The Economics of Workplace Charging

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June 1, 2016 TU Berlin, Konferenz Verkehrsökonomie

Published: *Transportation Research Part B*, 88: 93-118, 2016.

Introduction

- Obstacles for buying electric vehicles (EV)
  - Low battery performance
  - Missing charging infrastructure
- Options:
  - **Charging at home (**home place charging, **HPC)**
  - **Commercial or public charging (CPC)**
  - **Charging at the workplace (**workplace charging**, WPC)**
- Policy programs to foster WPC
  - E.g. US program (US Dep of Energy, 2014a): 600,000 workers, 300 employers in 2014
  - Québec (2014): subsidy 5000$ per charging station, electric power is free of charge to employers

Our Questions

1. **Will workplace charging (WPC) be a decentral outcome?**
2. **Which policy is effective in promoting WPC?**
   - Public charging stations, energy price, subsidies, technologies

Benefits of WPC

Benefits for employees

- **Fringe benefits** (Leibowitz 1983)
- **Reduces range-anxiety (Neubauer and Wood 2014)**
- **Extends availability of EV**

Benefits for employers

- **Lower costs**
- **Higher productivity**
  (Delmas/Pekovic 2013, Lanfranchi/Pekovic 2014; Grolleau et al 2013)

Social benefits

- Car and mode choice (Sierzchula 2014)
- Externalities (Thiel et al 2010; Buekers et al 2014)

Our Research and Literature

1. Suggest a model of decisions on workplace charging
2. Analyze incentives and barriers on demand / supply of WPC.
3. Consider policies to foster WPC

Relates to

- De Borger and Wuyts (2009): Employer-paid parking
- De Borger and Wuyts (2011): Company cars offered to workers

Results

Main results

- There is no private WPC contract {wage, charging fee} beneficial to both employer and employee.
- Direct subsidies to employer ($\pm$ specific energy price policies) could be a way to foster WPC.
- Not effective:
  - Lower charging time at public/commercial charging stations (CPC)
  - Reduction of energy prices to workers (Home place charging)

The Worker - Notations

D	total daily distance
γ	share of charging based on cost minimization
$1-\gamma$	share of minimum charging (at home) minimum load due to functionality and efficiency of battery (∼20%) minimum load required to access next chosen loading station
$H = \{HPC, CPC\}$	charging package W – CPC = public / commercial charging, – HPC = home charging
$W = \{HPC, WPC\}$	charging package W – WPC = workplace charging

Worker - Three Stage Decision

1. **Choice of charging location for each package** H **and** W
   - Idiosyncratic daily shock on charging costs at WPC and CPC
   - $\beta_H \left(\underset{-}{p_H}, \underset{+}{p_C} \right)$ share of HPC within H
   - $\beta_W \left(\underset{-}{p_H}, \underset{+}{p_W} \right)$ share of HPC within W
   - Expected charging costs

$$c^i = (1-\gamma)\, p^H + \gamma \begin{cases} \beta^H p^H + \left(1-\beta^H\right) p^C & \text{if } i = H \\ \beta^W p^H + \left(1-\beta^W\right) p^W & \text{if } i = W \end{cases}$$

   - Expected travel time per VMT

$$t_D^i = t_d + \begin{cases} \gamma \left(1-\beta^H\right) t_c & \text{if } i = H \\ 0 & \text{if } i = W \end{cases}$$

Worker - Three Stage Decision (ctd.)

2. **Choose consumption and traveling** D

- **Utility** from consumption x, leisure, l, and travel, D

$$U^i = U^i(x^i, l^i, D^i), \qquad i = H, W.$$

- The (daily) **monetary budget** and **time constraint**s are,

$$x^i + c^i D^i = \omega^i \, (1 - \tau) \, t_w, \qquad i = H, W$$

$$l^i + t_w + t_D^i D^i = T, \qquad i = H, W,$$

- FOC: $u_D^i / \lambda^i = \rho^i$,
- VTTS: $\rho^i = c^i + t_D^i \xi^i$
- VOT: $\xi^i = u_l^i / \lambda^i = \omega^i \, (1 - \tau)$

Worker - Three Stage Decision (ctd.)

3. **Choose** H **or** W (contract)
   - Indirect utility V^i
   - Idiosyncratic preference ε for WPC
   - An employee accepts a contract W if

$$V^W + \varepsilon > V^H$$

- **Probability to choose contract** $W = \{HPC, WPC\}$

$$\theta = \frac{1}{2} - \frac{V^H - V^W}{2a} \quad (1)$$

Comparative Statics - Lemmas

1. θ increases with the labor tax (fringe benefit)

2. θ declines
   - Lower wage ω^W to compensate WPC
   - Lower charging time at public stations (CPC)

3. θ ambiguous
   - Increase in charging fee p^W at WPC
   - Increase in charging costs p^C at public stations
   - Increase in charging costs p^H at home

   - Direct price effect between H and W
   - Countervailing price effect of substitution within H or W

The Firm – Costs

- Representative firms, input is labor, wage $\bar{\omega} = MPL$
- WPC affects costs (not productivity)
- **Firm may offers five different contracts**

