EMISSION TRADING

A REAL TIME SIMULATION

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EXECUTIVE SUMMARY

In June-July 2000, delegates from seventeen Parties to the UNFCCC explored the development of an international emission-trading regime in a simulation organised by the International Energy Agency. Participants included IEA Member countries, countries with economies in transition and several private-sector stakeholders that played the role of domestic companies engaged in international trading.

The purpose was to learn about the development of international trading in the conditions set by the Kyoto Protocol. The 24 participants were asked to elaborate strategies to reduce emissions domestically and to trade CO_2 if that made economic sense. These strategies took into account uncertainties on participants' future emission levels.

Eight trading sessions were held to mirror the 2000-2013 time period. While the number of participants was limited, market depth was assured by concentrating trading in fixed periods. Price competition proved rather intense. Hedging and speculation, common features of markets, were observed in the simulation.

A relatively stable price emerged quickly after an initial stage of volatility. Participants started early to trade emission reductions (assigned amount units or AAUs) while at the same time taking domestic actions to reduce their emissions at low cost. Inventories of annual emissions showed that, overall, participants would be in compliance with their Kyoto objectives: the trading of AAUs then assured that individual compliance was achieved.

All participating "countries" – and companies – eventually complied with their emission objectives, and did so more cheaply than what an exclusively domestic effort would have cost. Reliance on trading varied greatly across participants. Overall savings in compliance costs amounted to 60 percent.

In spite of the large economic benefits from trading, participants did not systematically adjust their domestic cost to the international price of traded AAUs – a surprise, as theory argues that such an approach would constitute the least-cost strategy.

Several features of this "real time" simulation help explain why:

- Parties need to start taking domestic measures (and in some cases have already done so) without any certainty about future AAU prices;
- These measures are unlikely to be fully adjustable to the international price of AAUs: policy stability may be perceived as more desirable to reduce emission in the long run than near term efficiency. However, domestic emission-trading systems where companies have access to the international market could fully adjust to the international price;
- Future emission levels will remain uncertain from one year to the next because fluctuations in economic growth, energy prices and climate can significantly

affect emissions. Such uncertainty calls for a cautious approach by governments and companies alike.

While the simulation produced considerable savings, it did not achieve reductions at the very lowest possible cost. As a result of the above uncertainties and rigidities, the average price observed in the simulation was some 30 percent above the price at which participants could have met their collective and individual objectives. This high price was not, however, the result of price manipulation by participants. The trading system adopted for the simulation, based on competitive pricing, probably helped diffuse this risk.

The simulation raises some key issues. Very few participants set aside AAUs for use in a future commitment period – an option available in the Protocol and known as "banking". Participants might have banked AAUs if the emission objectives for the second commitment period had been known and if the cost of compliance had been expected to climb in the future. With full information, the price of AAUs before 2012 would necessarily have reflected this future constraint.

It currently takes about two years to gather national inventories. If this remains true in 2008-2012, trading for the first commitment period will extend well beyond 2012, at which point new policies would have no effect on the amount of AAUs available for the commitment period. The simulation optimistically assumed a one-year delay in inventories, yet prices still fluctuated from one year to the next as a result of changes in expected emission levels.

A number of conclusions can be reached from the simulation.

- Emissions trading can work to help cut the cost of meeting the Kyoto Protocol goals.
- This remains true even with the likely policy inertia at country level and the price uncertainty that can be expected from the system.
- Trading by private companies could help countries adjust their efforts to the international price of traded tonnes.
- An emission-trading market would encourage further emission reductions in countries with low cost of abatement. The question is whether it will be enough to trigger the ambitious policies needed in countries in transition if they are to sell additional AAUs.
- Timely inventories and trading reports are essential to market stability and predictability.
- An early decision on emission constraints after 2008-2012 will provide critical information for the development of the market in the first period.
- International emission trading could accommodate a variety of domestic policy choices.

FOREWORD AND ACKNOWLEDGEMENTS

The design and implementation of this simulation was a collective effort of the IEA Energy and Environment Division under the supervision of Jonathan Pershing. Richard Baron led the project. Alessandro Lanza designed the core of the models distributed to participants to elaborate their mitigation and trading strategies. Martina Bosi provided comments on the design and participated in an early pilot of the simulation. Cédric Philibert participated as the Clean Development Mechanism project developer in the simulation, together with Pierre Audinet (Non-Member Office). Jonathan Pershing and Scott Sullivan provided extensive comments on an earlier draft of this document.

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The following experts made contributions during an IEA consultation on the design of this simulation: Peter Bohm (Stockholm University); Jan Corfee-Morlot (OECD); Raymond Crémadès (ParisBourse); Garth Edward (Natsource); Matthew Evans (International Petroleum Exchange); Peter Karpoff (US Department of Energy); Taisuke Hamaoka (Industrial Bank of Japan); Andrea Pinna (UNFCCC); Charles Thomas (BP-Amoco); Tatsuyoshi Saijo (Osaka University).

Most of all, the success of this simulation was ultimately due to long hours spent by more than 30 delegates of participating countries to design their strategies, engage in the Internet emissions trading market, report on their emissions and trades and provide feedback throughout the four-week simulation.

