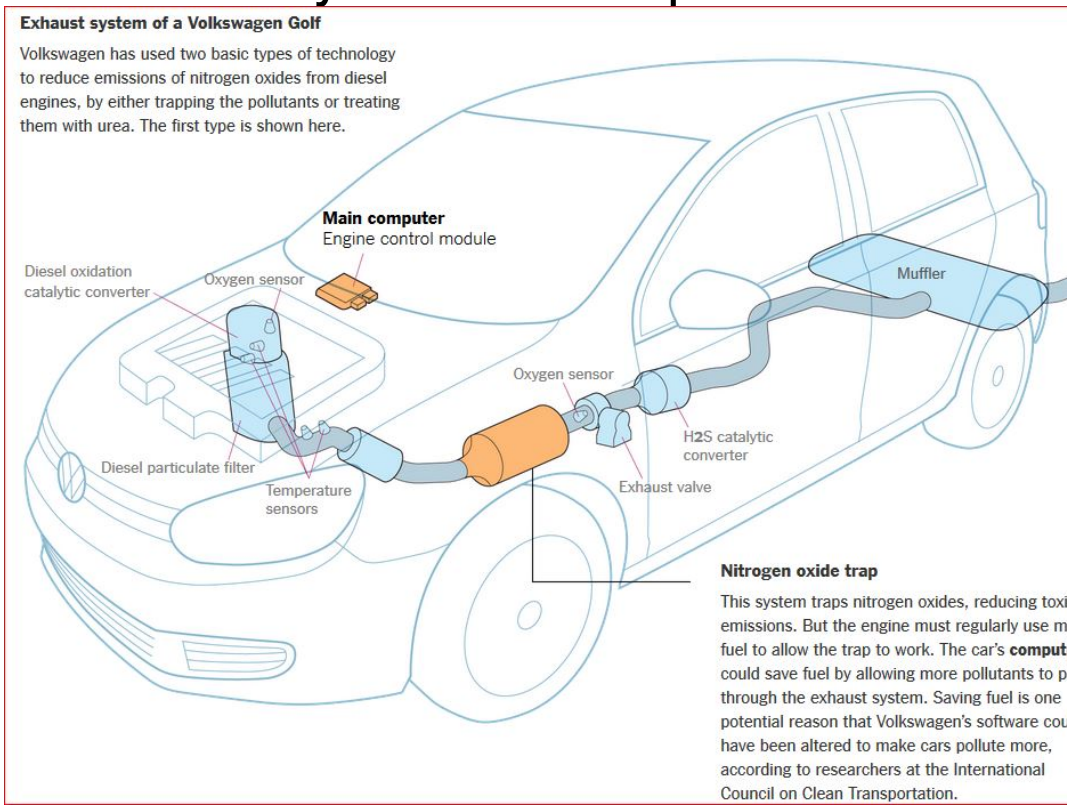
Problem: designing next gen diesel engine: High performance & efficiency but Low NO_X emissions

VW Engineers: Ingenious Technical Solution?

To pass standard emission tests, VW (engineers) employed software-based illegal defeat devices to falsify emission reports.

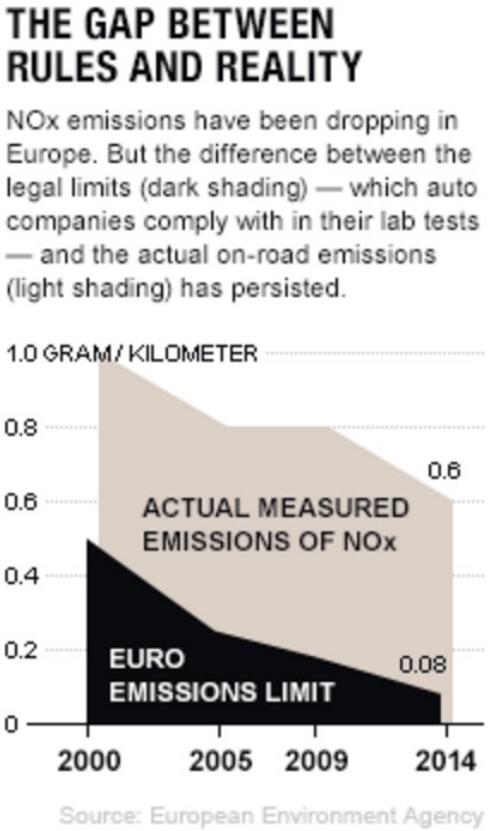
- 2008 “Next-gen turbo diesel special for N. America”; deception begins
- 2011 Exhaust sys modified; deception intensifies
- US: 0.5mln cars
- Worldwide: 11 mln total; 2.1 mln Audi

Source: Wikipedia: VW emissions scandal & refs. therein



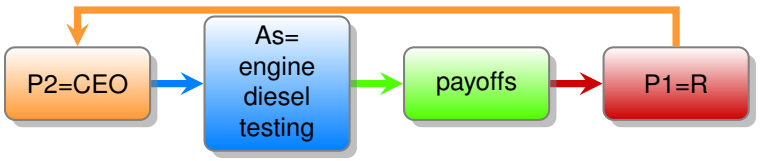
WV scandal from P&A perspective I

The gap between ex ante (required) and ex post (real)



Nested P&A settings

- P1 = R (EPA, CARB)
- A1 = VW (hidden info)
  - P2 = VW (top) management
  - As = VW engineers (from separate divisions):
    - engine electronics
    - diesel motor development
    - motor testing



Problem: VW reputation and stock in free fall I

Deceit uncovered: VW Engineers: The fallout

- Lab test USA: standard duration = 1,370 sec.

