Computational Methods for Global Change Research

Agent-Based Computational Economics

Overview

- Introduction to ACE
  - comparison with CGE
- Example model
  - EU Emissions Trading Scheme
- ACE advantages and disadvantages

Agent Systems: Origins

- Biology
  - von Neumann: self-reproducing automata ('50s)
  - Conway: game of Life ('60s)
  - Langton: artificial life (80's)
- Social science: various
- Computer science
  - AI, robotics, distributed AI, Multi-agent systems, OOP

What is ACE?

- Computational study of economic processes as **dynamic systems of interacting agents**
- An **experimental** approach to the theoretical study of economic processes
- Prompted by changes in actual and conceptualised economies

Contrasting Economic Mindsets

Neoclassical	Agent-Based
• Global information, centralized control	• Local information, networks, distributed control
• Mathematical progr.: scalar value function	• Competing values
• Firm as rational actor	• Many-agent firms
• Neoclassical constrained utility maximisation	• Behavioural economics: multiple utilities
• Centralized markets, single price vector	• Decentralized markets: heterogeneous prices

ACE Experimental Method

- Modeler constructs a virtual economic world populated by various types of agents
- Modeler sets initial world conditions
- Modeler runs model to observe how the world develops over time with no intervention (imposed equilibrium, etc)
- World runs autonomously, driven by inter-agent interactions and intra-agent behavioural changes

Agents

- Population – tens to millions
- Agent has internal *state* and *rules of behaviour* (cf. *object* in OOP)
- Agents are autonomous (may cooperate)
- Agents interact with each other and the environment (non-agent *world*)
- Aggregate structure emerges from agent interactions

ACE Agent Types

- Individual, social, biological or physical entities
- *Cognitive* agents may be capable of:
  - behavioural adaptation
  - social communication
  - goal-directed learning
  - endogenous evolution of interaction networks
  - autonomy: private internal processes determine actions

How are ACE models implemented?

- Each agent is an object
  - instance variables represent internal state
  - methods represent behaviour
- Agent-groups can be an object
- Topology of interaction: spatial environment and/or social network
- Mechanism for activating agents (controlling simulation)
- Non-model objects for data-gathering, storage and display
- Typically implemented in ABM packages (Repast, NetLogo, Mason) or hand-coded

Model World: Initial Conditions

- Structural conditions
  - Numbers of agents
  - Networks of interaction
- Institutional arrangements
  - e.g., markets, regulations
- Behavioural disposition of agents
  - initial ruleset
  - learning paradigm

Experimental Process

- Establish initial world conditions
  - embody the key variables of interest
- Run the model, gather result data
- Analyse the data for regularities
  - usually focus on the key variables
  - looking for larger regularities encompassing many agents
  - no guarantee of any insights!

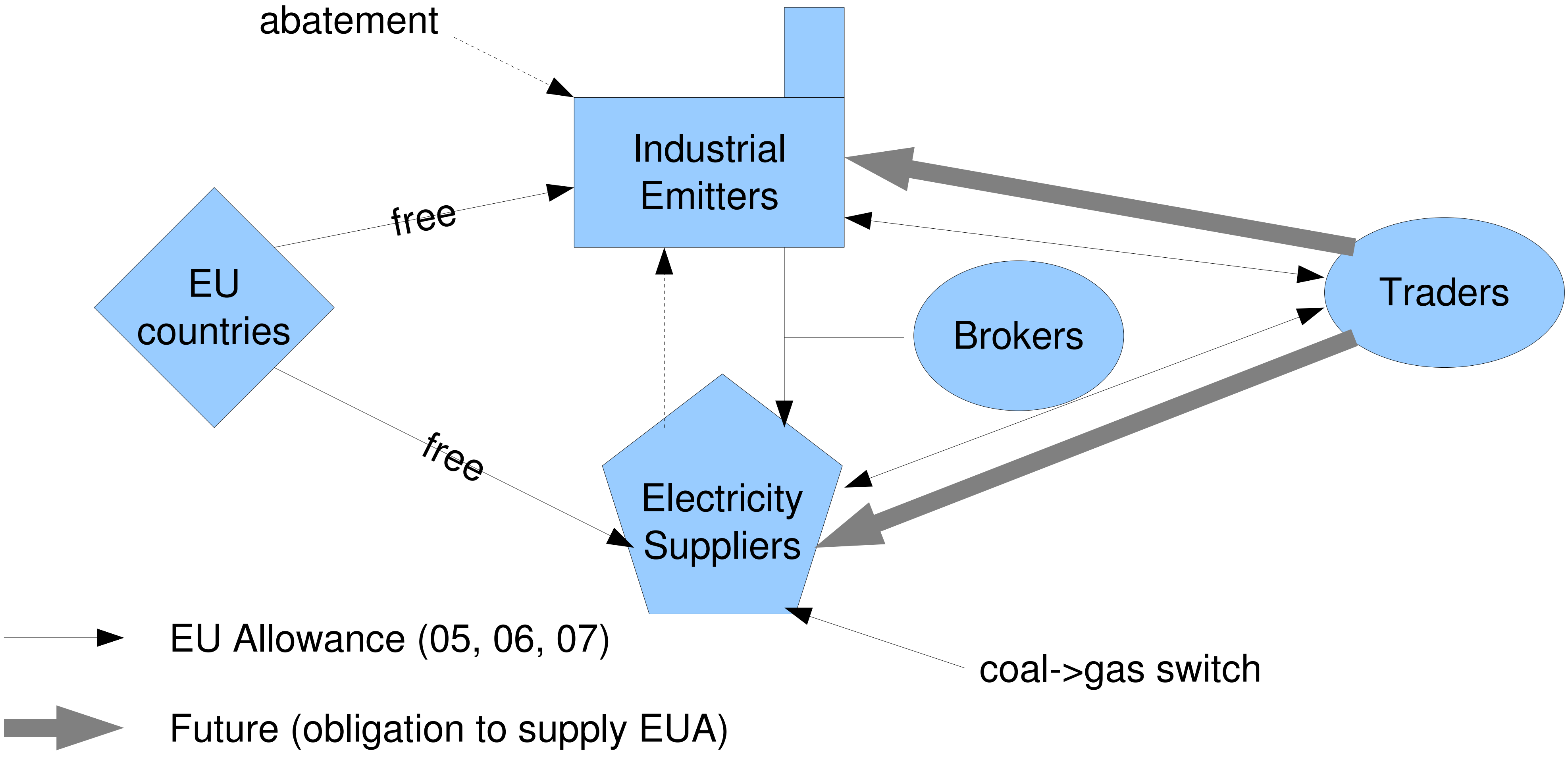
Example Model: EU Emissions Trading Scheme Model