The project was made possible by contributions from the governments of Australia, the United Kingdom, and the United States and the European Commission.

GLOSSARY

Adjusted assigned amount (AAA): An assigned amount adjusted for the sale and purchase of assigned amount units from another participant (see Assigned Amount).

Assigned amount (AA): A country's greenhouse-gas emission objective expressed as a percentage of 1990 emissions, to be achieved over five years between 2008 and 2012.

Assigned amount units (AAUs): Trading units expressed in tonnes of carbon equivalent. In the simulation, one AAU equals one million tonnes of carbon equivalent (or MtC).

BnM: Billions of mony (see mony).

International emission trading (IET): A mechanism in the Kyoto Protocol whereby Parties can transfer or acquire parts of assigned amounts from other Parties in order to comply with their emission commitments.

Mony: A virtual currency used in the simulation.

MnM: Millions of mony (see mony).

MtC: Million tonnes of carbon equivalent.

P&M: Policies and measures undertaken domestically to reduce greenhouse gas emissions. In the simulation, these are expressed as a "carbon value" applied to CO_2 emissions, in mony per tonne of carbon equivalent.

tC: One tonne of carbon equivalent. One tC is equal to 3.67 tonnes of CO_2.

1. INTRODUCTION: WHY SIMULATE INTERNATIONAL EMISSIONS TRADING UNDER THE KYOTO PROTOCOL?

Since its introduction in the 1997 Kyoto Protocol, international emission trading (IET) has been the subject of much debate. Some question the feasibility of implementing such an instrument between countries, when the only emission trading carried out so far has been in connection with industrial activities in individual countries and under firm regulatory frameworks. The Kyoto Protocol emission limits apply to governments, most of which have had no experience with tradeable permits as an environmental policy tool. In addition, the agreement reached at Kyoto failed to settle the modalities, rules and guidelines for emission trading.

A number of studies have examined potential rules for an international trading regime. Others have focussed on the quantitative dimensions of trading: market price, volume of international transfers across regions and savings that may be brought about by the flexibility mechanisms. In addition emission trading has been tested in several simulations earlier. Bohm (1997) organised an experiment among four Nordic countries even before the Kyoto Conference of the Parties. None of these efforts has reflected the time dimension of the Protocol, i.e., the time path of domestic policy decisions, their effects on inventories and on international trading decisions.[1] Still, other simulations focussing on particular sectors or companies have neglected the role of governments in emissions trading under the Protocol.[2]

A critical aim of this effort was to address these shortcomings. It sought to include the time dimension and to focus on the role of individual governments under the Protocol. This simulation also sought to provide delegations with a hands-on experience with international emission trading which could shed some light on the *development* of an international regime to control greenhouse gas emissions. We focussed on the essential elements of international emissions trading (making assumptions where necessary to compensate for the yet-undecided rules). The simulation was unique: it allowed participants to reflect governments' behaviour, including political and social concerns even if only indirectly. By so doing, it moved beyond earlier efforts, which set economic efficiency as the paramount goal. In this respect, our simulation helps negotiators develop more realistic rules for international emission trading.

Part 2 of this report presents the rules used for the simulation and lays out briefly the various instruments provided to participants for the elaboration of their strategies: an emission/cost model, and an Internet-based emission trading exchange, further developed in annexes. The development of the market during the simulation is described in Part 3, together with a typology of behaviours in the simulation. Lessons from the exercise are drawn in Part 4, followed by key messages.

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1. See Carlén (1999), Hizen and Saijo (1999).
2. See IEA-ParisBourse-Eurelectric-Unipede (1999) and Caneill (2000). BP-Amoco also conducted a simulation internal to the company as a dry run for its internal emission trading system.

2. SIMULATING EMISSIONS TRADING UNDER THE KYOTO PROTOCOL

Participants

Table 1 gives a list of participants in the simulation, along with:

- The *label* corresponding to each participant, as used throughout this report;
- The *geographical coverage* for participants that played for more than one "country";
- Domestic companies and allowed by their countries to trade on the international market.

Most participants were closely linked with the actual negotiation of the Kyoto Protocol flexibility mechanisms, as delegates, advisors to delegations or private sector players. Players nevertheless participated in their personal capacity, so that the strategies described below cannot be taken to reflect their respective country's position in the debate, nor their possible future trading positions.

TABLE 1. SIMULATION PARTICIPANTS

Label	Simulated "Country" / Participant	Label	Simulated "Country" / Participant
AUS	Australia (government)	FRA	France
AUS1	Private sector in Australia	HON	Hungary
AUS2	Private sector in Australia	ITA	Italy
AUS3	Private sector in Australia	JAP	Japan
AUT	Austria	NET	the Netherlands
CAN	Canada (government)	POL	Poland
CAN1	Private sector in Canada	RU	United Kingdom
CAN2	Government participant as private sector	RUS	Russian Federation
DAN	Denmark	SWI	Switzerland
DEU	Germany	TCH	Czech Republic
EUA	United States	CDM	IEA participant for Clean Development Mechanism projects
EIT	IEA participant covering the assigned amounts of: Bulgaria, Romania, Slovakia, Slovenia and Ukraine	REU	European Commission participant covering the assigned amounts of: Belgium, Greece, Ireland, Luxembourg, Portugal, Spain

Simulation rules

Time in the simulation

The simulation covered the period from 2000-2013 in four weeks with eight trading sessions, each corresponding to a given year (or years) in the period.[3] Participants reported inventories and net trades after each session. No retroactive corrections were possible except in rare cases of mistakes in inventories. This meant that participants could not undo past policies based on their observations as the simulation unfolded.