  Emission tests require platforms [chassis dynamometers (dynos)]

- 2014. Lab & road tests discrepancies ▶

  West Virginia Univ. Report, ICCT grant (2013)

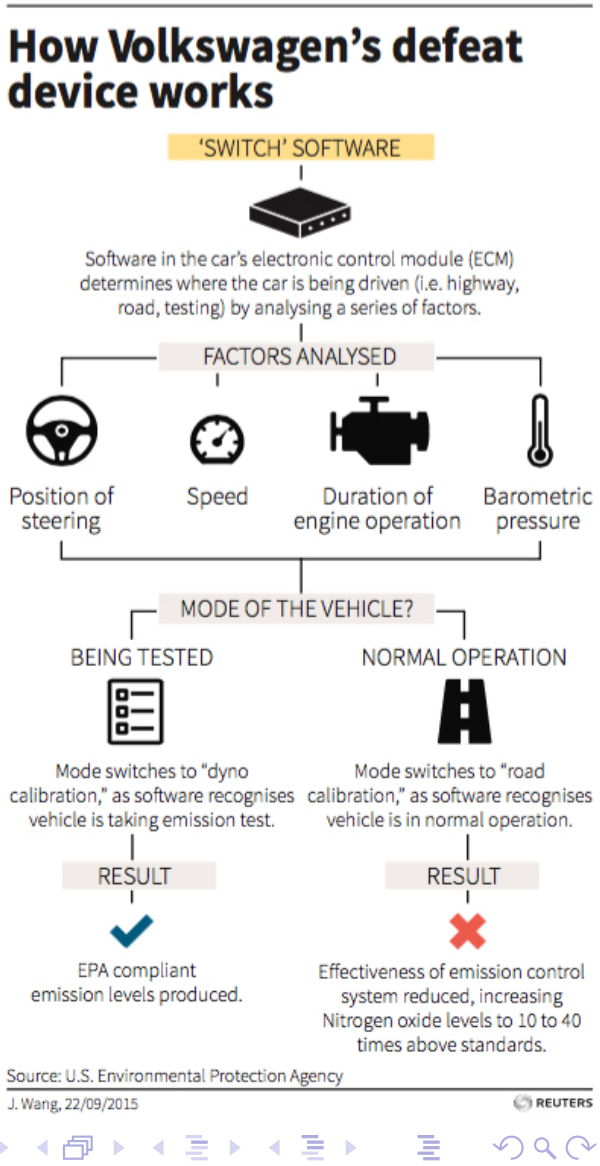
- Full speed ahead: ICCT + CARB

  ICCT=International Council on Clean Transportation, CARB= CA Air Resources Board

- 2015 July EPA request for explanations. VW engineers admit deception

  After denials, admit installing software that triggers

  a “second calibration intended to run only during certification testing.”



Unraveling: (ICCT) [non-profit] & (CARB) [regulator] I

Software calibrated to emit legally for 1,370 sec. At 1,371st sec. the software switches settings & the car emits nine times the permitted amount of NOx.

- VW engineers view deception as a stopgap measure
- Did they (?)

A worker tests a red 2016 Volkswagen AG Golf TDI emissions certification vehicle inside the California Air Resources Board Haagen-Smit Laboratory in El Monte, California Photo: Bloomberg

2015 - 2016 Grand unraveling: VW statements

- Software manipulation (starting Nov. 2006) in 3 departments:
  - engine electronics
  - diesel motor development
  - motor testing

- Reason: "VW employees realized they could not meet emissions rules legally within the time and budget allotted." *allotted by whom!?*
- Heads of brand development (top execs) suspended:
  - Core VW, Audi (+ VW group tech development), Porsche (+ VW engine & transmissions development)
- 11mnl vehicles; $7.3 bln earmarked
- 2016 Internal inquiry: 17 suspects (up from 6)

Outside of VW: Friends in high places I

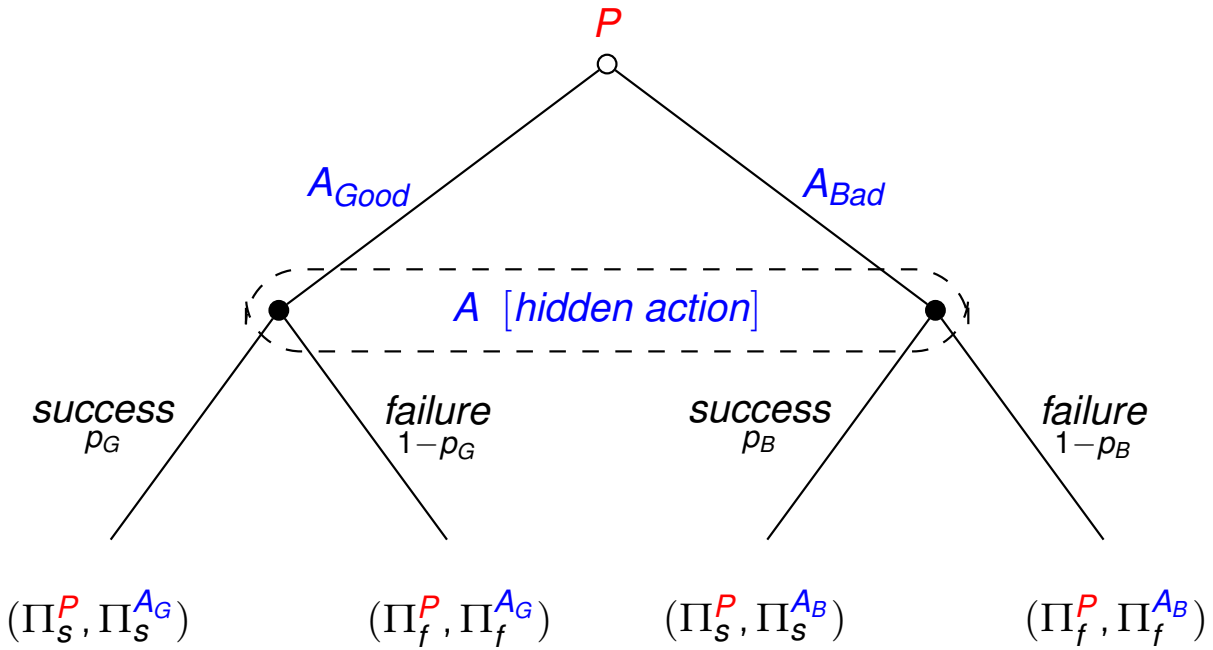
VW importance for German economy

- 2010 “The strict nitrogen oxide limits in CA are damaging German carmakers,” ★ *(lobbyist) Chancellor Merkel* to CARB Chief
- 2015 Extraordinary EU leaders summit on VW crisis (German govt was aware for months)

