Modelling industrial demand response:

The case of wastewater treatment

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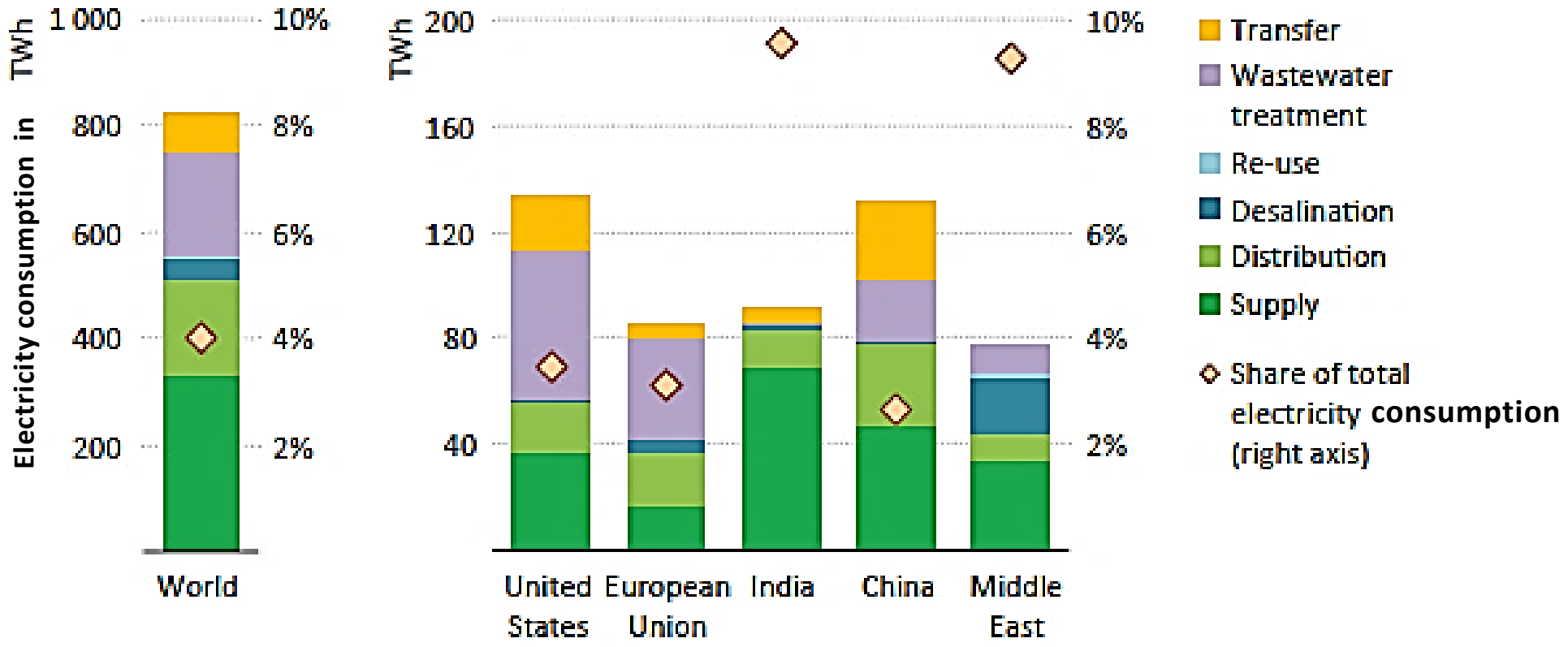
Wastewater treatment in Europe is an electricity-intensive industry.



Electricity consumption in the water sector by process and region in 2014 (IEA, 2016).

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Case studies find potential for flexible operation of wastewater treatment equipment.

Aeration

Can be turned off for between 15 minutes (Berger et al., 2013) and 120 minutes (Schaefer et al., 2017).

Pumping

Switch-off times up to 30 minutes for inlet pumps (Nowak et al., 2015) and 60 minutes for recirculation pumps (Schaefer et al., 2017)

Biogas

Flexibility potential arises from biogas storage and use for on-site electricity generation.

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However ...

There has not yet been an attempt to quantify the demand response potential of the wastewater treatment sector on an energy system level.