- Scope
- Design
  - agents
  - interactions
  - initial conditions
- Results

EU ETS Model: Scope

- EU ETS sets up an annual market in "allowances" - permission to emit 1 tonne CO2e
  - supply – grant allowances some players
  - demand – require all players to redeem allowances for their recorded emissions
- Phase I (2005-2007)
  - players are energy suppliers and energy consumers who emit over a threshold
    - industry burns gas, oil, coal
    - electricity generators burn gas, oil, coal

EU ETS

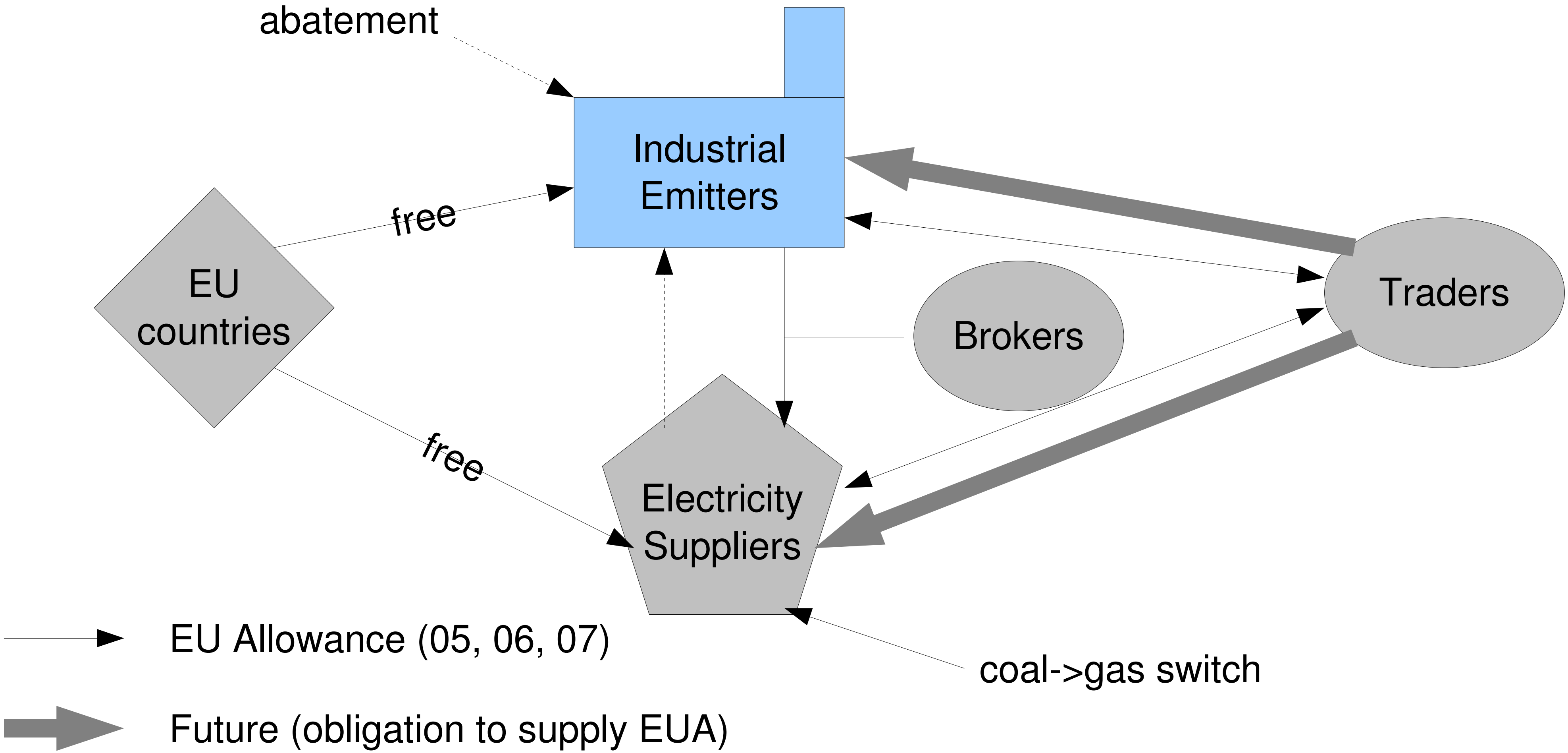


abatement
Industrial Emitters
free
EU countries
free