- VW financial services one of the largest EU banks
- VW scandal Reurters, 10-23-2015 bigger threat to Germany (& EU?) than Greek debt crisis

Myerson [2008] Game 1 Moral Hazard
Extensive form game with hidden action: *P*&*A*

K	capital
R	revenue
p_G	success prob. if A_G
p_B	success prob. if A_B
p_B	$< p_G$
B	A's hidden benefit
w	A's wage if success
A	A's collateral



Numerical example

K	100
R	240
p_G	1/2
p_B	1/4
B	30

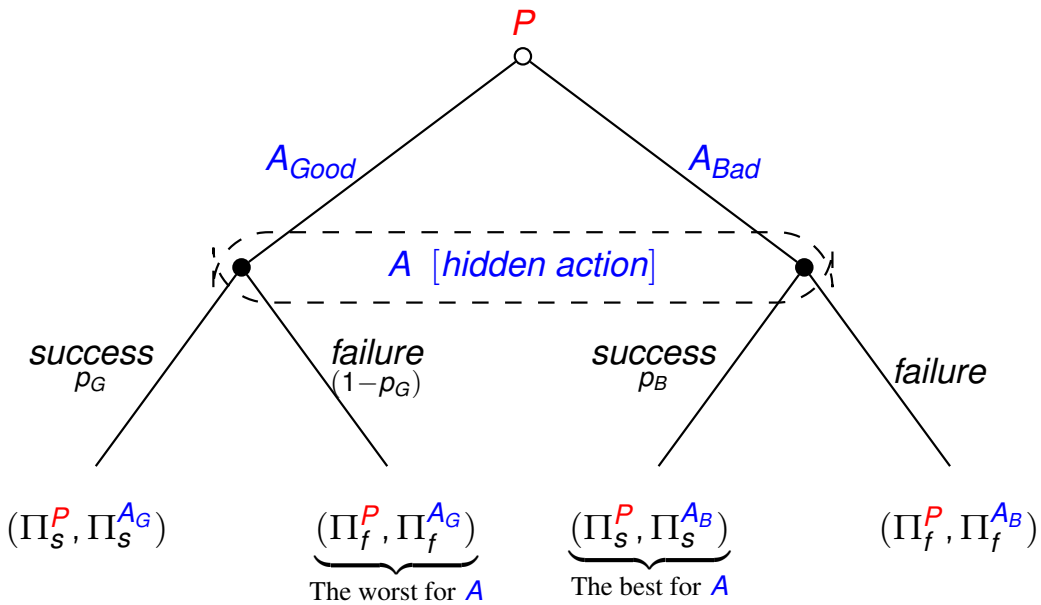
$$\Pi^P = p_G(R-w) + (1-p_G)A - K$$

$$\Pi^A = \begin{cases} p_G w - (1-p_G)A & \text{if } A_G \\ B + p_B w - (1-p_B)A & \text{if } A_B \end{cases}$$

$p_B R + B < K < p_G R, \quad A < K$ [makes Game interesting]

Myerson Game 1: MH with hidden action

- hidden action: agent chooses (A_G or A_B)



$$\Pi^A = \begin{cases} p_G w - (1-p_G)A & \text{if } A_G \\ B + p_B w - (1-p_B)A & \text{if } A_B \end{cases}$$

Note 1: In equal., A is punished for a failure (w/ prob. $(1-p_G)$ or $(1-p_B)$)
Note 2: If p_G and p_B are close, and B high – expect problems (violated constraints)

Myerson Game 1 MH: Solution

A's IC and IR constraints are:

$$p_G w - (1 - p_G)A \geq p_B w - (1 - p_B)A + B \quad [IC]$$

$$p_G w - (1 - p_G)A \geqslant 0 \quad [IR]$$

then, in eq.

$$w^* = w_{IC}^{\min} = \frac{B}{[p_G - p_B]} - A > B\frac{[1 - p_G]}{[p_G - p_B]} = w_{IR}^{\min},$$

A earns positive rent $\Pi^A > 0$ (in expectation) if

$$\Pi^A = p_G w^* - (1 - p_G)A = p_G \left\{ \frac{B}{[p_G - p_B]} - A \right\} - (1 - p_G)A$$

$$A < p_G \frac{B}{[p_G - p_B]} \Leftrightarrow \Pi^A > 0.$$

Myerson Game 1 MH: Discussion

Numerical example

K	100
R	240
p_G	1/2
p_B	1/4
B	30

$$A < p_G \frac{B}{[p_G - p_B]} \Leftrightarrow \Pi^A > 0$$

If A's assets are below 60, his has rents: $\Pi^A > 0$

P contracts with A only if expects non-negative profit Π^P

$$\Pi^P = p_G R - \frac{p_G B}{[p_G - p_B]} + A - K = \{p_G R - K\} - \left\{ \underbrace{\frac{B p_G}{[p_G - p_B]}}_{>0} - A \right\}$$

$$\Pi^P > 0 \Leftrightarrow A > \frac{B p_G}{[p_G - p_B]} - \{p_G R - K\}$$

Myerson Game 1 MH: Analysis

Numerical example: $\Pi^P + \Pi^A = p_G R - K = 240/2 - 100 = 20$

$$\Pi^P \leq 0 \Leftrightarrow A \leq \frac{B p_G}{[p_G - p_B]} - \{p_G R - K\} \Leftrightarrow A \leq 40.$$

With collateral below 40, mechanism fails: project is non-viable:

$$\Pi^P = 0 \quad \text{and} \quad \Pi^A = 0, \quad \text{if} \quad A \in [0, 40)$$

$$\Pi^P = A - 40 \quad \text{and} \quad \Pi^A = 60 - A, \quad \text{if} \quad A \in [40, 60] \quad *** \text{ [the most realistic]}$$

$$\Pi^P = 20 \quad \text{and} \quad \Pi^A = 0, \quad \text{if} \quad A \in [60, 100)$$

Q: Will A be truthful if $A = 65$? Or some $A \in [60, 100]$?
A: No: if A could, he will claim $A < 60$ Hurwitz meets Myerson?

