Efficiency of Markets for Generator Ramp Capability in Electricity Spot Markets

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Outline

I. Wind variability & need for energy "ramp"

II. Why a separate ramp product?
2 proffered reasons

III. What is the performance of:
- *deterministic ISO market model + ramp product*

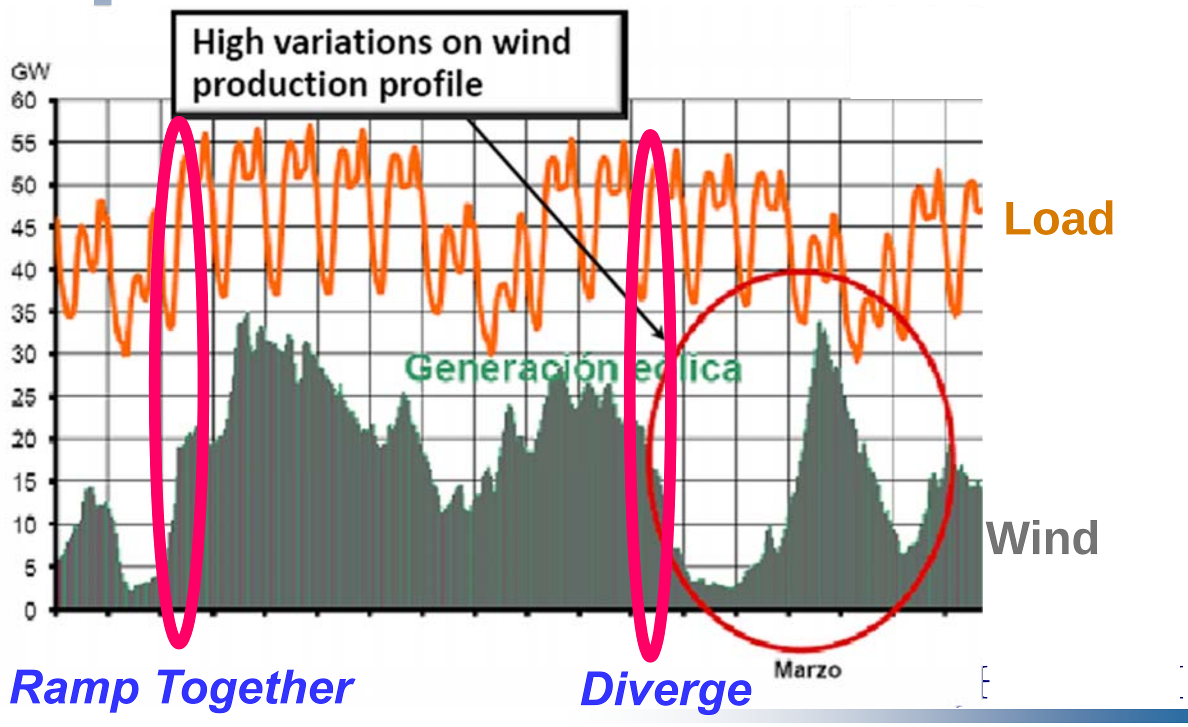
vs.

- *the ideal of stochastic programming?*

I. Challenge: Imperfectly Predictable Variability

2020 Spanish Wind Profile Relative to Load

(de la Torre & Paradinas, 2010; thanks to C. Batlle)



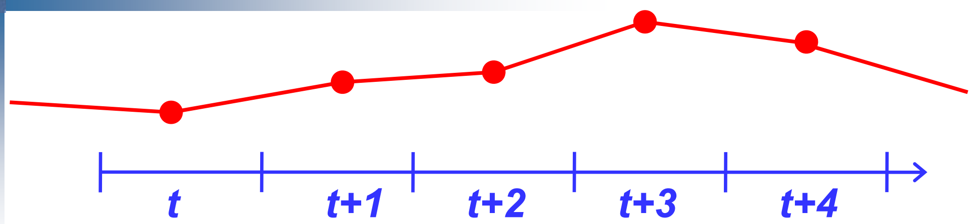
II. Two Claimed Reasons for Separate Ramp Product

1. <u>Forecast</u> ramp of net load
   - *But* energy prices ($/MWh) incent profit-maximizing generators to provide right amount

2. Net load forecast <u>errors</u>
   - Surprisingly high or low load
   - Realized loads more volatile
   - *Ideal solution:* stochastic programming
     - *Practical:* flexiramp (new "market product")

Insights from theorem, simple examples

Reason 1. Dealing with Forecast Ramp



If:

1. Zero load forecast error
2. Generator ramp limits correctly represented, &
3. Costs convex (no lumpy costs, prohibited regions) ….