Brokers
Traders
Electricity Suppliers
coal->gas switch
EU Allowance (05, 06, 07)
Future (obligation to supply EUA)

EU ETS: Agents

- Industry Agents
  - 6 industries x 4 fuels x 23 countries => 552 agents
- Energy Agents (generating electricity)
  - 3 fuels x 23 countries => 69 agents.
- MarketTrader
  - speculative traders in a market. Can offer futures.
- Broker
  - deal mediator in a market, using spreads
- RegulatoryBody
  - regulatory functions of European Commission 1

EU ETS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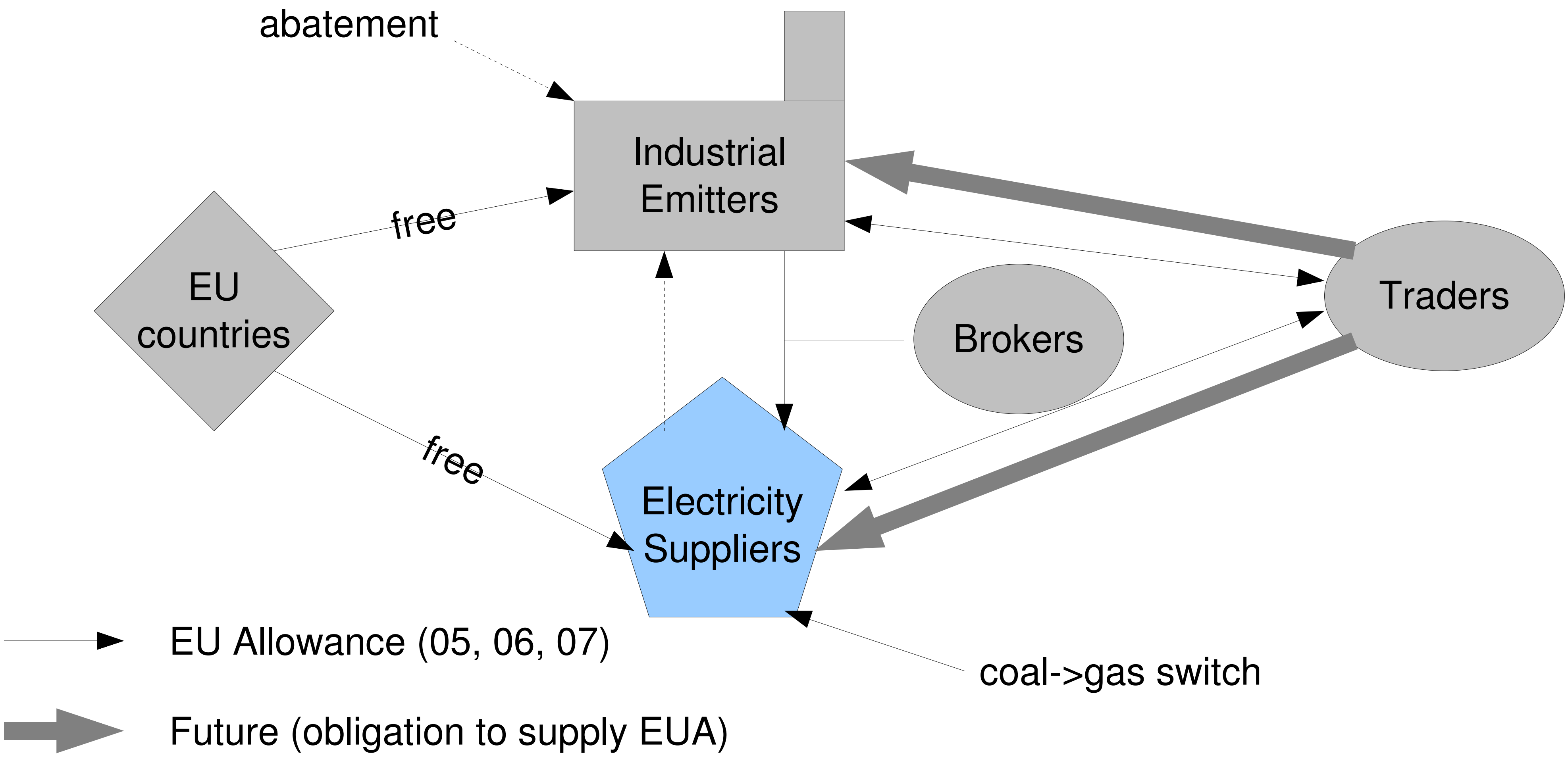
EU ETS: Industry Agents