Modified Myerson Game $\tilde{G}$ (with added randomness)

Game $G = G(K, R, A, B, p_G, p_B)$ (parameters $p = \{K, R, A, B, p_G, p_B\}$)

- Modified game $\tilde{G} = \tilde{G}(x_K, x_R, x_A, x_B, x_{p_G}, x_{p_B})$.
  - $\{K, R, A, B\}$ stat. independent from each other & from $\{p_G, p_B\}$
  - Drawn by player N (nature)
    from distr. $F_p(x)$ with continuous densities $f_p(x)$ on support(s) $[x_p^{\min}, x_p^{\max}]$
  - Success prob. $F_{p_B} \leq F_{p_G}$ (first order stat. dominance)
  - Expected value of x_p coincides with the value of p of G:

$$E(x_p) = \int_{x_p^{\min}}^{x_p^{\max}} f_p(x)dx = p, \quad p = \{K, R, A, B, p_G, p_B\}$$

Proposition

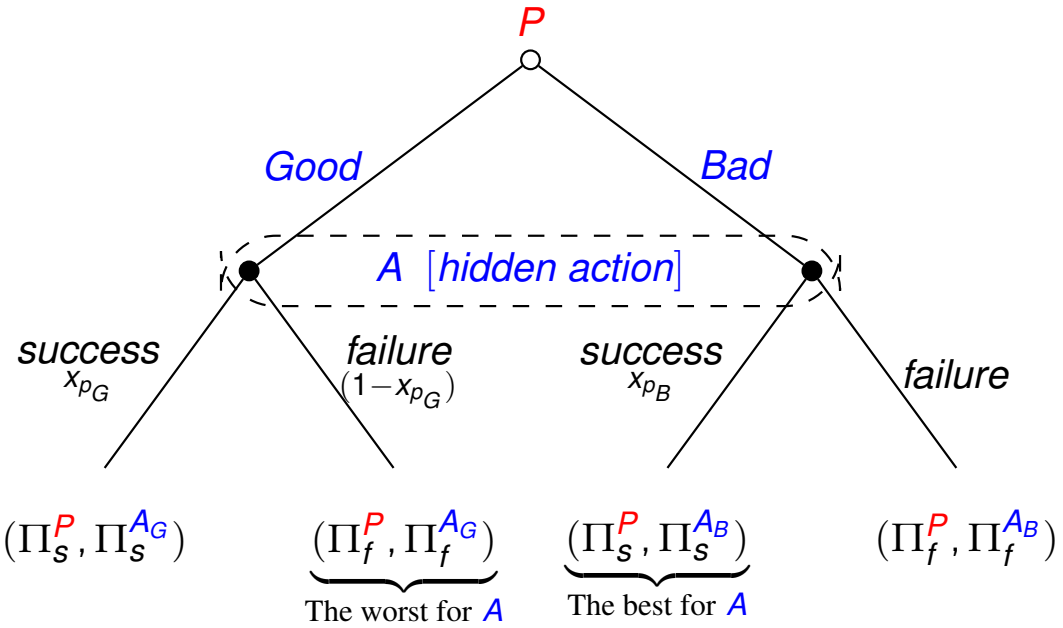
If parameters realized after A acts, equilibria of $\tilde{G}$ and G coincide.

Proof: In expectation, $\tilde{G}$ is identical to G (P & A are risk neutral).

Modified game with hidden action

- hidden action agent chooses (*Good* or *Bad*)

- Game G: $p_B < p_G$
- Game $\tilde{G}$: $F_{p_B} \leq F_{p_G}$
  [first order stat. dominance]



$$\Pi^A = \begin{cases} x_{p_G} w - (1 - x_{p_G}) x_A & \text{if Good} \\ x_B + x_{p_B} w - (1 - x_{p_B}) x_A & \text{if Bad} \end{cases}$$

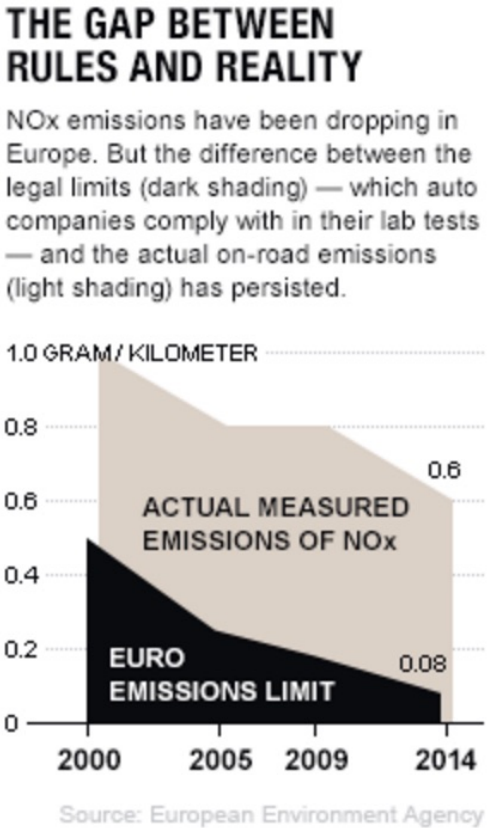
$$E(\Pi^A) = \begin{cases} p_G w - (1 - p_G) A & \text{if Good} \\ B + p_B w - (1 - p_B) A & \text{if Bad} \end{cases}$$

$$\Pi^P + \Pi^A = x_{p_G} x_R - x_K$$

$$E(\Pi^P + \Pi^A) = p_G R - K$$

WV scandal from P&A perspective: Game 1 or 2?

