Who pays for network infrastructure? The catch-22 of decentralised energy technology.

Dr Anna Rita Bennato and Prof. Monica Giulietti (Loughborough University)
Dr Andrew Burlinson (Warwick University)

Background

Context

- Storage "one of eight great technologies" (HoP, 2015)
- A real "game changer" (World Energy Resources, 2016)
- Disruptive technologies…transform the way we live, work and…upset[s] the established order" (MGI, 2013: iii)

Literature

- Our analysis extends Gautier, Jacqmin and Poudou (2018)
- Related to literature on the 'death spiral' of legacy infrastructure (Decker, 2016)

Research question

Does an increase in self-consumption of distributed generation (via solar and storage) increase costs for 'traditional' consumers?

- If so, is this the beginning of the end of legacy energy infrastructure?

The model

The technology

- $N = N_p + N_{np}$ (normalised to 1)
- Solar PV synchronisation process: $0 < \varphi < 1$
- Solar-storage generates: $k = K\alpha\beta$
- Storage process: $0 < \rho < 1$
- Surplus electricity $k[1 - (\varphi + \rho)]$ sold at competitive price, p
- N_p supplement demand (via grid) $q - (\varphi + \rho)k$ at price p

The model

The investment decision

- Lifetime cost $\mathrm{L(s)} = x + \gamma m s$

Where x = sunk costs, m = maintenance costs and…

- γ represents investment inefficiencies i.e. consumers behave as if they discount the future such that $0 < \gamma = \frac{1}{1+\delta} < 1$
- $s \in [\underline{s}, \bar{s}]$ represents heterogeneous operating costs with F(s) and f(s). Hence $N_p = F(s)$ and $N_{np} = 1 - F(s)$
- $\mathrm{NV(s)} = \mathrm{k}[-x + \gamma(p - sm) + \xi] \rightarrow p + \frac{\xi}{\gamma} > \frac{x}{\gamma} + sm$

The model

The grid

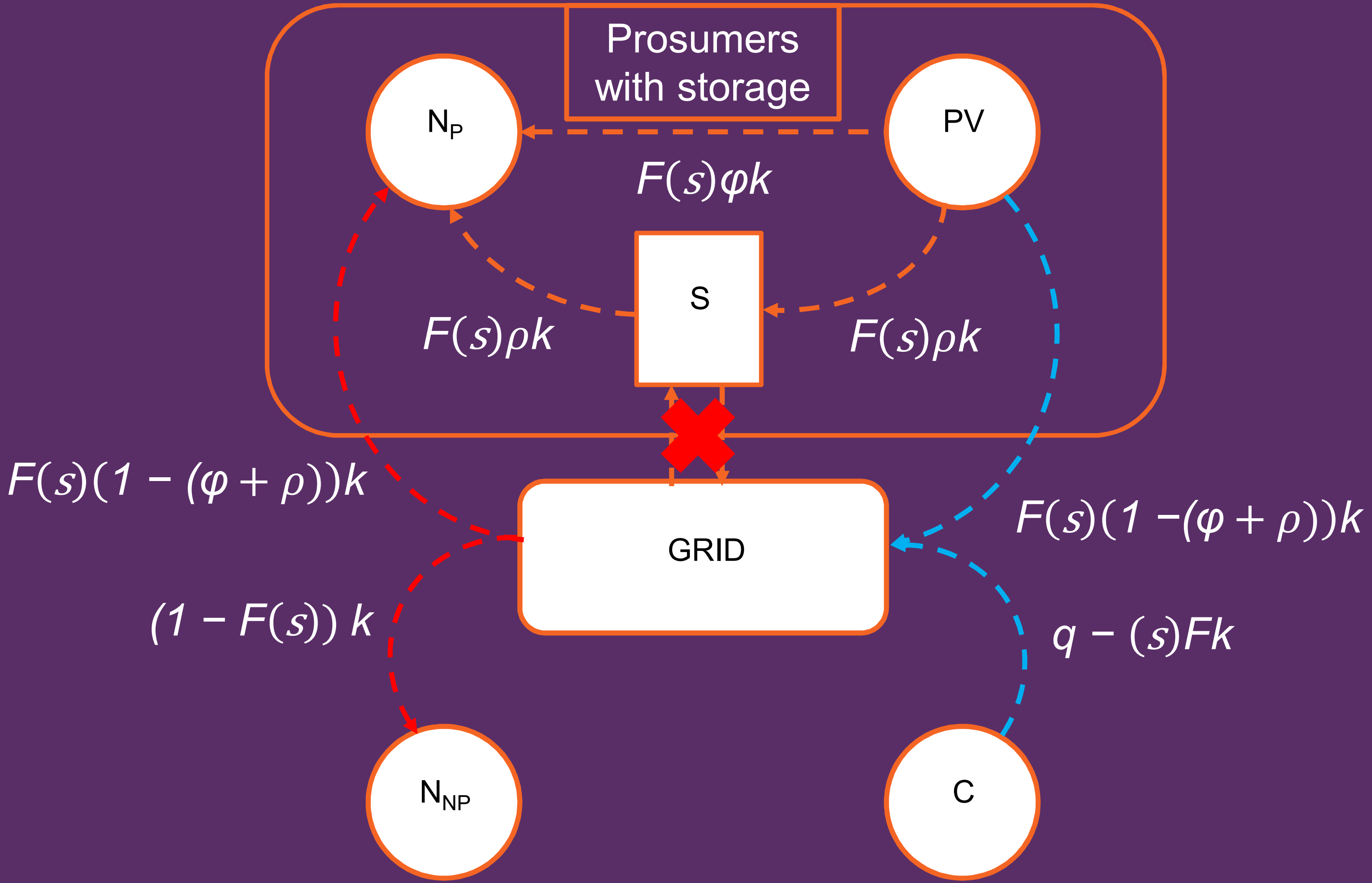
- $EX_p = \mathrm{F(s)}[1 - (\varphi + \rho)]k$ and $EX_c = \mathrm{q} - \mathrm{F(s)}k$
- Centralised competitive price p = c
- Social cost $\epsilon[q - F(s)k]$