1. $WPC_0 =$ no workplace charging at all: $\{\bar{\omega}, 0\}$
2. $WPC_1 = \{\omega^W = \bar{\omega}, p^W = 0\}$ – employer paid charging
3. $WPC_2 = \{\omega^W \leq \bar{\omega}, p^W = 0\}$ – wage discount, no fees
4. $WPC_3 = \{\omega^W = \bar{\omega}, p^W \geq 0\}$ – market wage but fees
5. $WPC_4 = \{\omega^W \leq \bar{\omega}, p^W \geq 0\}$ – fully flexible choice of ω^W, p^W

Expected costs

Daily expected costs (t_W working hours - **fully flexible contract** WPC$_4$):

$$
\begin{aligned}
C\left(\omega^W, p^W\right) = \bar{\omega} t_w & & \textit{market wage costs} \\
+\, \theta \Big[\left(\omega^W - \bar{\omega}\right) t_w & & \textit{wage reduction} \\
+ \left(\bar{p} - p^W\right) d^e & & \textit{net energy cost} \\
+ \frac{1}{k}\left(r\bar{c} - \delta\right) \Big] & & \textit{net facility cost}
\end{aligned}
$$

Expected costs

Employer paid WPC, $\text{WPC}_1 = \left\{\omega^W = \bar{\omega}, p^W = 0\right\}$

$$
\begin{aligned}
C\left(\omega^W, p^W\right) = \bar{\omega} t_w & \qquad \textit{market wage costs} \\
+ \theta \Big[0 & \qquad \textit{wage reduction} \\
+ \bar{p} d^e & \qquad \textit{net energy cost} \\
+ \frac{1}{k}\left(r\bar{c} - \delta\right) \Big] & \qquad \textit{net facility cost}
\end{aligned}
$$

Expected costs

Wage discount only, $\mathrm{WPC}_2 = \{\omega^W \leq \bar{\omega}, p^W = 0\}$

$$
\begin{aligned}
C\left(\omega^W, p^W\right) = \bar{\omega} t_w & \qquad \textit{market wage costs} \\
+ \theta \left[\left(\omega^W - \bar{\omega}\right) t_w \right. & \qquad \textit{wage reduction} \\
+ \bar{p} d^e & \qquad \textit{net energy cost} \\
\left. + \frac{1}{k} \left(r \bar{c} - \delta\right) \right] & \qquad \textit{net facility cost}
\end{aligned}
$$

Expected costs

Charging fee only, $WPC_3 = \{\omega^W = \bar{\omega}, p^W \geq 0\}$

$$
\begin{aligned}
C\left(\omega^W, p^W\right) = \bar{\omega} t_w & \qquad \textit{market wage costs } \bar{\omega}, 0 \\
+ \theta \Big[0 & \qquad \textit{wage reduction} \\
+ \left(\bar{p} - p^W\right) d^e & \qquad \textit{net energy cost} \\
+ \frac{1}{k}\left(r\bar{c} - \delta\right) \Big] & \qquad \textit{net facility cost}
\end{aligned}
$$

Simulation Benchmark of WPCs

Variable	Symbol	No WPC	WPC_1	$WPC_{2/4}$	WPC_3
General consumption	X	91	93	86	91
Leisure	l	8.49	8.35	8.36	8.52
Mobility	D	52.71	65.88	65.54	59.18
Monetary travel cost	c	0.058	0.022	0.022	0.058
Gen travel cost	ρ	0.349	0.284	0.265	0.310
Value of Time	ξ	10.15	10.50	9.71	10.07
Utility	U	3.417	3.439	3.403	3.428
Probability WPC	θ	—	0.82	0.29	0.65
contract	$\omega^W \| p^W$	—	19.65|0	18.22|0	19.65|0.081
WPC employee	ev	—	+7.88	−4.72	+3.77
WPC employer	ps	—	−4.02	+1.98	−2.11
WPC benefit	$ev + ps$	—	+3.86	−2.74	+1.65
WPC employee			majority	**minority**	majority
WPC employer			**no offer**	offer	**no offer**

WPC: Workplace charging EV-E: Electric Vehicle using employee

$(p - p^W) d^e$

Simulation - Results

- If WPC is beneficial for employee, there is no supply (WPC_1,WPC_3).
- If WPC is beneficial for employers there is only a small demand (only for those with high idiosyncratic preferences for WPC)

Simulations - Interventions: WPC_1

Table: WPC_1 remedies $\{\bar{\omega}, 0\}$

Variable	Symbol	Remedy (a)	Remedy (b)	Dimension
WPC facility subsidy	$\delta \uparrow$	1110[1]	878[2]	€/EV-E*year
Tariff paid by employer	$\bar{p} \downarrow$	—	0	€/km
Probability WPC before	θ	0.82	0.82	%
Probability WPC after	θ	0.82	0.82	%
WPC employee benefit	ev	+7.88	+7.88	€/EV-E*day
WPC employer benefit	ps	±0.00	±0.00	€/EV-E*day
WPC benefit	$ev + \Delta P$	+7.88	+7.88	€/EV-E*day
WPC decision	employee	majority	majority	
	employer	offer	offer	