The gap between ex ante (required) and ex post (real)



Nested P&A settings

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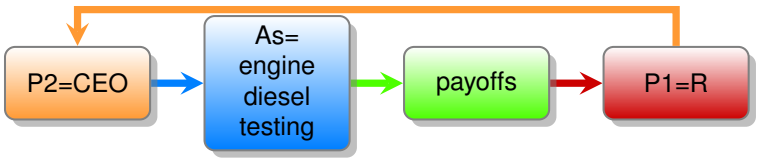
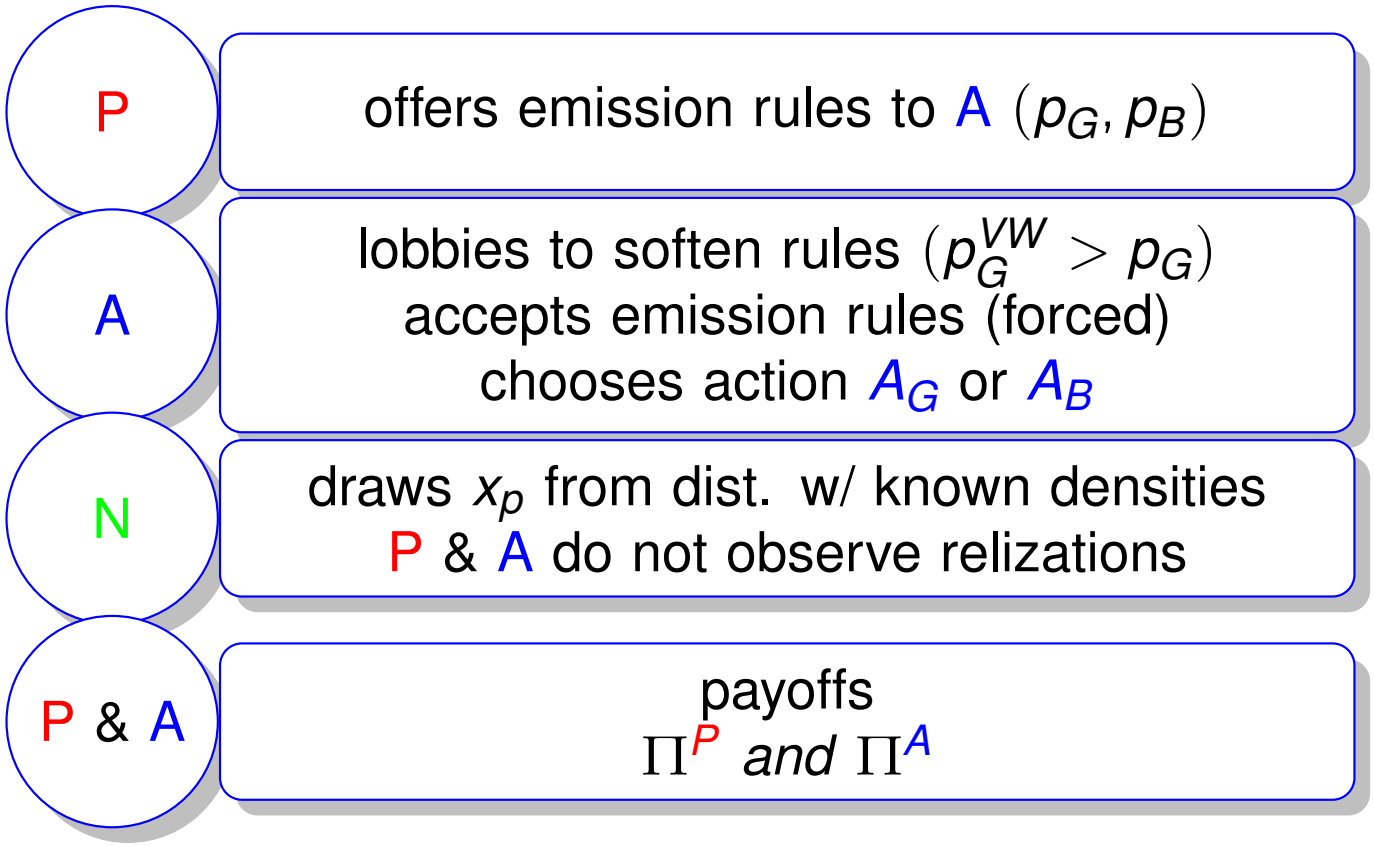
    - engine electronics
    - diesel motor development
    - motor testing



Modified game 1: VW emissions test

Timing



$$E(\Pi^P + \Pi^A) = p_G R - K$$

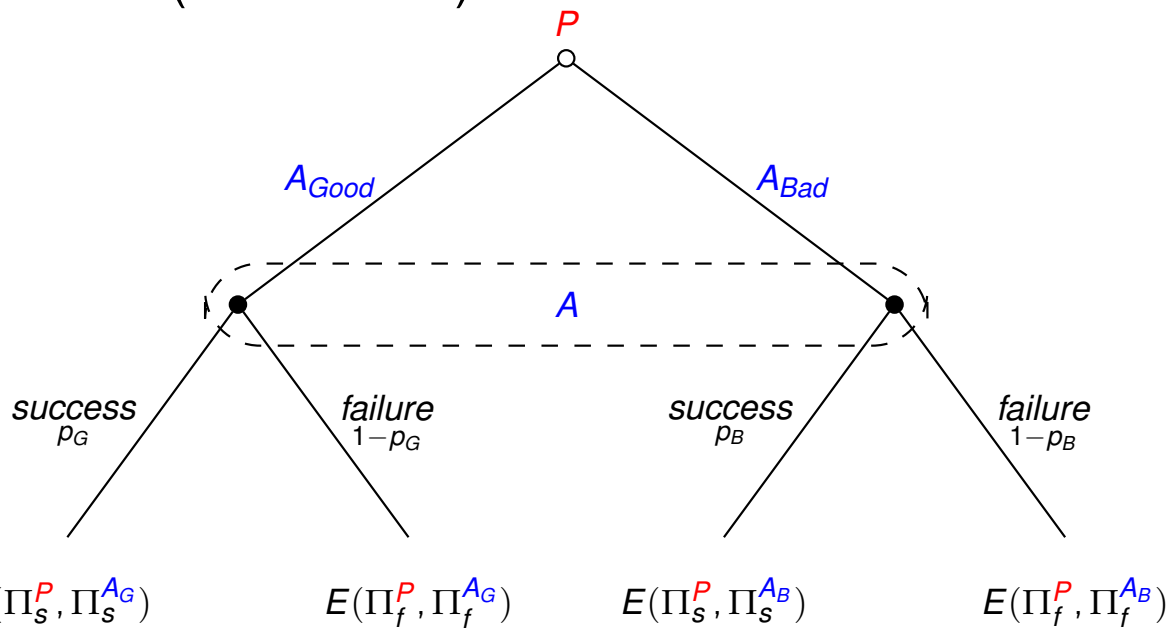
$$E(\Pi^A) = \begin{cases} p_G w - (1 - p_G)A & \text{if } A_G \\ B + p_B w - (1 - p_B)A & \text{if } A_B \end{cases}$$