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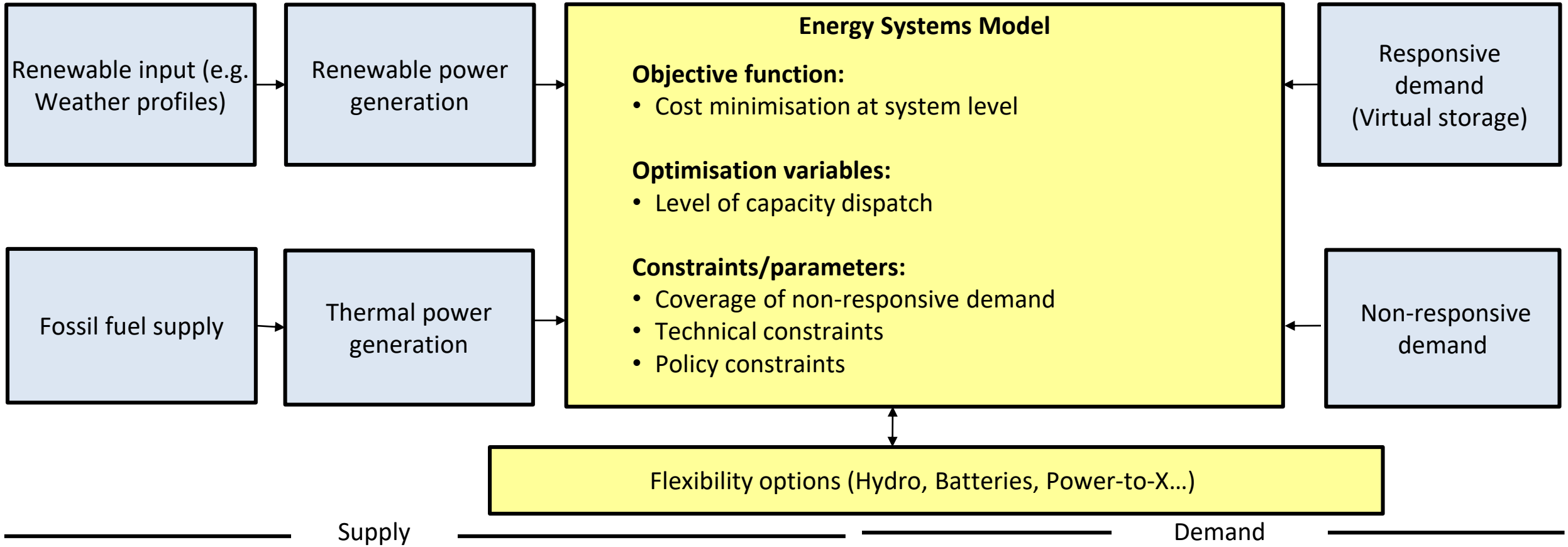
Traditional power system models often model demand response as a virtual storage.



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This approach is insufficient for many industrial demands for two reasons.

1. It neglects process constraints within the industrial process and distort results.

   - Intertemporal interdependency of production processes and the precision in timing
   - Input and output constraints (e.g. wastewater inflow and effluent quality)

2. Reliable energy data is often not available.

   - Information on electricity load profiles can be confidential and competition-sensitive
   - Installing energy monitoring equipment can be expensive

   “The level of energy data collection in Irish WWTPs is often limited.” (Fitzsimons et al., 2016)