3. The eight periods were 2000-2003, 2004-2007, 2008, 2009, 2010, 2011, 2012 and 2013.

Compliance

Under the simulation, participants were called upon to comply with the greenhouse gas emission objectives listed in Annex B of the Kyoto Protocol. The commitments made under the EU burden-sharing agreement were used for countries of the European Union. Emission objectives were expressed in carbon equivalent (million tonnes of carbon, or MtC).

Compliance with emission objectives could be achieved either through domestic reductions or through the acquisition of so-called assigned amount units (AAUs). No penalty was imposed for non-compliance, as it was expected that participants would meet their objectives if they played "properly", i.e., adopted a rather cautious attitude.

The IEA provided interactive models that allowed participants to project national or sectoral emissions trends into the future. Using this model, participants could simulate sudden variations in their inventories and the effects of domestic policies on emissions. They could estimate the economic cost of either domestic action or purchases of tons for compliance. Details of the model are provided in Annex X.

Two "countries" (AUS and CAN) devolved commitments of assigned amounts to private "companies". Such commitments were distributed arbitrarily by the IEA Secretariat. For these two countries, the government player was left with an assigned amount to manage as well as the overall responsibility for the country's compliance. Table 2 shows the five-year emission limit (Assigned Amount) and the business-as-usual emissions for each participant over the period 2008-2012 (what emissions would be if no effort were made to reduce them). The gap indicates the effort needed to bring emissions down to the Kyoto target.

TABLE 2. ASSIGNED AMOUNTS AND "BUSINESS-AS-USUAL" EMISSIONS (2008-12)

	Assigned amount (MtC)	BAU emissions (MtC)	Gap		Assigned amount (MtC)	BAU emissions (MtC)	Gap
AUS	96.8	138.2	43%	FRA	515.9	610.6	18%
AUS1	135.6	185.0	36%	HON	87.3	88.4	1.3%
AUS2	58.1	77.2	33%	ITA	520.4	650.2	25%
AUS3	96.8	118.0	22%	JAP	1361.0	1774.8	30%
AUT	74.9	97.4	30%	NET	206.7	289.9	40%
CAN	317.8	395.9	25%	POL	575.6	536.9	-6.7%
CAN1	120.6	169.9	41%	RU	698.5	860.8	23%
CAN2	109.6	166.4	52%	RUS	3257.4	2324.3	-29%
DAN	57	89.1	56%	SWI	55.5	67.1	21%
DEU	1057.3	1279.3	21%	TCH	177.9	173.4	-2.5%
EUA	6180.4	8994.7	45%	CDM	NA	--	--
EIT	1238.0	100.7	-19%	REU	731.7	905.5	24%
				Total	17,730.8	20,993.7	18%

Note: Emissions reported under the business-as-usual scenario were established for the sole purpose of the simulation. They also incorporate "external shocks" that were introduced during the simulation and had the effect of inflating cumulative emissions by a few percentage points. They do not necessarily reflect countries' own official projections.

Eligibility, market access and transparency: GHG inventories

In order to assure full transparency, participants were required to submit their annual emission inventories after each session (i.e., every year or so). Those that did not do so were ineligible to trade in the next period and could not resume trading until past inventories were submitted. Only two participants ran afoul of this rule. Participants also had to report their net trades for each session.

These requirements aimed to guarantee that participants had access to all available information on overall emission levels and international transfers. Such information is crucial to assess the development of the market and to anticipate price changes.

Forward trades

While the formal commitments under the Kyoto Protocol cover only the years from 2008 to 2012, participants in this simulation could undertake forward trades as early as 2000-2003. Emissions traded in this period would be for delivery within the commitment period, although the transfers of AAUs were recorded at the time of the trade. Participants could also choose to agree bilaterally to conduct a transaction at a given future date, say in 2010. Such transaction would only become official in 2010, once the actual transfer was recorded.

True-up period (grace period)

At the end of the simulation (year 2013), a final trading session was established for participants who wished to acquire additional AAUs (either for "banking" or to cover their 2008-2012 emission obligations). In the simulation, all inventories and international transactions had been public by this time. Participants knew how many AAUs remained in the system and whether there were enough to allow countries not yet in compliance to meet their obligations through trading. Of course, the availability of excess tonnes did not necessarily reduce their price.

Liability rule

A number of liability rules have been discussed at the international level.[4] For instance, a "buyer liability" regime would put the burden on the buyer for the purchase of AAUs that the seller was not in position to sell. Buyers need to know from what Party they are buying, as they may want to purchase AAUs only from those with a high chance of compliance. Such a regime therefore requires the creation of a market where buyers can discriminate according to the country of origin, i.e., potentially one market per seller. Otherwise, prospective buyers would not be able to select issuers based on expectations of likely compliance.