Modified Game 1: VW emissions scandal

WV top management as an agent

- P1 = R (EPA, CARB) & A1 = VW (hidden info)

x_K	capital; $x_K \in [x_K^{\min}, x_K^{\max}]$
x_R	revenue; $x_R \in [x_R^{\min}, x_R^{\max}]$
x_{p_G}	A_G success prob.; $x_{p_G} \in [...]$
x_{p_B}	A_B success prob.; $x_{p_B} \in [...]$
x_B	A's (hidden) benefit; $x_B \in ...$
w	A's gov. grants if success
x_A	A's fines, etc.; $x_A \in ...$



Num. example

$K = 100$ $R = 240$
$p_G = 1/2$ $p_B = 1/4$
$B = 30$ [high VW profits]

$$E(\Pi^P) = p_G(R - w) + (1 - p_G)A - K$$

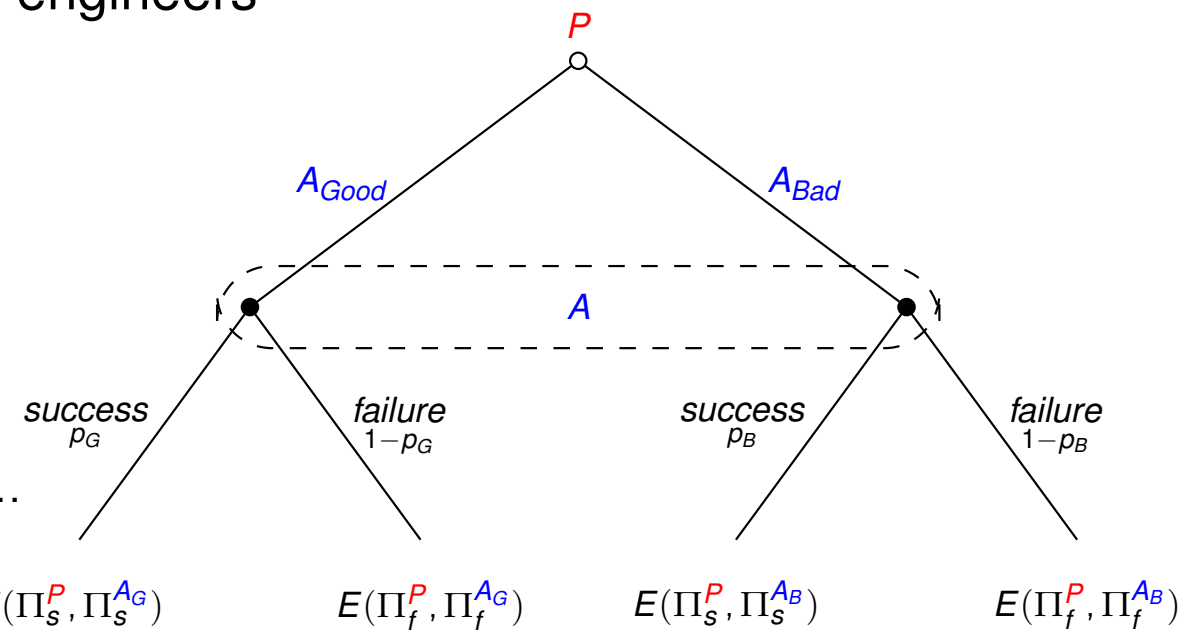
$$E(\Pi^A) = \begin{cases} p_G w - (1 - p_G)A & \text{if } A_G \\ B + p_B w - (1 - p_B)A & \text{if } A_B \end{cases}$$

Modified Game 2: VW emissions scandal

WV engineers an agents

- P2 = VW (top) & As = VW engineers

x_K	capital; $x_K \in [x_K^{\min}, x_K^{\max}]$
x_R	revenue; $x_R \in [x_R^{\min}, x_R^{\max}]$
x_{p_G}	A_G success prob.; $x_{p_G} \in [...]$
x_{p_B}	A_B success prob.; $x_{p_B} \in [...]$
x_B	A's (hidden) benefit; $x_B \in ...$
w	A's bonus if success
x_A	A fired, imprisoned(?) $x_A \in ...$



Num. example

$K = 100$ $R = 240$

$p_G = 1/2$ $p_B = 1/4$

$B = 30$ [big bonus?]

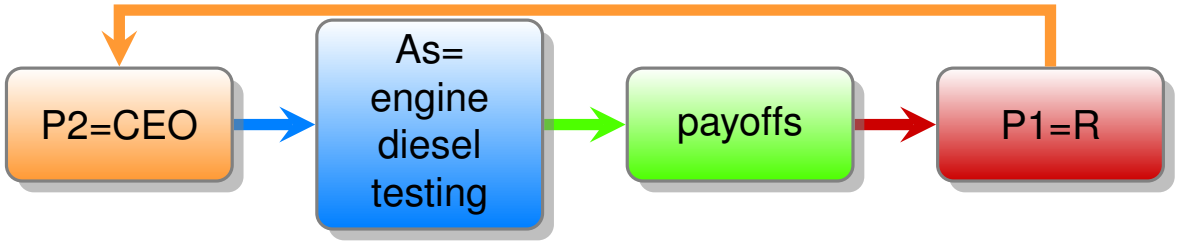
VW engineers (different divisions):

- engine electronics
- diesel motor development
- motor testing

$$E(\Pi^P) = p_G(R - w) + (1 - p_G)A - K$$

$$E(\Pi^A) = \begin{cases} p_G w - (1 - p_G)A & \text{if } A_G \\ B + p_B w - (1 - p_B)A & \text{if } A_B \end{cases}$$

VW scandal from P&A perspective
Why there were 6 suspects (initially)?