- Represent major CO2 emitting industries
- Assets: money and allowances (initialised)
- Expected emissions (extrapolated from data)
- Position: willing to buy / sell / neither
  - varies with predicted need
- Bid/offer price – adaptive using Roth-Erev RL
  - payoff varies with lower/higher price, and quantity
- Abatement preference (not used in Phase 1)

EU ETS



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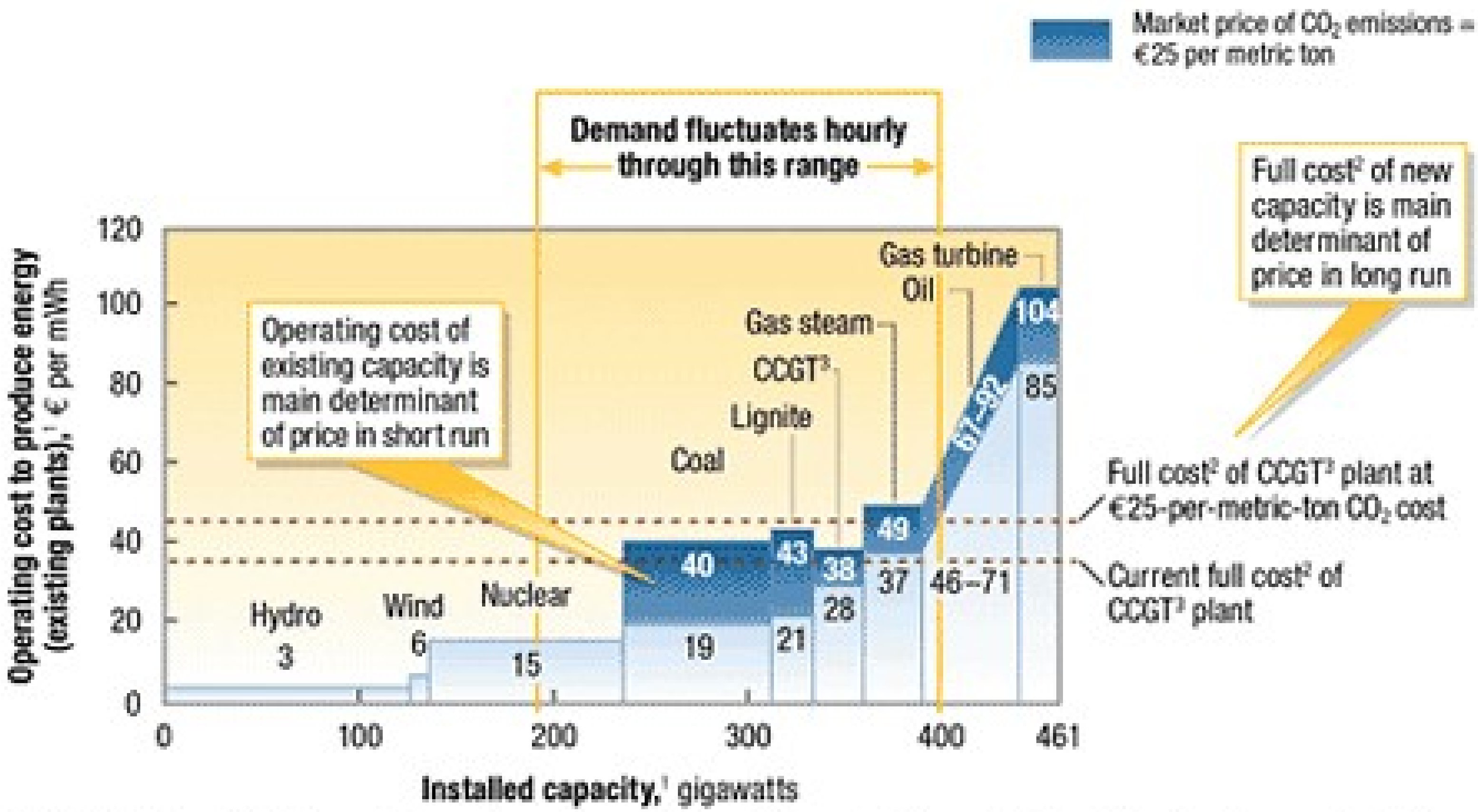
EU ETS: Energy Agents

- Represent electricity generators
- Like Industry Agents: assets, emissions, position, price
- Emissions calculated daily
  - national electricity commitment from data
  - merit order

