(HOW)
Could hydro generators operate and survive in a water market?

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Public/political pressure favours some charge on some “water users”

Per litre taxes seem simple, but no consistent economic rationale has been suggested:

- The biggest issue, for many, is actually not clean water “extracted”, but dirty water returned

Hydro generators are not targeted by current proposals

- Perhaps because they do not “consume” water,
- And taxing hydro would effectively encourage fossil fuel burn.

BUT

A market arrangement seems much more likely to achieve rational pricing

- With prices varying across time and space
- Reflecting the opportunity cost of alternative use where scarcity exists
  (NOT the activities or ownership of the user)

Raffensperger and Milke (2017)

And hydro generators could find themselves right in the middle of a “rational” market arrangement.

So how would they cope?

NOTE that….

Water is not “consumed”, by (virtually) anyone

- It flows through networks over space and time
- Just like “electrons/waves” in electricity networks

What matters is not “owning” water

- But deriving benefit from its flow

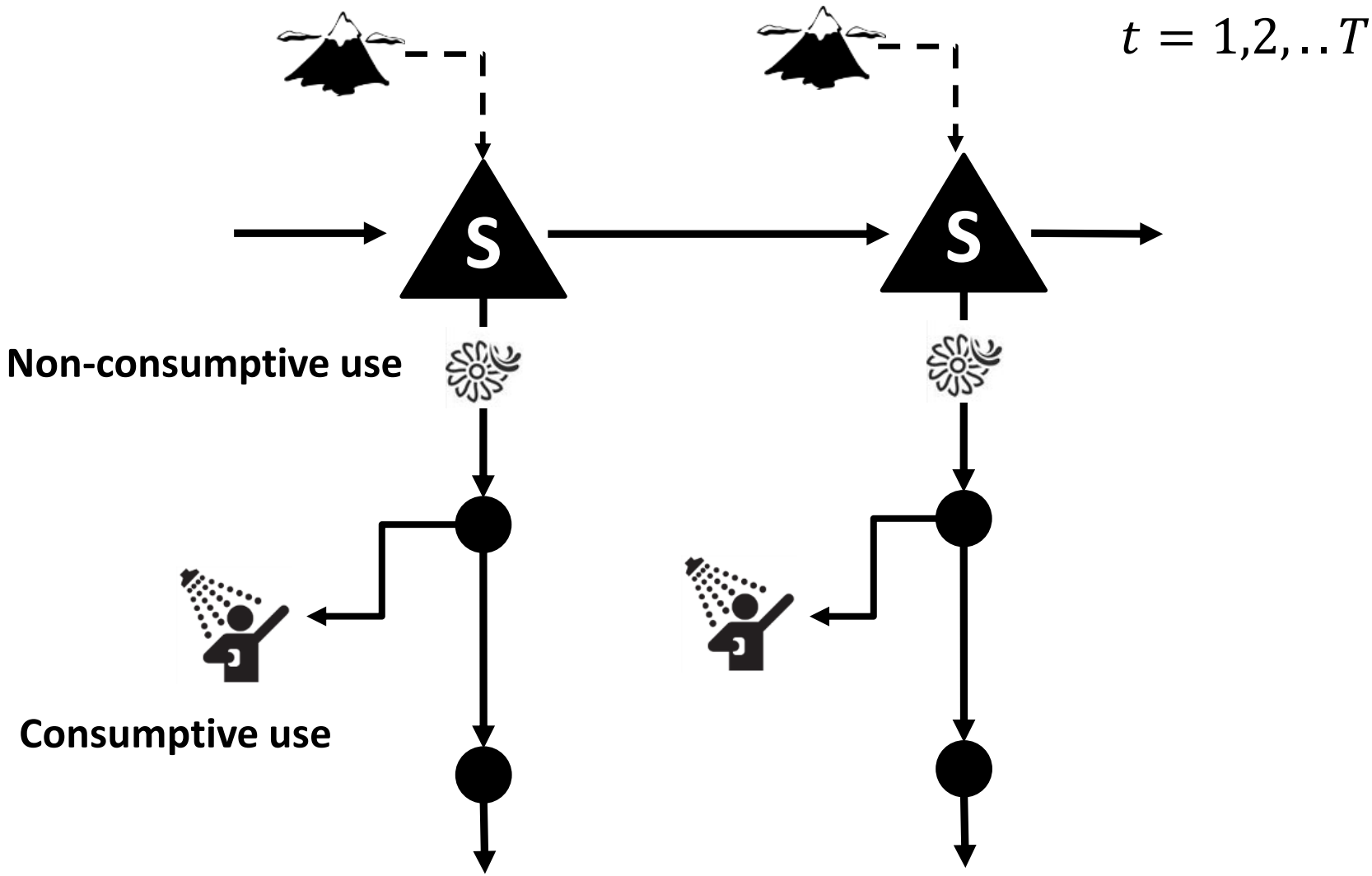
Still, we can usefully distinguish:

- “non-consumptive” flows within a network
- “consumptive” flows from a network into the wider environment.