***Then* calculated energy *P*'s "support" the solution**

- No generator can increase profit by deviating from schedule
- Includes up- and downward price spikes
  - Up-spikes compensate ramping generators for down-spikes
- Why? Fundamental properties of convex optimization

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Proving the Supporting Price Result

1. CENTRAL DISPATCH:

MIN COST = $\Sigma_i \Sigma_t C_i \, g_{i,t}$

s.t. $\Sigma_i \, g_{i,t} = D_t \quad \forall t \quad (\lambda_t)$

$0 \leq g_{i,t} \leq CAP_i \quad \forall i,t$

$-RL_i \leq g_{i,t+1} - g_{i,t} \leq RL_i \quad \forall i,t$

2. MARKET EQUILIBRIUM:

Market clearing condition:

$\Sigma_i \, g_{i,t} = D_t \quad \forall t \quad (\lambda_t)$

+

For each plant *i*, solve:

MAX PROFIT$_i$ = $\Sigma_t (\lambda_t - C_i) g_{i,t}$

$0 \leq g_{i,t} \leq CAP_i \quad \forall i,t$

$RL_i \leq g_{i,t+1} - g_{i,t} \leq RL_i \quad \forall i,t$

The following conditions are equivalent:

1. KKTs for central dispatch

2. Market equilibrium problem (Market clearing + concatenated KKTs for all profit problems)

Thus, the central dispatch solution is a market equilibrium
Energy price spikes suffice! (even in long run?)

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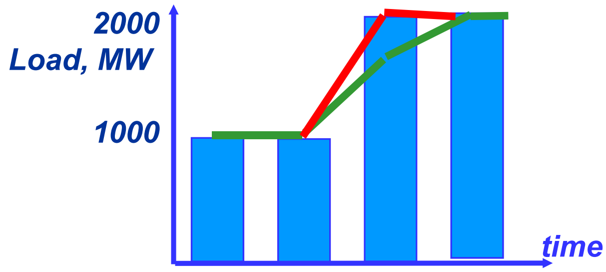
Example

A system with two types of generation:

1000 MW of quick start peakers @ $70/MWh

2100 MW of slow thermal @ $30/MWh, with max ramping = 600 MW/hr

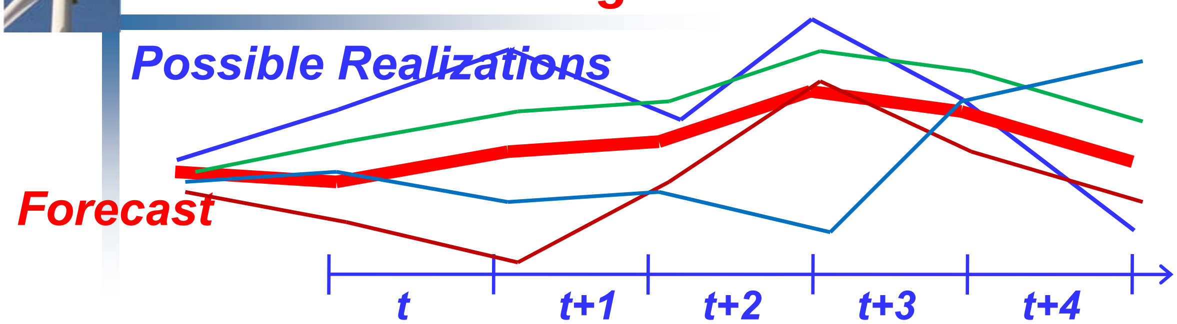
Morning ramp up and resulting generation:



Fast	*0*	*0*	*400*	*0*	*MW*
Slow	*1000*	*1000*	*1600*	*2000*	*MW*
Price:	*30*	*-10*	*70*	*30*	*$/MWh*

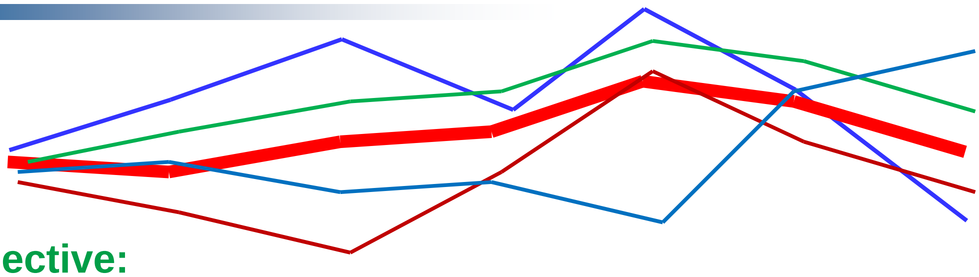
- **Don't need "ramp product" (at least for this reason!)**
- **Prices "support" the schedule**
- **Prices give right *short- and long-run incentives!***

Reason 2. Dealing with Forecast Errors



- **Actual loads (compared to forecast)**
  - **Level may be under- or over-forecast (3-5% RMS errors in day-ahead forecasts)**
  - **Higher volatility / steeper ramps**
- **Ideally: "Stochastic unit commitment"**
  - **Schedule gen considering probabilities of load scenarios, imposing "non-anticipativity" constraint**
  - **Long-term dream**

Characteristics of Optimal Stochastic Schedules



- **Objective:**
  - **Minimize commitment + probability weighted dispatch costs**
- **An individual generator:**
  - **Might be held back "out of merit order" to provide rampability**
    - **"Endogenous" reserves / flexiramp**
- **Assuming convex costs ⇒**
  - **Stochastic energy prices support solution**
    - **operation is *ex ante* E(profit) maximizing**
  - **Separate reserve or flexiramp prices unneeded!**
- ***But practically*: Nudge deterministic ISO schedules in optimal (stochastic) direction via a flexiramp product**
  - **MISO, CAISO**
  - **How close can you get to ideal?**

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III. What is the performance of:

- ***deterministic ISO market model with a ramp product vs.***
- ***the ideal of stochastic programming?***

III. How Close Does a Flexiramp-Based Dispatch (or Unit Commitment) Come to the Stochastic Ideal?

Compare:

- **"Ideal": Stochastic dispatch (UC) model**
  1. Solve for energy schedule
  2. Settle based on 1st period prices, then roll forward (solve again for 2nd period, etc.)
  3. Calculate E(costs, payments)
- **… vs. "Actual": Deterministic dispatch (UC) model**
  1. Solve for energy & flexiramp schedule
  2. Settle on 1st period prices, then roll forward
  3. Calculate E(costs, payments)

Possibilities proven:

- **Flexiramp can *improve* deterministic solution**
  - Sometimes yields same E(Cost) as stochastic model
- **But flexiramp can schedule wrong generators**
  - Generator providing ***fr*** might have very high energy cost, ignoring positive probability of being required
- **Ideal payments may > or < than deterministic**

Ideal: Stochastic Programming

$$\text{MIN COST} = \Sigma_i \Sigma_t \Sigma_s P_s C_i\, g_{i,t,s}$$

$$\text{s.t.}\quad \Sigma_i\, g_{i,t,s} = D_{t,s} \qquad (\lambda_{t,s}) \qquad \forall t,s$$

$$0 \le g_{i,t,s} \le CAP_i \qquad \forall i,t,s$$

$$-RL_i \le g_{i,t+1,s} - g_{i,t,s} \le RL_i \qquad \forall i,t,s$$

$$g_{i,t,s'} = g_{i,t,s} \qquad \forall i,t,s, \qquad \forall s' \in S(s,t)$$

Where S(s,t) is the set of scenarios s′ that have the same history as s until t

→ ***Nonanticipativity!***

(UC version not shown)