4. See Baron (1999) for an assessment of various liability rules.

"Issuer beware" – putting the responsibility on the original seller, not on the buyer – was applied as a default liability rule in this simulation for several reasons:

- A proper assessment of other participants' emission situations would be time-consuming, especially when there was only one or two days between trading sessions.
- As there was no real cost or incentive for non-compliance with objectives in the simulation, compliance was not expected to be a problem, and a "buyer beware" regime was therefore pointless.[5]

It was nevertheless possible to track traded AAUs based on their country of origin. This information would allow a post-simulation examination of the effect of non-compliance, had a "buyer beware" regime been chosen.

Second commitment period

In order to avoid market distortions at the end of the simulation period, it was assumed that a second commitment period would follow immediately after 2012. The rules allowed banked units in 2008-2012 to be used to meet commitments in the second period, as per Article 3.13 of the Kyoto Protocol, even though the simulation did not cover years beyond 2012. As can be seen from the discussion below, this rule in the simulation had an important bearing on some countries' emission trends and emissions trading strategies.

Elaboration of mitigation and trading strategies

The simulation's goal sought to focus on the international dimension of the Kyoto Protocol, and on emissions trading in particular. The IEA Secretariat developed a simple model to help participants project their emissions throughout the simulation period (2000-2012), to evaluate the effect of costs applied to their domestic emissions and to build their trading strategy. Annex X describes the main features of the model.[6]

In order to minimise overall compliance cost, participants should theoretically have sought to keep marginal costs of domestic actions at the price of internationally traded AAUs. If the marginal cost were higher, it would be worthwhile to reduce domestic actions and acquire AAUs from the market to offset the increase in emissions. On the other hand, if a participant has a marginal (domestic) cost lower than that of the international market, it would be foolish to buy AAUs, from a straight economic standpoint. The country should decrease its international purchases and increase domestic actions. A seller should take a

5. Note however that the Eurelectric-Unipede / IEA / ParisBourse simulation, completed in 1999, resulted in two virtual companies being in non-compliance. A detailed description of this simulation and an explanation of these results can be found at: http://www.iea.org/clim/cop5/pubs/report.pdf

6. Further details on the model can be downloaded from http://www.iea.org/simulation. Username: trading, password: leffe.

similar position: it should increase its domestic effort in order to generate AAUs that could be sold on the market at a profit.

Currency in the simulation

A virtual currency – called "Mony" – was used throughout the simulation. Participants could therefore not rely on what they already knew about the marginal costs in their own countries in order to decide on domestic reductions vs. international transactions. They had to perform their own marginal-cost assessment with the model.

CDM in the simulation

Credits generated by the Clean Development Mechanism will help Annex I Parties to meet their Kyoto emission commitments. But the mechanics of the CDM remain unknown at this stage, and as our primary purpose was to test IET among Annex I Parties, the CDM component was deliberately limited. Nevertheless, a limited quantity of CDM credits was allowed into the simulated market. These were generated using an assumed marginal cost curve with increasing quantities of CDM tons available at increasing cost. The shape of the cost curve was unknown to the non-IEA participants. The CDM player would only sell credits on the market at a profit. The total amount of CDM credits available in the simulation was 600 MtC, starting at 10 mony per tC, and rising to 50 mony per tC.

The international dimension: trading and reporting

Trading AAUs: an anonymous competitive exchange

An Internet-based market was used to run the simulation. It was originally developed (and modified for this simulation) by the Laboratory for Experimental Economics and Political Science of the California Institute of Technology (Pasadena, USA).[7] The tool was designed to allow participants in different regions of the world to trade AAUs on a single market place.

For the sake of simplicity and economic efficiency, a competitive market was organised based on the so-called "double auction" rule. Under this rule, the exchange displays two offers at any given time:

- the quantity (in AAUs) and highest offer to buy,
- the quantity and lowest offer to sell.

The best price of AAUs for sale would always be higher than the best offer to buy. All offers made on the exchange were anonymous. Participants could not identify the country selling or buying units, and the price was the only discriminating factor. Annex Y describes the mechanics of the exchange in more detail.

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7. The exchange can be accessed at http://eeps2.caltech.edu/market-carbon. Click on Login. The Country# *21* and Password *ybq* will open the account of the EIT participant, where all its transactions have been recorded.

A bilateral market

In addition to using the public exchange, participants could enter into bilateral transactions. The main differences between these bilateral markets and the public exchange were that offers made on a participant's market were seen by the participant alone, and that the identity of the participant offering the transaction was also disclosed.

A priori, participants had no interest in conducting bilateral transactions. In a two-way deal in either the buyer or the seller would necessarily come out worse than in a transaction on the public exchange. Indeed, bilateral transactions in the real world, in which the price diverged from the market price would probably involve some other element in the transaction. As the simulation did not include any other commodity than AAUs, it seemed unlikely at the start that it could test the utility of bilateral markets. Notwithstanding this, 500 MtC were traded on the bilateral exchange, 13 percent of the total amount exchanged during the simulation.

Tracking transactions

Transactions on the exchange and bilateral markets were tracked in real time, and assigned amounts were adjusted immediately for both the buyer and the seller. The market platform also kept track of the country of origin of traded AAUs, although participants themselves did not have access to that information.