Merit Order

EXHIBIT 4

As costs rise, so do prices

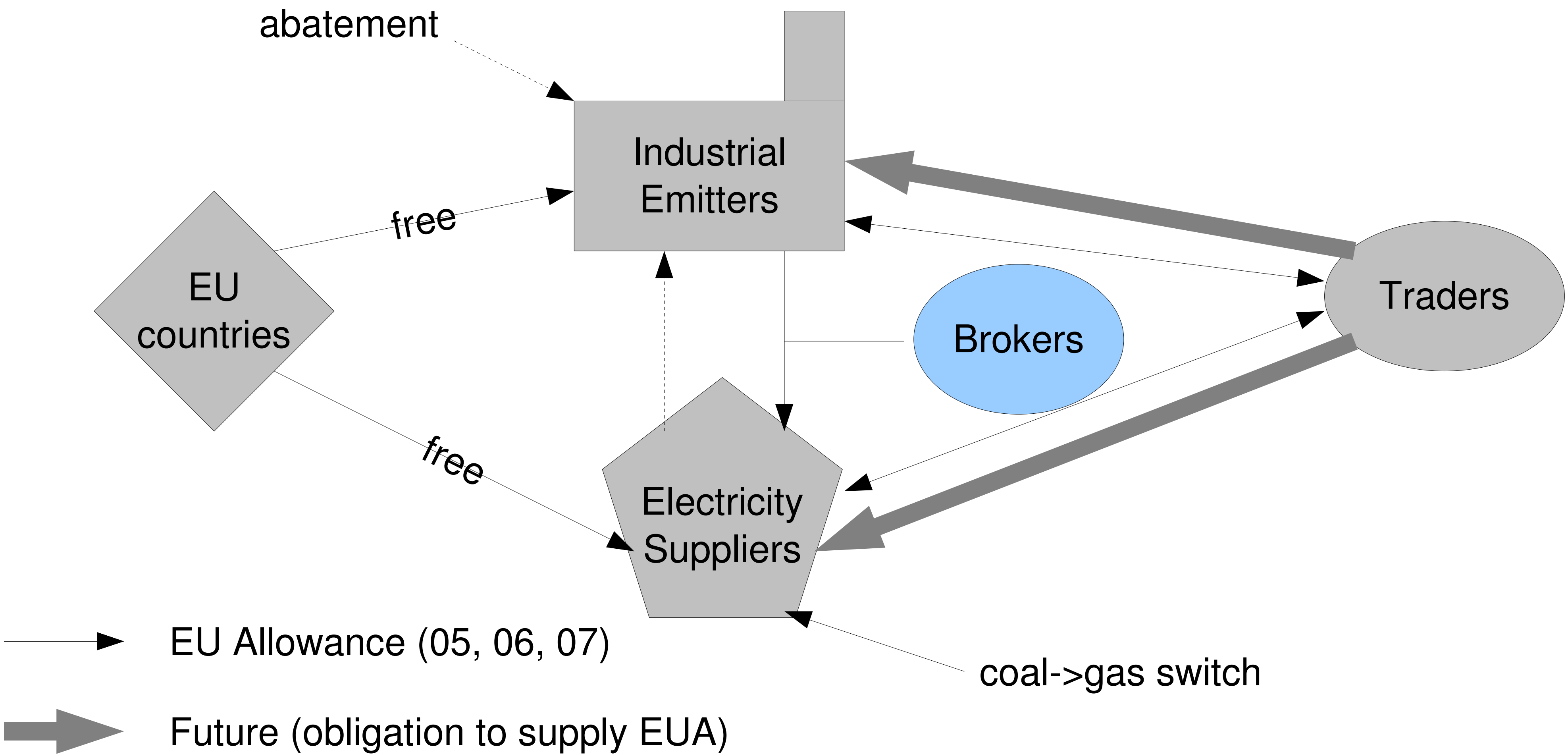


[1]For Austria, Belgium, Finland, France, Germany, Luxembourg, Netherlands, Norway, Sweden, and Switzerland; costs shown are simplified—actual model examines costs on a plant-by-plant basis.
[2]Includes capital costs.
[3]Combined-cycle gas turbine.

EU ETS: Energy Agents

- Represent electricity generators
- Like Industry Agents: assets, emissions, position, price
- Emissions calculated daily
  - national electricity commitment from data
  - merit order
- Merit order is modified by EUA cost
  - coal produces 25% more CO2e than gas