WPC: Workplace charging EV-E: Electric Vehicle using employee

[1] Implies $(\overline{c} - \delta) = -435$ €/EV-E*year

[2] Implies $(\overline{c} - \delta) = -203$ €/EV-E*year

Simulations - Interventions: WPC_3

Table: WPC_3 remedies $\{\bar{\omega}, p^W\}$

Variable	Symbol	Remedy (a)	Remedy (b)	Dimension
WPC facility subsidy	$\delta \uparrow$	728[1]	655[1]	€/EV-E*year
Tariff paid by employer	$\bar{p} \downarrow$	—	0.000	€/km
Probability WPC before	θ	0.65	0.65	%
Probability WPC after	θ	0.65	0.65	%
WPC employee benefit	ev	+3.77	+3.77	€/EV-E*day
WPC employer benefit	ps	±0.00	±0.00	€/EV-E*day
WPC benefit	$ev + ps$	+3.77	+3.77	€/EV-E*day
WPC decision	employee	majority	majority	
	employer	offer	offer	

WPC: Workplace charging EV-E: Electric Vehicle using employee

[1] Implies $(\overline{c} - \delta) = -53$ €/EV-E*year

[2] Implies $(\overline{c} - \delta) = +20$ €/EV-E*year

Remedies for WPC 2/4

Table: WPC_4 remedies $\{\omega^W, p^W\}$

Variable	Symbol	Remedy (a)	Remedy (b)	Remedy (c)	Remedy (d)
Tariff HPC	$p^H \uparrow$	0.088	—	—	—
Charging time	$t^C \uparrow$	—	0.054[1]	—	—
Labor tax	$\tau \uparrow$	—	—	0.80	—
Tariff CPC	$p^C \downarrow$	—	—	—	0.017
p WPC before	θ	0.30	0.30	0.30	0.30
p WPC after	θ	0.50	0.50	0.50	0.50
WPC employee	ev	+0.00	+0.00	+0.00	+0.00
WPC employer	ps	+3.19	+2.71	+3.34	+3.26
WPC benefit	$ev + ps$	+3.19	+2.71	+3.34	+3.26
WPC decision	employee	majority	majority	majority	majority
	employer	offer	offer	offer	offer

WPC: Workplace charging EV-E: Electric Vehicle using employee

[1] Implies a recharging time of $\approx$ 11 hours for a driving range of 200 km

Conclusions

- WPC is either not supplied by firms or not demanded by the majority of workers.
- Subsidies to employer are the most promising remedy to raise WPC
- Subsidies to worker are not working!
  (see also Hirte/Tscharaktschiew 2013)
- There is a trade-off between supporting CPC and WPC

- The approach can be applied to legal and illegal uses of firms resources (e.g. Internet)
- We do neither consider productivity effects nor green branding $\rightarrow$ downward bias in probability to choose WPC

Thanks for your attention!

Calibration

Description	Symbol	Value	Dimension
Transport data			
Degree of range-anxiety	γ	0.7	%
Driving time	t_d	1.5	min/km
Recharging time	t_c	1.32	min/km
Prices, costs, taxes			
Market wage rate	ϖ	19.65	€/h
Wage rate EV-E	ω^W	$\leq$ 19.65	€/h
Electricity tariff for HPC	p^H	0.052	€/km
Charging fee WPC	p^W	≥ 0	€/km
Electricity fee for CPC	p^C	0.091	€/km
Electricity tariff paid by the employer[5]	$\overline{p}$	0.027	€/km
Price general consumption goods	p^X	1	€/unit
Labor tax rate	τ	0.40	%
Unit capital cost	r	1.03	–
WPC facility costs	$\overline{c}$	675	€/EV-E*year

Data

Description	Symbol	Value	Dimension
Other data			
Preference general consumption	η_X	0.47	–
Preference leisure	η_l	0.44	–
Preference mobility	η_D	0.09	–
Time endowment	T	18	h/day
Daily working time	t_w	8	h/day
Parameter WPC probability function	a	0.04	–
Number of contract days	k	225	days

WPC: Workplace charging EV-E: Electric Vehicle using employee
Average driving speed is $\frac{1}{t_d} = 40$ km/h
Recharging time of 2.2 hours for a driving range extension of 100 km
Assuming electricity price of 0.29 €/kwh and EV energy intensity of 0.18 kwh/km
Assuming that the employer's electricity cost is 52% of the employee's cost at home
Benchmark case $\delta = 0$; Others; $\delta \geq 0$

Simulation - Function, Charging Shares, Rents

Cobb-Douglas utility function

$$U\left(X^i, I^i, D^i\right) = \eta_X \log\left(X^i\right) + \eta_I \log\left(I^i\right) + \eta_D \log\left(D^i\right) \tag{2}$$

The relative charging shares

$$\beta^H\left(p^H, p^C\right) = \frac{1}{1+\exp\left(p^H - p^C\right)}$$
$$\beta^W\left(p^H, p^W\right) = \frac{1}{1+\exp\left(p^H - p^W\right)}$$