Reporting

Participants representing governments were required to make "annual" reports on their national emissions (based on the model described above) and on their net trading operations for the period. Participants were also required, on a confidential basis, to provide information on the level of their domestic abatement cost to date. The IEA Secretariat (acting both as a centralised repository of information and as an inventory-verification authority) checked on the accuracy of reported inventories.

The Secretariat made a complete report on the inventories of all participants, on their trading position and on their Adjusted Assigned Amount following each trading period. Participants were therefore aware of each other's emission trends, and could use this information to project future demand for AAUs. The Secretariat also provided estimates of the compliance prospects for participants based on most recent inventories and acquired or transferred AAUs. It is anticipated that under a real-life regime, private sector companies would perform this analysis function themselves, much as is the case now in commercial markets.

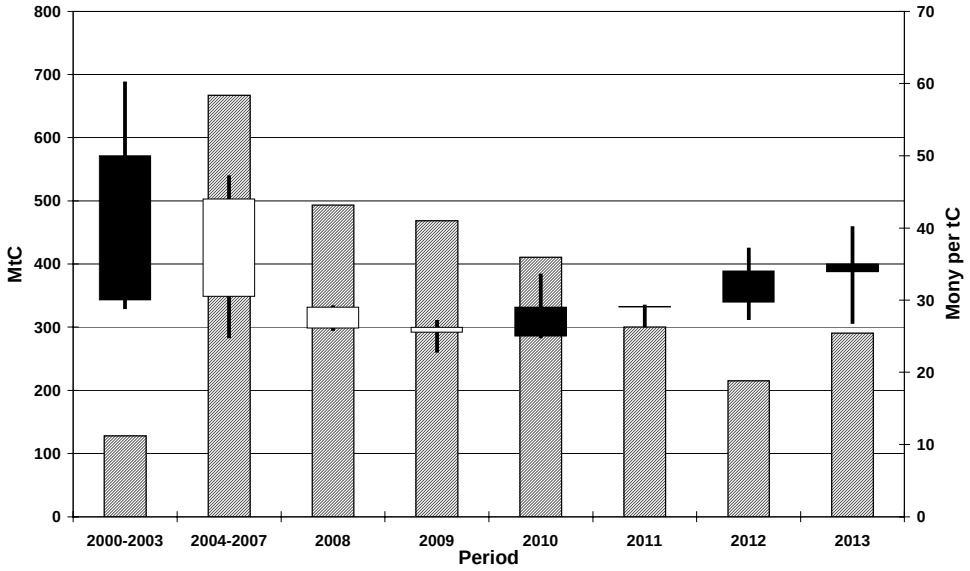
3. RESULTS: COMPLIANCE AT REDUCED COST IN SPITE OF UNCERTAINTIES

All participants in the simulation complied with their emission goals, all participants had access to the trading exchanges and the overall cost of compliance was significantly below what it would have been using domestic action alone. The simulation was, therefore, a considerable success. At the same time, the emission trends on a country-by-country basis were up for a majority of buyers at the end of the simulation. Sellers had more or less stabilised emissions. Buyers reduced their emissions by 15 percent and sellers by 13 percent from their business-as-usual trend.

The simulation period by period

Figure 1 indicates the total volumes traded in each session of the simulation. The majority of trades took place early in the simulation except for the very first period, when RUS (ultimately the largest volume seller) was absent from the market. About 60% of total volumes were traded before 2010. Participants were testing the price, and they were still able to hedge their compliance commitments through domestic policies if prices on the market proved to be too high. Later in the simulation, as prices became firm, and as countries were required to make domestic investments to insure compliance, the traded volume fell.

FIGURE 1. TRADED VOLUMES AND PRICES



Note: The striped bars indicate traded volumes for each session (using the left-hand scale). The dark vertical line indicates the price range in the session (minimum and maximum, using the right-hand scale). The black or white areas indicate the opening and closing prices : white indicates an opening higher than closing; black the reverse; thus the market price climbed during the 2000-2003 session, fell in the second, third, and fourth session, and climbed in all subsequent sessions).

After a first session where wide price variations were observed, a more stable and liquid market started emerging. After 2004, prices declined from almost 50 mony per tonne to 30, and remained around that level until the end of the simulation.

Price variations between sessions can largely be explained by changes in expectations regarding compliance. In 2009, a lot of trading still needed to take place before each participant could be confident about its own compliance. The following warning was issued at the close of trading in 2009:

> *"[…] the emission outlook for the remainder of the commitment period is not as rosy as previous trends indicated. Indeed, due to GDP growth in the OECD Europe region and unexpectedly low oil prices, emissions are likely to be some 3% higher than anticipated in 2011 and 2012. According to projections based on current inventories and the new economic environment, the Annex I participants may be only some 13 MtC below the assigned amount at the end of the commitment period. While this means overall compliance (and CDM tonnes could add to that amount), this may be worrisome when it comes to the second commitment period, targets for which are still to be elaborated."*

This had a marked effect on the international price in the next trading session: the average price of AAUs moved from 25 to 30 mony per tC – a 20% increase – between 2009 and 2010. This increase in price triggered a release of CDM credits to the market. The 2010 market report said that the system was likely to be in compliance overall, although a few participants still needed to acquire AAUs in order for all to comply with their individual objectives.