EU ETS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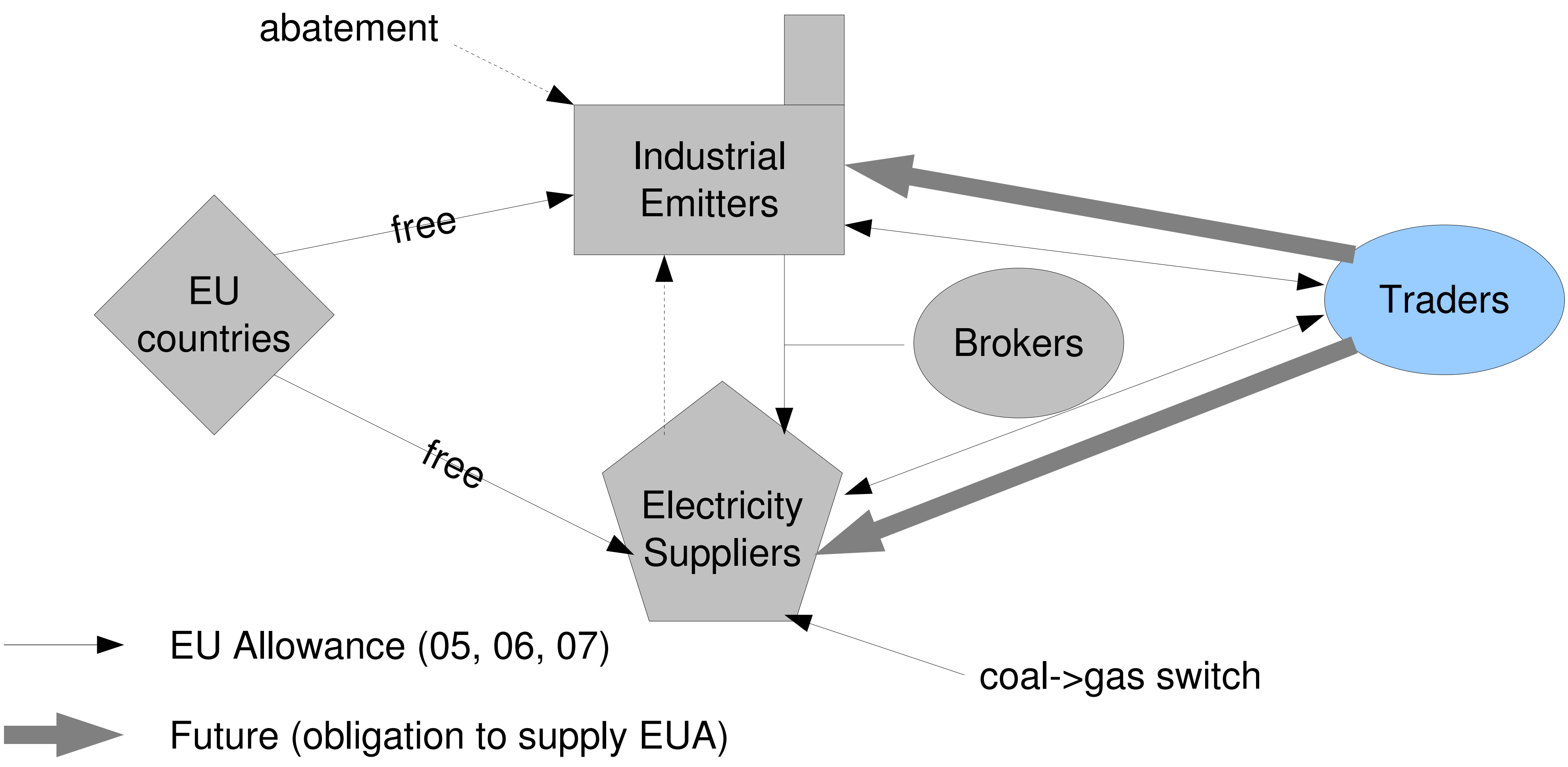
EU ETS: Broker

- Motivated by *spread* (buy low, sell high)
- Maintains list of bids/offers received
- Interaction initiated by InteractionModel
  - can respond with bid/offer
  - trades executed until no matching bids/offers
- Uses Roth-Erev RL to adapt spread
  - payoff is spread x quantity