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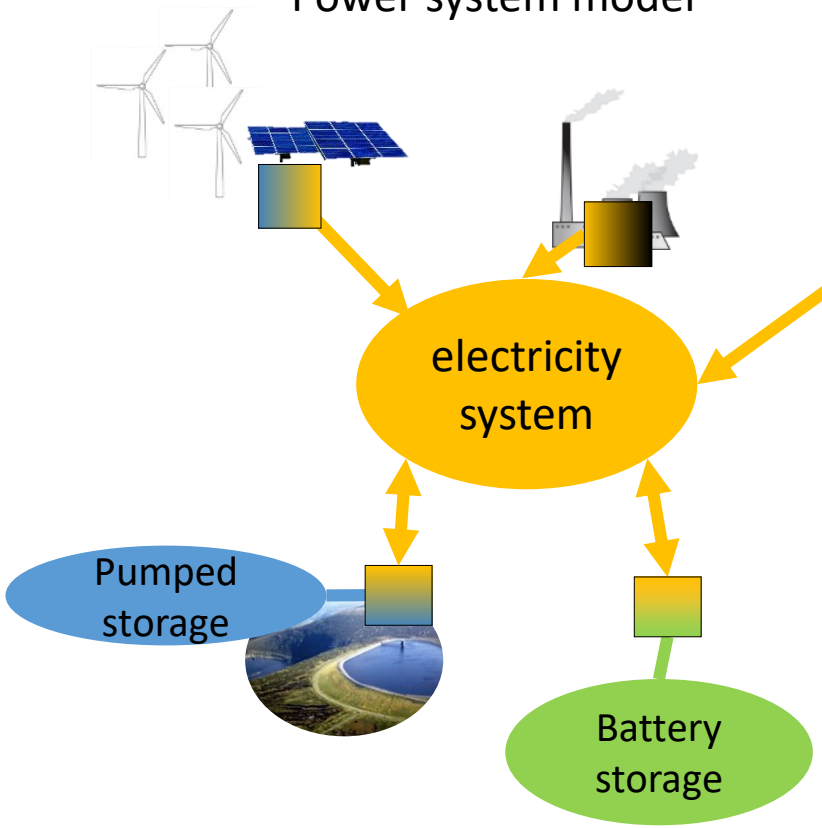
Therefore, we use an integrated energy systems model for the wastewater treatment process.

Power system model



Blower

Three-component wastewater process model

Aerated tank

Dissolved oxygen
DO = (inflow-outflow) + oxygen supply - consumption

Micro organisms
X = (inflow-outflow) + growth - decay

Substrate
S = (inflow-outflow) - consumption

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These models come from two completely different classes of models.

	Energy system models	Wastewater treatment plant models
Mathematical approach	(MI)LP	System of non-linear differential equations
Subject of analysis	System operation (supply side)	Biochemical processes
Integration	End-users as black-boxes	Closed system
Model elements	Objective function and system constraints	Process rates and mass balance equations
Aim of model	System cost minimisation	Evaluation of control strategies
Time frame	Discrete time steps	Continuous time

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The integration requires a reduction and linearization of the standard wastewater treatment model.

Standard model ASM1
(Activated sludge model no. 1)

heterotrophic biomass *BH*
autotrophic biomass *BA*

readily biodegradable substrate *SS*
slowly biodegradable substrate *XS*
inert particulates *XP*

particulate organic nitrogen *XND*
soluble organic nitrogen *SND*
ammonia *SNH*
nitrate *SNO*

dissolved oxygen *SO*

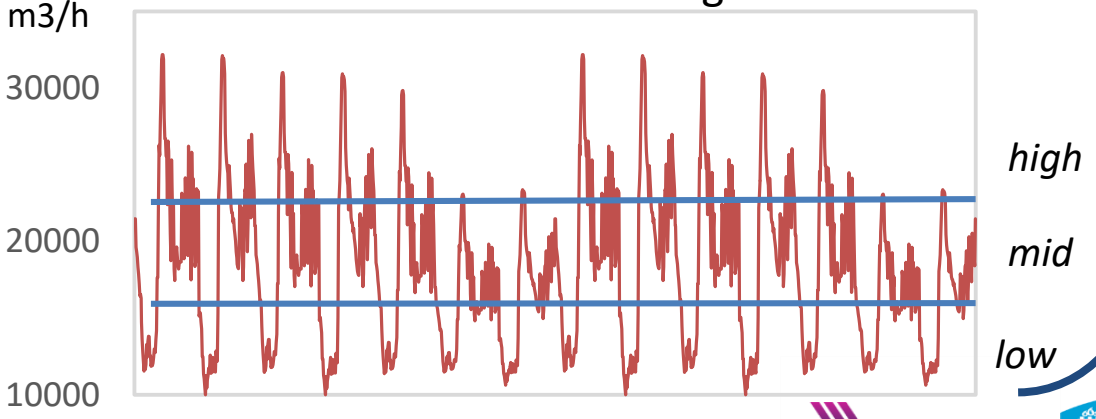
Reduced model

biomass *X*
Substrate S
α and β
dissolved oxygen *DO*

Linear model
Locally valid

Weighted linear combinations, following Smets et al. (2003)