What if water flows in a catchment were managed by a market, with…

- A benefit-maximising optimisation, such as SLP, clearing the market to determine flows and prices, given..
- Constraints reflecting physical flow limits
- Participant bids reflecting their marginal benefit from
  - Consumptive flows out of the network, at nodes
  - (Non-consumptive inter-temporal storage flows at nodes)
  - Non-consumptive flows on arcs, including
    - Hydro generation benefits
    - Environmental benefits, etc
- With contracting via financial water/inflow/ storage/ delivery rights

Physical Network Elements



Market-clearing formulation (part)

$$\max_{x,q,s}\left(\sum_t\sum_i\sum_b P_{i,b}^t q_{i,b}^t + \sum_t\sum_{(i,j)\in A}\sum_{k\in\Omega(i,j)}\sum_b P_{k,b}^t x_{k,b}^t\right) + \cdots\cdots$$

Subject to:

Arc Flow : $q_i^t + \sum x_{ij}^t - \sum x_{ji}^t = f_i^t$ Shadow Price : $\lambda_{i,t}$

Bounds: $\underline{X}_{ij} \le x_{ij}^t \le \overline{X}_{i,j}$ Shadow Price : μ_{ijt}^-, μ_{ijt}^+

Not our focus in this talk

Where,

$\underline{X}_{ij}$ and $\overline{X}_{ij}$: Lower and Upper arc flow bound of arc (i,j)

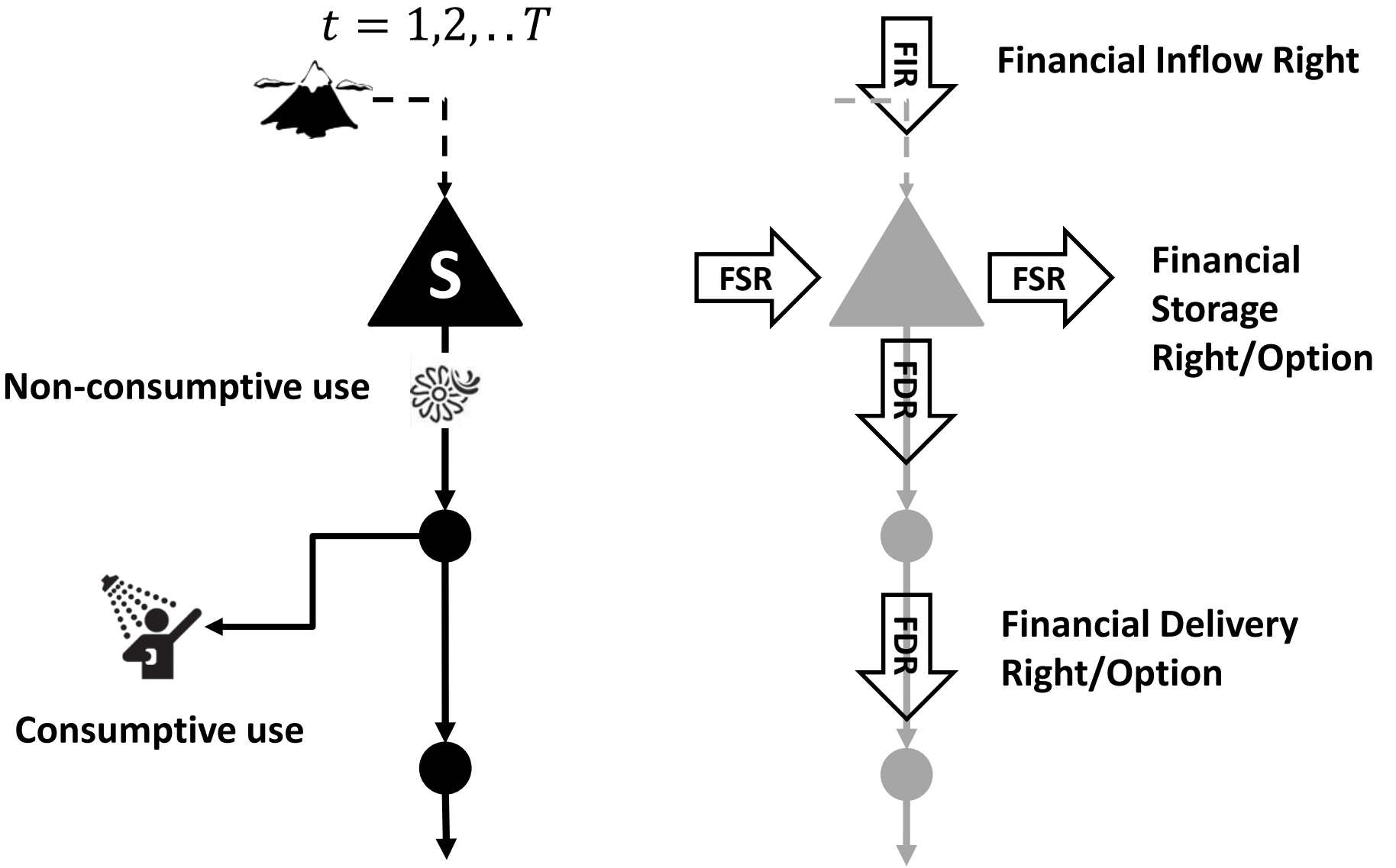
$P_{i,b}^t$ and $P_{k,b}^t$: Consumptive and non-consumptive bid price