Reality: Deterministic Scheduling

- **Heuristic Scheduling (as in CAISO):**
  - <u>Simple rules & additional non-energy products</u> (operating reserves, flexiramp requirements) nudge *deterministic solution* towards *stochastic optimum*
    - Pay generators who provide these additional products
  - Yet <u>suboptimal</u> (won't minimize expected cost)

$$\text{MIN COST} = \Sigma_i \Sigma_t C_i \, g_{it}$$

$$\text{s.t. } \Sigma_i \, g_{i,t} = E(D_t), \quad (\lambda_t), \quad \forall t$$ *Demand for energy*

$$\Sigma_i \, fr_{i,t} \geq D_{t+1,MAX} - E(D_t), \quad (\mu_t) \quad \forall t$$ *Demand for flexiramp*

$$0 \leq g_{i,t} + fr_{i,t} \leq CAP_i, \quad \forall i,t$$ *Gen capacity constraint*

$$-RL_i \leq g_{i,t+1} - g_{i,t} \leq RL_i \; ; 0 \leq fr_{i,t} \leq RL_i, \quad \forall i,t$$ *Ramp limits*

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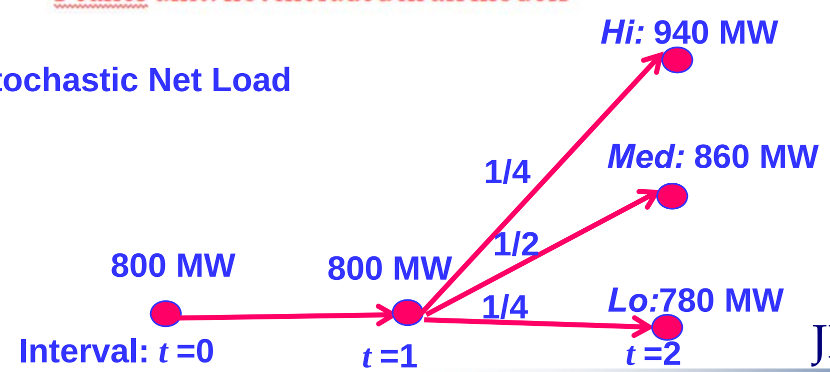
Simple Case Study Data

GENERATOR CHARACTERISTICS

Gen i	Capacity CAP [MW]	Ramp Limit RL [MW/5m]	Cost C [$/MWh]
G1	200	60	20
G2	200	40	40
G3	200	60	60
G4	600	0	0
G5*	100	100	300

* Peaker unit: not included in all models

Stochastic Net Load



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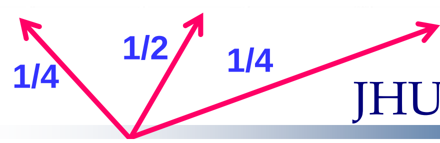
Deterministic Flexiramp (139.2 MW FR) vs. Stochastic Solution *with Peaker G5*

	Product	t=1 [MW]	
		Det-FR	Stoch
G1	Energy	193.6	161
	Ramp	6.4	-
G2	Energy	6.7	39.3
	Ramp	40	-
G3	Energy	0	0
	Ramp	47.8	-
G4	Energy	600	600
	Ramp	0	-
G5	Energy	0	0
	Ramp	44.9	-