> "[T]here are now more AAUs and CDM credits on the market than during the previous year, enough to cover all needs at this stage. *However, not all Parties hold enough AAUs to cover their projected emissions, and the unexpected economic growth and low international oil prices projected last year have since been confirmed. This will almost certainly result in an increase in overall Annex I emissions, and all the more as some Parties were confident about future low AAU prices and had decided to alleviate the pressure on domestic emissions. Inventories for 2011 will be particularly informative."*

The upward pressure eased in 2011, with an average traded price of 28.5 mony per tC, but resumed in 2012 and during the true-up period (2013 on this chart), when the average price reached 35.5.

What drove price variations?

The average price of traded AAUs for the whole simulation (including both bilateral and public exchanges) was 31.3 mony per tC. The average price on bilateral markets was 33.8 mony, that on the public exchange 30.6 mony. The higher bilateral level was a minor factor in the overall price as bilateral trades accounted for only 13 per cent of total traded volumes. These figures confirmed what was intuitively expected: that market participants are likely to rely on the most

competitive market place available to them. In a real world case of course, other factors besides competitive prices could influence such decisions – and this simulation could not test those factors.

In all, two main factors explain the price variations observed during the simulation. Uncertainty on emission trends in the beginning period and lack of information on the costs of mitigation explain the price volatility observed early on. Later, expected changes in inventories and their implications for overall compliance increased participants' willingness to pay for AAUs in order to guarantee compliance. Moreover, near the end of the commitment period, domestic actions to bring additional reductions became increasingly costly. This intensified competition on the buying side and led to a progressive increase in AAU prices from 2009 onward.

The question we then ask is: was the average price observed in the simulation "right"?

Market performance

Clearly, compliance costs were reduced by the trading system, as participants either bought AAUs at a price lower than the cost of their domestic reductions, or sold AAUs at a higher price than what it had cost to generate them. In that sense, making the right trades appeared simple even for non-professional traders. But was the system driven to its optimum performance?

Economic theory suggests that all participants in the trading regime should have applied similar policies (resulting in an equal marginal cost for achieved reductions) and relied on the market to offset any imbalance in the system. The market price at equilibrium would therefore indicate the tax to be applied throughout the regime (see *Elaboration of mitigation and trading strategies*).

An after-the-simulation analysis shows that compliance could have been achieved at a cost of about 25 mony per tonne of carbon. Under perfect market conditions including perfect knowledge of future emissions, this indicates both the price at which AAUs should have been traded and the marginal cost of domestic reductions among all participants. Yet the average traded price was 31.3 – about 20 percent higher. A number of explanations may be offered for this gap:

- Participants were unaware of each other's mitigation costs – except for countries in transition that had AAUs already available. Yet countries needed to make early decisions about their domestic policies, since delaying action could greatly increase costs. Once the market signal was clearer, some countries adjusted their policy levers, while others maintained their initial choice. In a regime where private companies would be the primary players, they are unlikely to reveal strategic information about their internal mitigation costs.
- Participants could not be entirely sure about their future emission levels. Their strategies were therefore rather cautious, hedging against the risk of non-compliance. The system as a whole generated more reductions than was necessary and costs that need not have been incurred.

- However, the market power of large participants is not to blame for a higher than optimal trading price. Some analysts have argued that large sellers could exert a monopoly on the IET market. Absent significant competition on the selling side, they could restrict supply so as to sell AAUs at a price higher than their marginal cost of reduction. A competitive market, one should observe on the contrary a selling price that is close to the marginal mitigation costs of sellers.[8] Indeed, the marginal cost in EIT and RUS were respectively slightly lower and slightly higher than the average trading price – 28 and 33.8 mony per tonne, against the average traded price of 31.3. To a large extent, the competitive pricing mechanism provided by the exchange made it more difficult for such market power to emerge, as any seller could be out-bid by a seller asking a lower price.

Another factor that affected price trends was the diverging strategies of participants vis-à-vis banked units. In 2011, overall compliance was certain – every individual participant was in compliance or knew that enough tonnes of carbon were on the market to ensure compliance. One participant (AUS3) looked at these factors and assumed that there would be strong competition to sell unused AAUs, leading to a price drop. In effect, AUS3 assumed that there was no value in banking units for a future commitment period, as the cost of compliance in that period was unknown. Under this assumption, AUS3 sold the entirety of its AAUs in 2011 – more than 130 MtC – hoping to buy them back at a lower price in the following years.

But the price did not fall. Those who had generated or bought more AAUs than they needed were ready to bank them if the offered price was below their mitigation or acquisition cost. Because AUS3 had sold its AAUs at a relatively cheap price (28 mony per tC) the cost of its speculative approach was fairly high.