f_i^t : Uncontrollable tributary flows coming into node i

q_i^t : Total nodal flow off-takes in time period t.

$x_{i,j}^t$: Flow through arc $i \to j$ in time period t.

Financial Right Structure



This is like the electricity market

But the “common transmission network” includes:

- Natural and constructed flow channels
- With flow delays
- PLUS storage reservoirs

So inter-temporal market-clearing becomes an issue:

- Stochastic optimisation seems necessary to produce realistic “dispatch schedules” over time
- Those schedules, and prices, should be hydrology dependent

Starkey et al (2012), Starkey (2014)

Focus

Previous presentations have outlined the mathematics of this kind of market/rights structure

(Mahalakanda et al 2012, 2014, 2015)

But what would it mean, in practice?

- How would a hydro generator actually operate?
- Could they survive, financially?
- What risks would they face?
- How could those risks be mitigated?
- Could an “acceptable” arrangement be found?

Nodal water prices in any period….

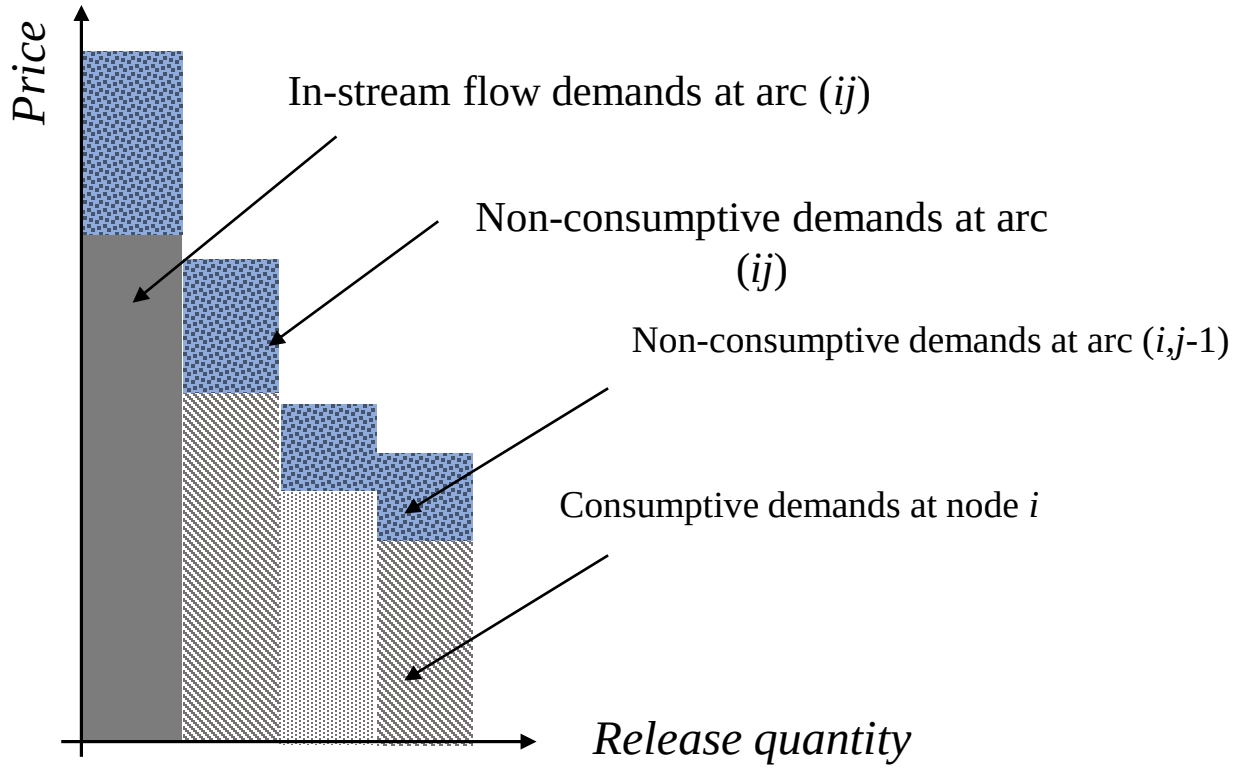
Reflect highest marginal value obtainable from:

- Storage for the future
- Upstream/downstream consumptive uses
  - Including flow to the ocean (MV =0)
- PLUS/MINUS cumulative value derived from increasing/ decreasing flow between this node, and usage nodes.

We have shown that:

- Prices can be determined by working towards the reservoir, irrespective of flow direction
- But they typically decrease in a “downstream” direction
- So water often flows from higher value to lower value nodes!

Demand curve for water, at a node



Mahakalanda et al (2012), Mahakalanda (2017)

In the spot market….

A generator wanting water to flow through its plant would have to offer:

- A high enough price to offset the decrease in value between upstream and downstream nodes
- Recognising that that price difference is driven by its own offer
- Which may complement or compete with offers from other participants for the same flow
- And also with offers from upstream/downstream users, both consumptive and non-consumptive

Without contracting….

Tight upstream/downstream interactions suggest a complex high stakes gaming situation, with

- An unacceptable level of risk
  - even before considering interactions with, and in, the electricity market
- A massive loss of value to generators
  - Because they pay for something they previously received,
  - In accordance with “rights” implicit in their physical location
- But a massive gain to “the system”
  - Which could fund FTR-like financial property rights

With contracting…

Who really ends up "paying" whom depends on who owns the "rights"

- To capture inflows
- To store them
- To flow them through various channels

In this kind of market those rights should logically be "financial"…like electricity market CfDs, FTRs etc

So we have previously reported on such concepts:

- and proved some "revenue adequacy" results

But fortunately…

The “revenue adequacy” condition really boils down to a simple rule:

> *“market rents will (only) support (financially) a web of contracts corresponding to flow patterns that the network can support (physically)”*

And, in this case, what the network will support can be largely determined on an asset by asset basis.

- So our rights are more like “Flow Gate Rights” than FTRs
- And they can (at best) deliver what ownership of those assets would deliver

So…

Aggregate financial contract allocations can be set to match physical asset capabilities

- And perhaps combined to form “virtual system models”.. Barrosso et al (2012), Read & Jackson (2014)

But, while the network capacity is fairly certain, inflows (and demands) are not

- So corresponding rights must be hydrology dependent

And (for example) financial storage rights corresponding to physical reservoir ownership can provide:

- An option (but no obligation) to store
- No certainty about water value, except in retrospect

Note that:

The literature on financial contracts describes them as “hedging instruments”

- And often focuses on their “second order” implications, for “risk management” and “gaming”
- Which incentivise contracted parties to align physical production/consumption with contracted quantities

Our concerns are much more primitive:

- Can contracts be formed to achieve the “first order” objective of “making things happen”?
- Can we thereby achieve the “zeroth order” objective of creating an acceptable market environment?

Remember from whence we came, in terms of market design…

Deliver 10 bags of corn by next Friday, and I will pay you one groat..

- But if not I will break your legs

Deliver 10 bags of corn by next Friday, and I will pay you one groat..

- But if not I will deduct one penny for each day's delay

Don't bother actually delivering any corn, because I'll get my own from the market (and probably want a different quantity anyway)

- But let's settle up, afterwards, as if you delivered 10 bags

This last “financial contract” approach works very well

In the context of an established market, where

- Alternative supplies are readily available on a “spot market”
- And that market is reasonably competitive.

But we are talking here about a very tight, possibly one-on-one upstream/downstream interaction:

- Where “second order” gaming incentives are very much a “first order” concern.
- And “risk management” includes mitigating the risk of physical non-delivery, and punitive behaviour.

Still, in theory, hydro could survive

A workable spot/contract should be possible:

- With financial contracts initially allocated to match prior physical rights of incumbents
  - Including “nature”

Entrants could negotiate their way in by acquiring contracts

- Probably at prices that make incumbents better off (in this market)
- But perhaps with some regulatory intervention (if incumbents block efficient entry in this or other markets)

But there is more to life than mathematics:

- And the performance of such a contractual regime has not been studied, in terms of mitigating
  - Distortionary “gaming”
  - Or risk

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