Optimal: *Hold back G1 for ramp*
Suboptimal: *Depend on costly G5 for ramp*



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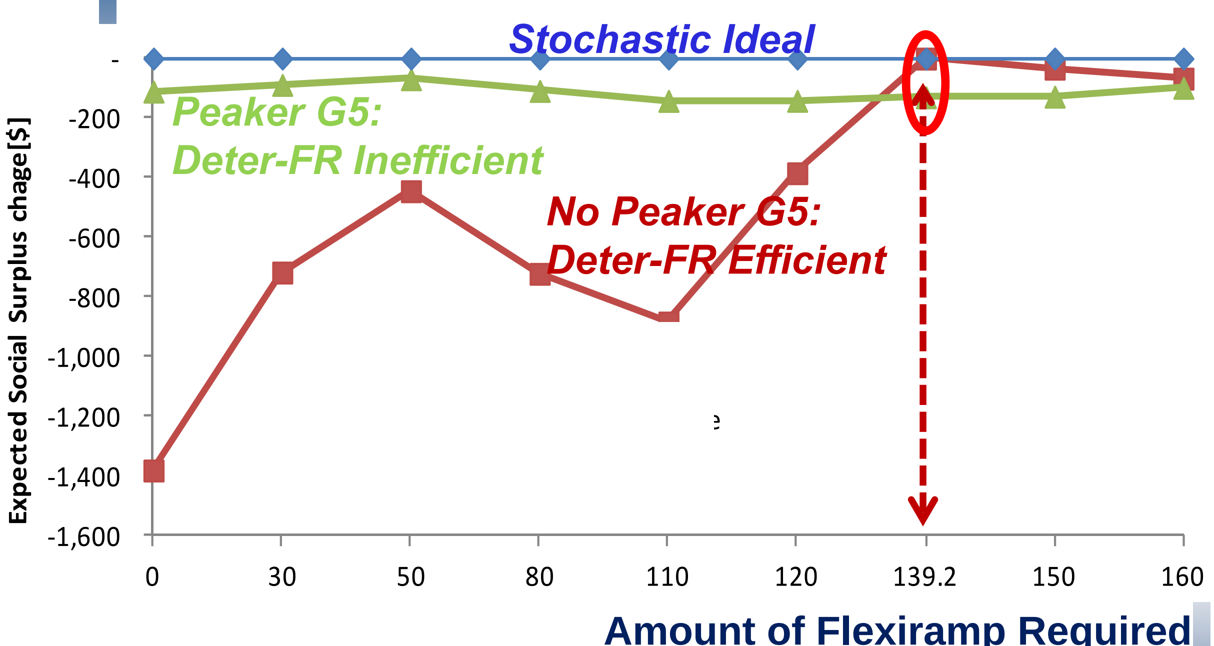
Loss of Market Efficiency ($) Relative to Stochastic Ideal



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Flexiramp Can Cost Consumers More

MARKET CLEARING PRICES (*FR*=139.2MW),
Without Peaker G5

Product	*t*=1 [$/MWh]	
	Deter-FR	Stoch
Energy	40 >	20
Ramp	20	-

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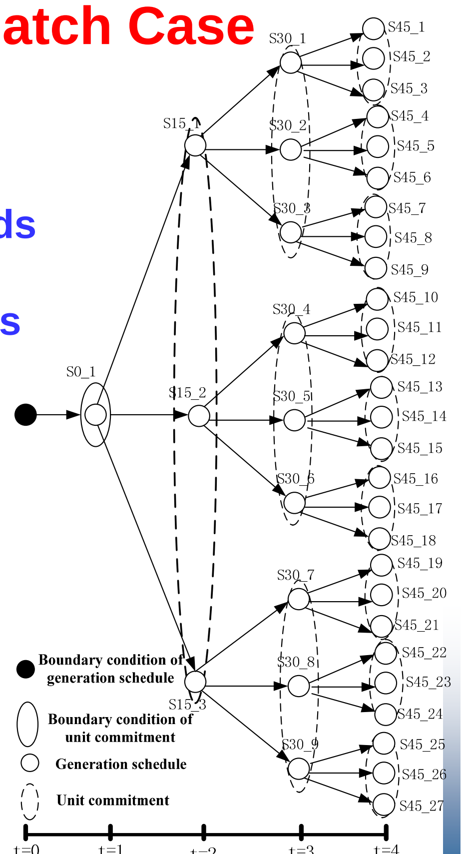
Unit Commitment & Dispatch Case

More general:

1. **Commit before dispatch**
2. **4 commitment/dispatch periods**
3. **Both up & down load ramps**
   → **FR-up & FR-down products**



FR market inefficient: Why?