EU ETS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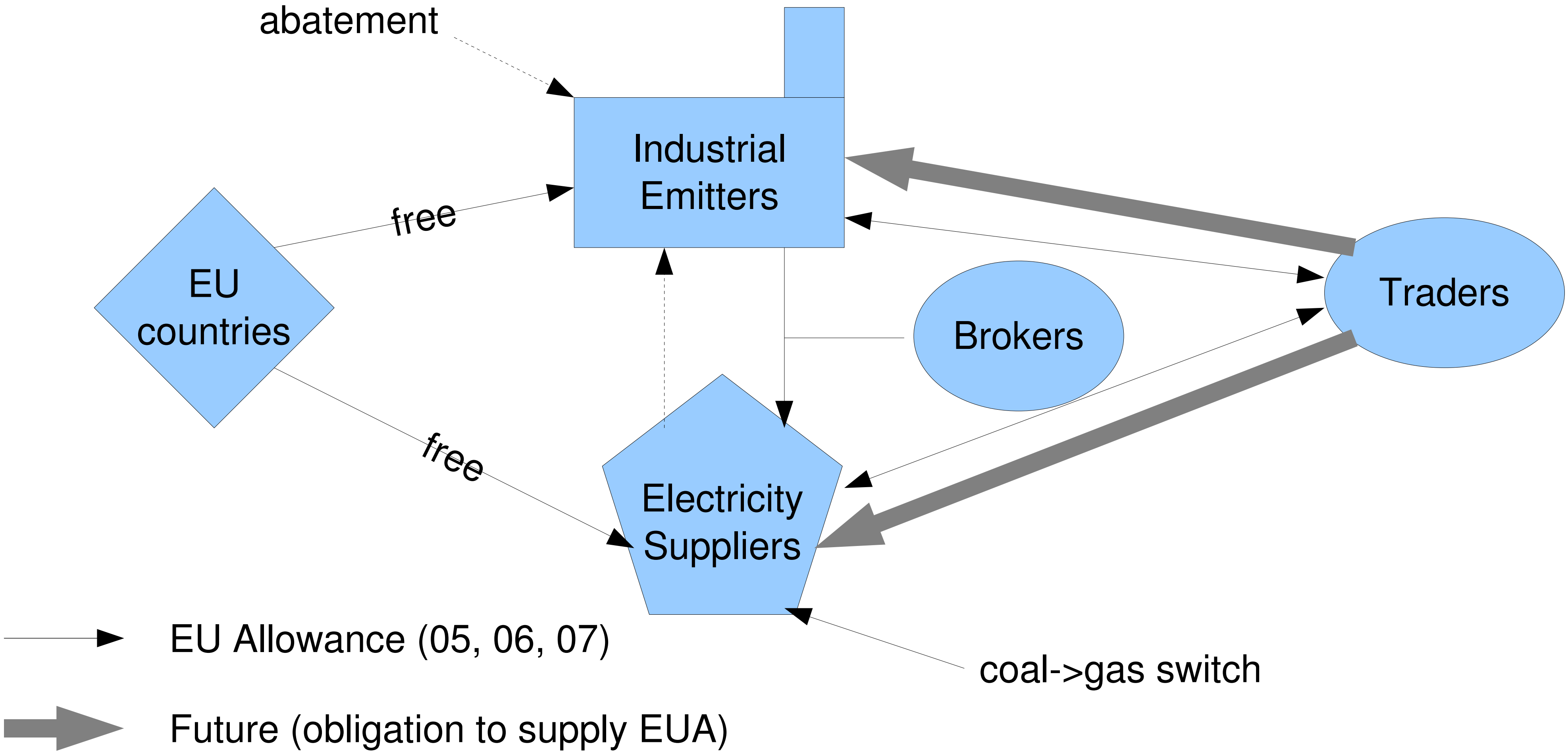
EU ETS: Trader

- Like Industry Agents but without emissions:
  - assets, position, price
- Portfolio: money, allowances, committments (to sell)
- Price belief moves towards market price
- Adaptation:
  - search space is too big for Roth-Erev
  - instead use a simple genetic algorithm
  - fitness(money, assets, commitments, price-belief)

EU ETS



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EU ETS: Regulatory Body

- Represents EC commission and countries
- Distributes EAU allowances initially (from data)
- Fines agents not surrendering sufficient EUAs

EU ETS: Markets

- 3 markets by year (2005 – 07)
  - allowances for one year are not transferable to the next
- Random matching
  - simulates agents randomly encountering each other, N steps per day (not traders)
- Double auction
  - buyers/sellers submit bids/offers, these are matched. Once per day. (not brokers)

EU ETS: Results

- Surrendered permits – ok
  - Double Auction good
  - Random Match ok with brokers or traders
- Traded volume
  - Good for 2005
  - Did not model increase for 2006/07
- Price
  - Random Match not good
  - Double Auction ok (corr. .82, .61, .57 for 05/06/07)