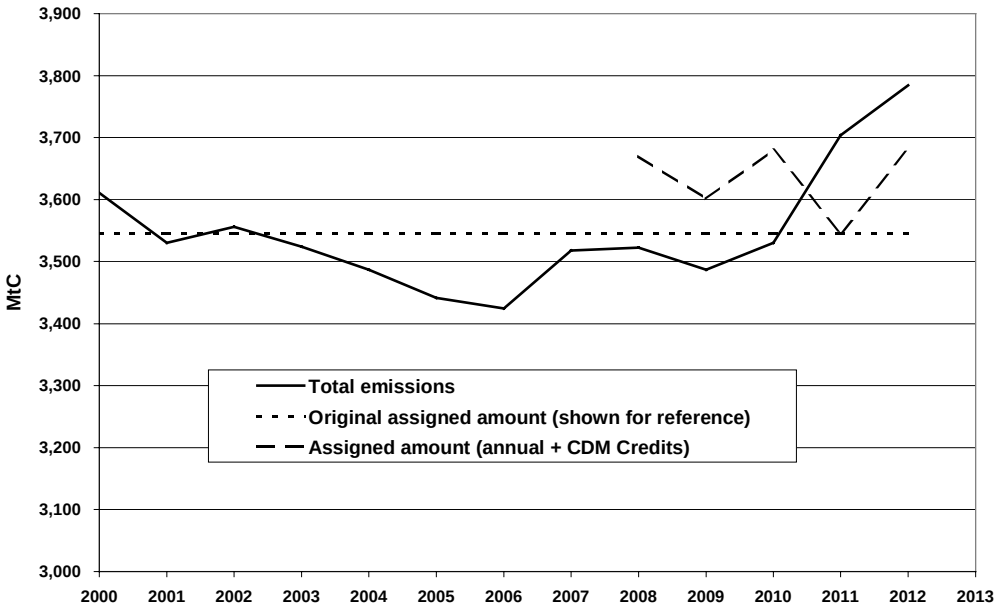
Figure 2 describes emission trends and the evolution of assigned amounts corrected for the addition of CDM credits as they were brought into the system. Early trends indicated an overall emission level (2003-2007) significantly below the overall assigned amount. Nearer the commitment period, the addition of CDM credits also alleviated the stringency of the emission cap, as reflected in figure 2 – see line labelled "Assigned amount (annual + CDM credits)".[9]

The very sharp increase in emissions in 2011-2012 was not enough to bring the system out of compliance. Participants had had an opportunity to test this possibility with their emission models, and had therefore implemented strategies that could bring them in compliance even in such a "worst-case scenario". The excess assigned amounts recorded in 2008, 2009 and 2010 more than offset emissions above the assigned amount in 2011 and 2012. On the whole, participants brought their emissions some 150 MtC below the emission level allowed in this simulation. Under Kyoto Protocol rules, these additional AAUs would be banked for future use. Note however that they amount to less than half

8. See Baron (1999) for a discussion of market power in IET.
9. This may give the false impression that CDM is what brought the system in compliance. In fact, CDM credits amounted to some 470 MtC out of net transfers of 2.1 Gtc. CDM credits in the simulation therefore accounted for less than 25 per cent of the flexibility mechanisms' contribution to compliance.

the difference between 2012 emissions and the original assigned amount (about 240 MtC). The integration of the next period's commitments into first-period's mitigation strategies could have resulted in different market dynamics.

FIGURE 2. TRENDS IN EMISSIONS AND EVOLUTION OF ASSIGNED AMOUNTS



Assessing trading and compliance strategies

Interesting lessons can be drawn from the analysis of participants' strategies. While participants may not have behaved precisely as real countries might, their strategies are likely to be reproduced in the actual IET regime, either by companies or countries.

Domestic action vs. trading

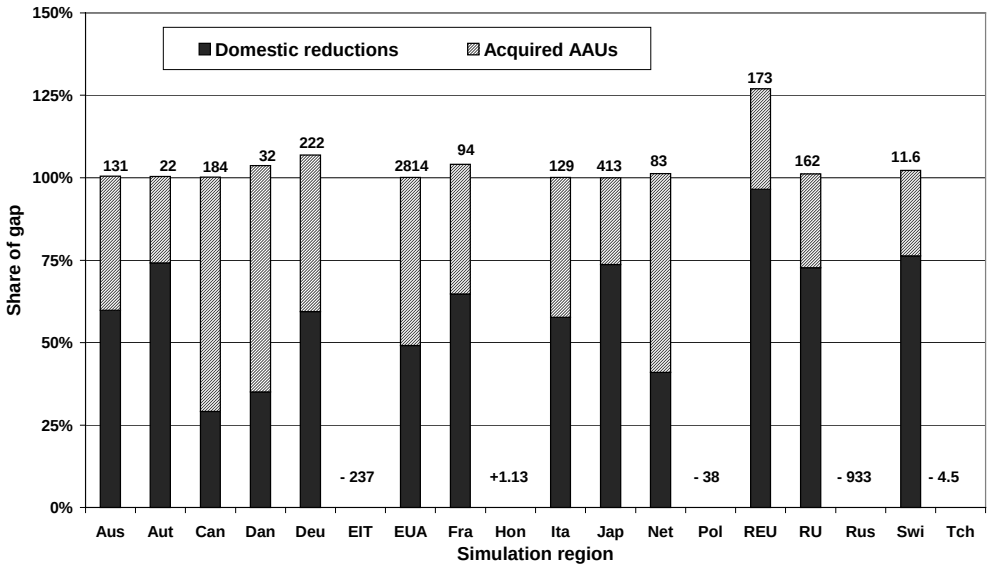
How much did participants rely on trading to achieve compliance? Figure 3 details the relative share of domestic reductions and acquired AAUs for each participant.