Question: Could (headstrong) VW engineers pull the rigging of US emission tests with no management knowledge?

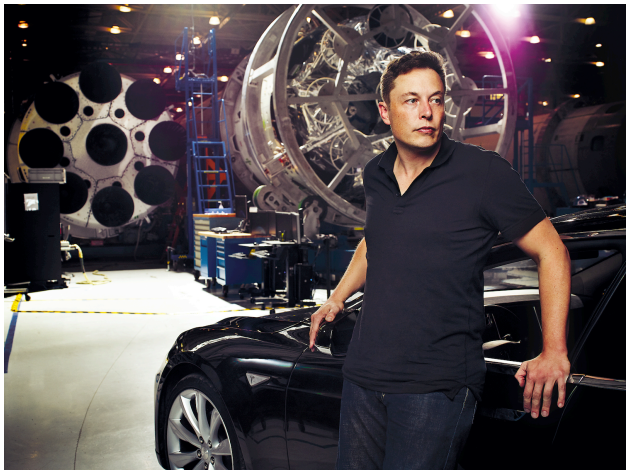
Factors to consider

1. A(s) may face enormous punishment, but limited reward
2. A(s) deceived repeatedly, for different models & technologies
3. A(s) deceived independently (VW & Audi, in several divisions)

- 2016 March. Internal inquiry: 17 suspects (up from 6)

What does the increased number of suspects mean?

Outside of VW: Expert opinions I



Judgement from new auto industry

"VW emissions scandal is mainly the result of physics meeting fiction." *Elon Musk [Tesla Motors CEO]*, Open letter to CARB:

Retrofitting is impractical. Instead, require VW to push a rollout zero emission vehicles.

Judgement from traditional auto industry

"I don't think you can do something like this hiding in the bushes." *Carlos Ghosn [Renault-Nissan CEO]*

I.e., it would be difficult to conceal internally an effort to falsify vehicle emissions data, such as has happened at Volkswagen Group.

VW deceit uncovered

Top management involvement: the revelations

- 2011 Whistleblower(s?) inform CEO of core VW
- Investigation possibilities: software audit trail & test logs
- 2015 Sept. DoJ order: "stop routine data deletions”

  IT center whistleblower: deletions continued (explanation “lack of storage space”)
- 2016 Jan. DoJ & EPA seek penalties of $46 bln; + criminal inquiry

Q: Similarities & differences with CPS cyber-security technologies ?

VW emissions vs CPS security I

VW

- software-hardware interact
- public good (environment)
- required level is well defined
- hard to estimate damages
- individual damages are small (in expectation)

CPS security

- software-hardware interact
- public good (security)
- required level is poorly defined
- even harder to estimate damages
- information asymmetry is worse for CPS security

Risk management: perfectly competitive [PC] insurers

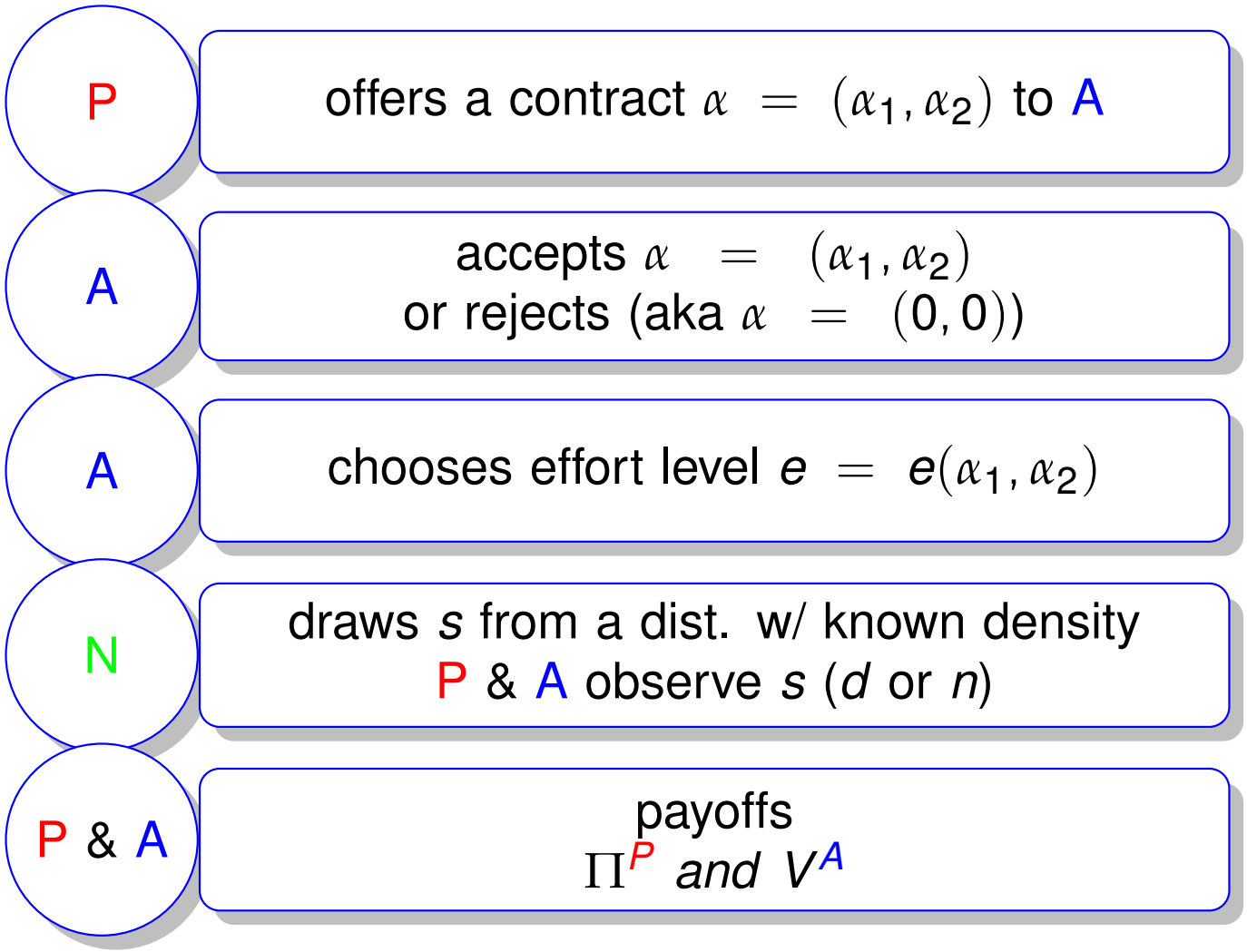
s	state $s = \{d, n\}$ (damage or no damage)
p	prob. of an accident (damage D)
W_s	agent's wealth in state s
D	damage from an accident
$p(e)$	$p'(\cdot) < 0; p''(\cdot) > 0$ [new]
e	$A's$ action (effort to reduce p) [new]
U_s	agent's utility in state s; $U'(\cdot) > 0; U''(\cdot) < 0$
Π_s	insurer profit in state s
α_1	insurance premium
$\hat{\alpha}_2$	coverage (if $s = d$)
α	contract $\alpha = (\alpha_1, \alpha_2)$
α_2	$\alpha_2 = \hat{\alpha}_2 - \alpha_1; \alpha(e) = (\alpha_1(e), \alpha_2(e))$