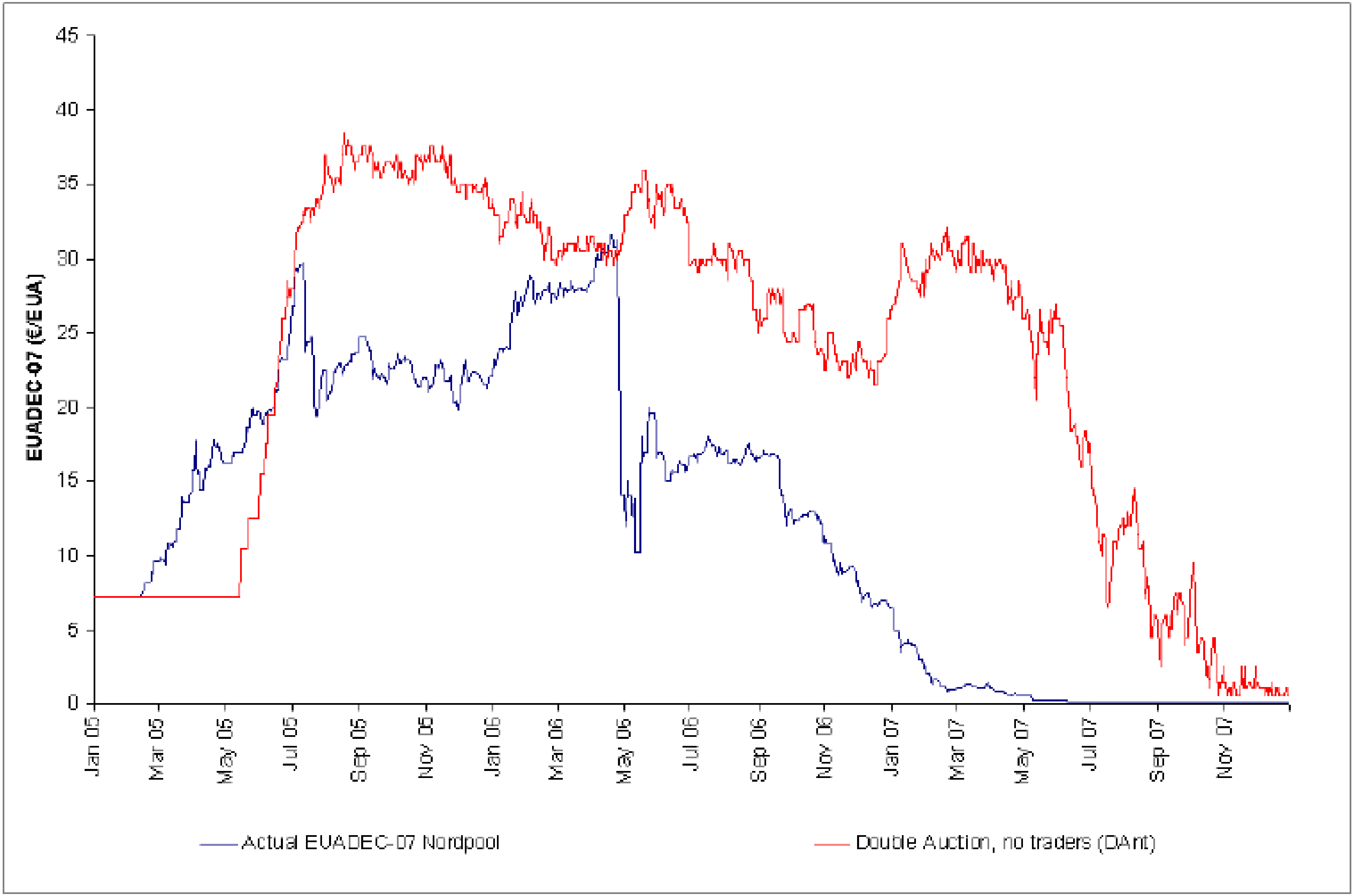

Figure A.5: Double Auction, No traders, No brokers

EU ETS: Lessons

- Agent behaviour – need either or both:
  - lots of data to learn from
  - behavioural rules from social science experiments
- Agent learning
  - can be computationally expensive
  - need lots of data to calibrate the model
- Real-world complexity
  - choose domain carefully!

Advantages of ACE for Economic Modelling: Micro

- Heterogeneous agents
- Bounded rationality
- “Local” interactions
- Focus on dynamics: paths to equilibrium, non-equilibrium trajectories

Agent Heterogeneity

- “Representative” agent models don't capture underlying heterogeneity
- Mathematical aggregation/abstraction only possible with highly restrictive assumptions
- Aggregated models give point estimates: very poor approximation to the underlying distribution
- Agent models not (necessarily!) subject to these problems

Bounded rationality

- Rationality (maximising utility) usually just assumed – no mechanism provided
- Learning to be rational is NP-hard
- Agent models exhibit bounded ("procedural") rationality – they provide a mechanism using available information

Local Interactions

- In CGE models, agents use representatives or interact indirectly via aggregates (e.g., prices)
- Local, heterogeneous, interactions are ubiquitous in the real world
- Arbitrary interaction graphs cannot be handled analytically, but are natural in ACE

Focus on Dynamics

- Disequilibrium is a better model of the world than equilibrium
- Equilibrium only computable with restrictive assumptions
- In non-equilibrium states, the dynamics are what is of interest
- In ACE, equilibrium can emerge, or dynamics can be studied

Advantages of ACE: Macro

- Permits systematic experimental study of empirical regularities, economic institutions, and dynamic behaviours of complex economic processes in general
- Facilites creative experimentation with realistically-rendered economic processes
  - Using ACE computational labs (pre-programmed)
  - ACE software allows easy modification

Disadvantages of ACE for Economic Modelling: Micro

- Robustness
  - Artifacts – spurious correlations
  - Parameters – too many free, how to set?
- Standards
  - Model availability, documentation
  - Interaction with existing models
  - Publication of results

Disadvantages of ACE: Macro

- Can be computationally intensive (e.g., ensemble runs to get robust results)
- Outcome distributions can be hard to interpret (e.g., multi-peaked rather than central)
- Can be difficult to separate model from implementation (reproducibility)
- (Effort to gain computational expertise can be significant)

Tesfatsion ACE Resources

- ACE Website
  - www.econ.iastate.edu/tesfatsi/ace.htm
- ACE Handbook (Tesfatsion & Judd, Handbooks in Economics Series, North-Holland, 2006, 904pp)
  - www.econ.iastate.edu/tesfatsi/hbace.htm