- **Disregards the chance that $fr_{i,t}$ would produce (costly) energy**
- **So overcommits costly units for FR, which then produce later (the rising load case) or earlier (decreasing load case)**

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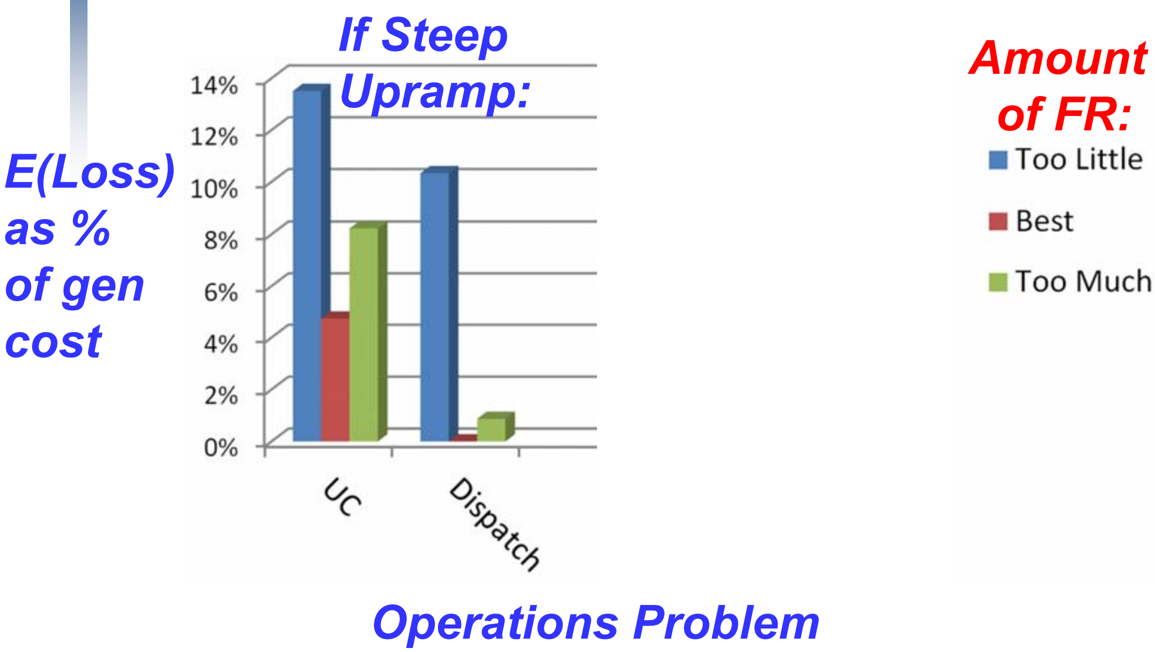
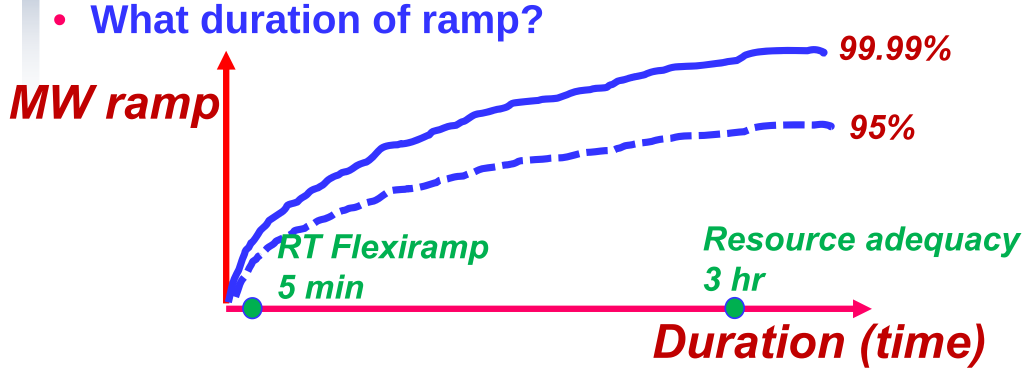
E(Loss of Market Surplus) as Function of Amount of *FR* Acquired



2013: CAISO Flexiramp Debate Continues

- Flexiramp or not?
- Separate down- and up-ramp?
- How much? Hard or soft constraint?
- What duration of ramp?



- When to buy?
  - *3 yr ahead ("resource adequacy")?*
  - *Or day-ahead? Or 15 minutes ahead?*
- How avoid inefficiencies?
- How allocate cost between variable gen & consumers? How much will consumers pay?