$$\Pi^P = (1 - p(e))\alpha_1 - p(e)\alpha_2$$

$$V^A = p(e)U(W - \alpha_1) + (1 - p(e))U(W - D + \alpha_2) - e$$

Benchmark (no info asymmetry): effort is observable

Timing



Benchmark (effort is observable): A solution

Contract $\alpha(e) = (\alpha_1(e), \alpha_2(e))$

$$\Pi^P = \begin{cases} \Pi_n = \alpha_1 & \text{if } s = n \\ \Pi_s = -\alpha_2 & \text{if } s = d \end{cases} \qquad V^A = \begin{cases} U_n = U(W - \alpha_1) & \text{if } s = n \\ U_s = U(W - D + \alpha_2) & \text{if } s = d \end{cases}$$

$$\Pi^P = (1 - p(e))\alpha_1 - p\alpha_2$$

$$V^A = \begin{cases} p(e)U(W) + (1 - p(e))U(W - D) - e & \text{if uninsured, } \alpha = (0,0) \\ p(e)U(W - \alpha_1) - (1 - p(e))U(W - D + \alpha_2) - e & \text{if } \alpha = (\alpha_1, \alpha_2) \neq (0,0) \end{cases}$$

Under perfect competition: $\Pi^P = 0$, for any $\hat{\alpha}_2 \in (0, D)$ and any e

$$(1 - p(e))/p(e) = \alpha_2/\alpha_1 \quad \textit{or} \quad \alpha_1 = p\hat{\alpha}_2 \qquad [\textit{actuarially fair contract}]$$

Risk averse agent buys full coverage ($\hat{\alpha}_2 = D$). Same utility in both states (d, n):

$$V^A = U(W - p^*D) - e \quad \textit{and} \quad (\alpha_1, \alpha_2) = (p^*D, (1 - p^*)D); p^* = p(e)$$

Benchmark (no info asymmetry)
PC insurers & agent effort observable I

Agents differ only by the prob. of an accident $p^i = p(e)$; $\alpha^i = \alpha(e)$
contract for type i = contact for effort e

$$\Pi^P = \begin{cases} \Pi_n = \alpha_1(e) & \text{if } s = n \\ \Pi_s = -\alpha_2(e) & \text{if } s = d \end{cases} \qquad V^A = \begin{cases} U_n(W - \alpha_1(e)) - e & \text{if } s = n \\ U_s(W - D + \alpha_2(e)) - e & \text{if } s = d \end{cases}$$

Contract $\alpha(e)$ for each e

$$(\alpha_1, \alpha_2, e) = (p(e)D, (1 - p(e))D)$$

$$V^A(e) = U(W - p(e)D) - e$$

Risk averse agents buy full coverage: ($\hat{\alpha}_2 = D$)

Next: Effort is unobservable [different e = different prob. of an accident $p(e)$]

Info asymmetry: PC insurers & hidden agent's effort

Agent type $i = H, L$; $p^H > p^L$. α^i – contact for i [Rothschild & Stiglitz'76]

$$\Pi^P = \begin{cases} \Pi_n = \alpha_1^i & \text{if } s = n \\ \Pi_s = -\alpha_2^i & \text{if } s = d \end{cases} \qquad V^{A^i} = \begin{cases} U_n = U(W - \alpha_1^i) & \text{if } s = n \\ U_s = U(W - D + \alpha_2^i) & \text{if } s = d \end{cases}$$

Agent action e; $p(e)$; $p' < 0, p'' > 0$. $\alpha(e)$ – contact for e [Arnott & Stiglitz'91]

$$\Pi^P = \begin{cases} \Pi_n = \alpha_1(e) & \text{if } s = n \\ \Pi_s = -\alpha_2(e) & \text{if } s = d \end{cases} \qquad V^A = \begin{cases} U_n(W - \alpha_1(e)) - e & \text{if } s = n \\ U_s(W - D + \alpha_2(e)) - e & \text{if } s = d \end{cases}$$

Proposition

PC market with MH requires rationing of insurance. [Arnott & Stiglitz'91]

Intuition: At any given price, agents want to buy a higher amount of coverage than optimal for insurers.

Arnott & Stiglitz'91: PC insurers with MH

[ideologically similar to Rothschild & Stiglitz'76: PC insurers with AS]