Wastewater inflow categories



Linear model
Globally valid

Switching function with binary variables

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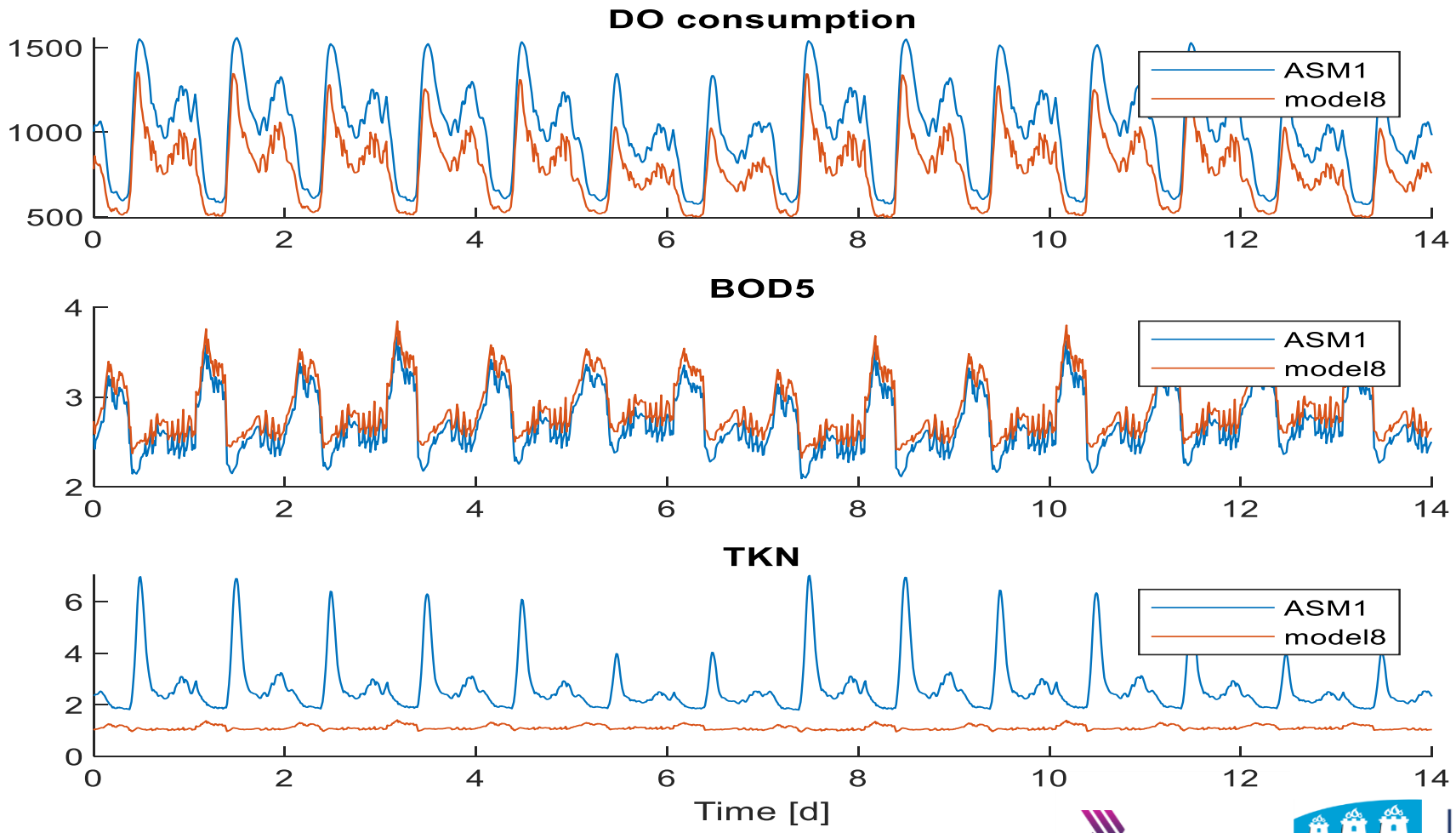
The reduced model yields reasonable results for the DO consumption and Biological oxygen demand (BOD5).



TKN = Total Kjeldahl Nitrogen

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The new framework will help to unlock industrial demand response more effectively.

- More accurate results for demand response activity and its system effects.
  - Taking into account process constraints (e.g. effluent standards in wastewater treatment)
- Overcoming energy data limitations
- The framework can be applied to other industrial processes
  - Nonlinearities occur in many industries

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