Costs

- $C(s) \equiv C_G(d) + C_D(s) = \left(xk + I_p\right)F(s) + I_c + \gamma\{(c + \epsilon)[q - F(s)k] + mH(s)k + \theta[q - F(s)(\varphi + \rho)k]\}$

Revenue

- $R = r_m\left(EX_c + EX_p\right) + r_x\left(EX_p\right)$


Prosumers with storage
N_P
PV
F(s)φk
S
F(s)ρk
F(s)ρk
F(s)(1 − (φ + ρ))k
GRID
F(s)(1 −(φ + ρ))k
(1 − F(s)) k
q − (s)Fk
N_NP
C

The results

System level: Marginal social benefit

- $MSB_s \equiv s^* = \frac{1}{m}[p - \frac{x}{\gamma} + \theta(\varphi + \rho) - \frac{I_p}{\gamma k} + \epsilon]$

At the upper bound s*

- The marginal private benefit $(p - \frac{x}{\gamma})$
- The marginal network benefit $(\theta(\varphi + \rho) - \frac{I_p}{\gamma k})$
- The marginal external benefit (ϵ)

The results

Consumer level: Marginal social benefit

- $MSB_{\hat{s}} \equiv \hat{s} = \frac{1}{m}[p - \left(\frac{x-\xi}{\gamma}\right) + r_m(\varphi + \rho) - r_x[1 - (\varphi + \rho)] + \epsilon]$

Thus

- The marginal private benefit: $p - \left(\frac{x-\xi}{\gamma}\right)$
- The marginal network benefit: $r_m(\varphi + \rho) - r_x[1 - (\varphi + \rho)]$
- The marginal external benefit: ϵ

The results

Break-even constraint

- $C_D(s) = R$

Locus of tariffs

- $\hat{r}_x(r_m, s) = (\theta - r_m)\frac{q - F(s)(\varphi + \rho)k}{F(s)[1-(\varphi+\rho)]k} + \frac{I_c + I_p F(s)}{\gamma F(s)[1-(\varphi+\rho)]k}$

Using the locus, System MSB and consumer MSB we can derive the equilibrium

The results

Equilibrium

- $\hat{s} = s^* + \frac{1}{m}\left[(r_m - \theta)\left(\frac{q}{F(s)k}\right) - \frac{I_c}{\gamma F(s)k} + \frac{\xi}{\gamma}\right]$

First best level of operation

- $\hat{s} = s^*$

If $r_m = \theta$ and $\frac{I_c}{\gamma F(s)k} = \frac{\xi}{\gamma}$

If $r_m \gtreqless \theta$ and $\frac{I_c}{\gamma F(s)k} \gtreqless \frac{\xi}{\gamma}$

The results

Distributional effects (derived from the locus of tariffs)

- $I = I_c + I_p F(s)$

$= \gamma\{(r_m - \theta)[q - F(s)(\varphi+\rho)k] + r_x F(s)[1 - (\varphi+\rho)]k\}$

When $r_m = \theta$

- $\frac{\partial I}{\partial \rho} < 0\,; \frac{\partial I}{\partial \rho \partial \varphi} < 0\ and\ \frac{\partial I}{\partial \rho \partial \gamma} < 0$

The results

When $r_m \neq \theta$

- $\frac{\partial I}{\partial \rho} = F(s)k[\theta - (r_x + r_m)]\gamma$

$If\ \hat{s} = s^*\ then\ r_m > \theta$

- Enforcing the optimal level of solar-storage will lead to a fall in grid revenues with increased levels of storage optimisation
- Greater import costs lead to further defection
- Traditional consumers pay relatively more (c.f. no storage)

Conclusion

Storage is a valuable asset

- Reducing power exchanges, alleviating grid congestion and reducing curtailment of renewables
- Variable costs likely to fall as solar-storage penetration increases
- Prostorers benefit from increased self-consumption and averting centralised production and network costs

However

- Traditional consumers contribute relatively more towards legacy infrastructure – clear challenges related to equity

Thanks and contact details

Thank you for listening!

Email

- A.R.Bennato@lboro.ac.uk
- Andrew.Burlinson@warwick.ac.uk
- M.Giulietti@lboro.ac.uk