Most of the participants met their emission objective by a fairly small margin. Eight of them held surplus AAUs that they sold in the true-up period, once they knew they would not need them. One atypical player in that respect is REU (playing several European Union states), which over-shot its objective by more than 25 per cent and came out of the simulation with a large amount of banked AAUs. This participant almost met its objectives exclusively through internal reductions. Its strategy was nevertheless to acquire AAUs whenever they appeared to be cheaper than domestic abatement cost and bank them.

As a whole, buyers resorted to IET (and CDM credits) for 45 per cent of their mitigation effort; the result was of course heavily influenced by the behaviour of a few large participants (EUA, JAP and DEU, in particular). Individual country participants' shares ranged from 26 to 71 percent through IET. One private sector

player (CAN2) relied entirely on trading to comply with its emission goal, reflected in the relatively high reliance of CAN on trading.

FIGURE 3. HOW DID COUNTRIES MEET THEIR EMISSION OBJECTIVES?



Note: Each participant's total effort is indicated at the top of the bar, e.g., AUS needed to reduce its emissions by 131 MtC in order to meet its emission goal. Net sellers are not represented here.

The role of trading in overall compliance was the result of two inter-linked factors: the gap between business-as-usual emissions and the emission cap, and the marginal cost of achieving reductions domestically. The larger the gap and the higher the domestic cost, the greater the savings that could be achieved through trading. Figure 4 indicates the difference between the marginal cost of reductions if participants had reduced emissions domestically, and the domestic costs eventually applied under the IET regime.[10] These reductions in domestic cost come from the partial substitution of AAUs for domestic measures (see in particular, DAN, CAN, JAP).

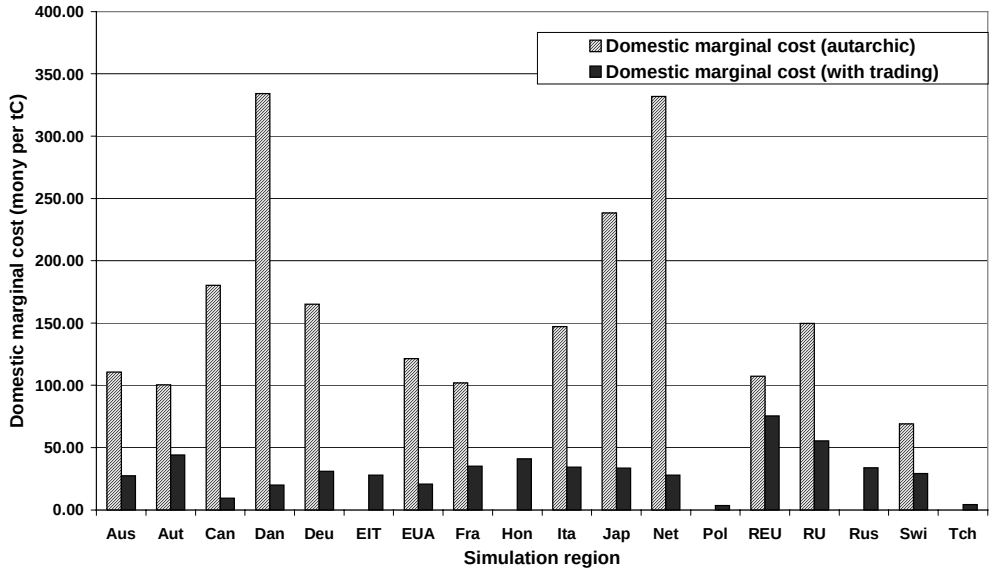
Looking at the marginal cost of domestic emissions in the simulation, we observe differences among participants which suggest that the overall economic efficiency of the regime could, in theory, be improved. Strategic choices by players as well as the policy inertia embedded in the model help explain the discrepancies. But there were also differences in participants' expectations of what could realistically be achieved in real world conditions.

Figure 4 also shows that participants with economies in transition, almost all of them had emissions below their assigned amount in business-as-usual conditions, introduced domestic measures to reduce their emissions still further and sell AAUs on the market. The early emergence of a market price provided the

10. See the Annex on the emission / cost model for details on the elaboration of various strategies.

necessary signal for such actions. Originally, with the exception of HON, all economies in transition had emissions lower than their target, meaning that compliance would not cost them any additional effort. In the simulation, however, EIT, HON and RUS reduced emissions by 14, 13 and 15 per cent below business-as-usual projections. POL and TCH were less aggressive in their domestic policy, with five and three percent reductions respectively. Countries for which compliance with Kyoto objectives can be achieved with no effort may not introduce ambitious domestic policies just for the sake of selling additional AAUs. Other economic choices could very well interfere with climate change objectives.

FIGURE 4. DOMESTIC MARGINAL COST IN AUTARCHY COMPARED WITH DOMESTIC COST OBSERVED IN THE SIMULATION



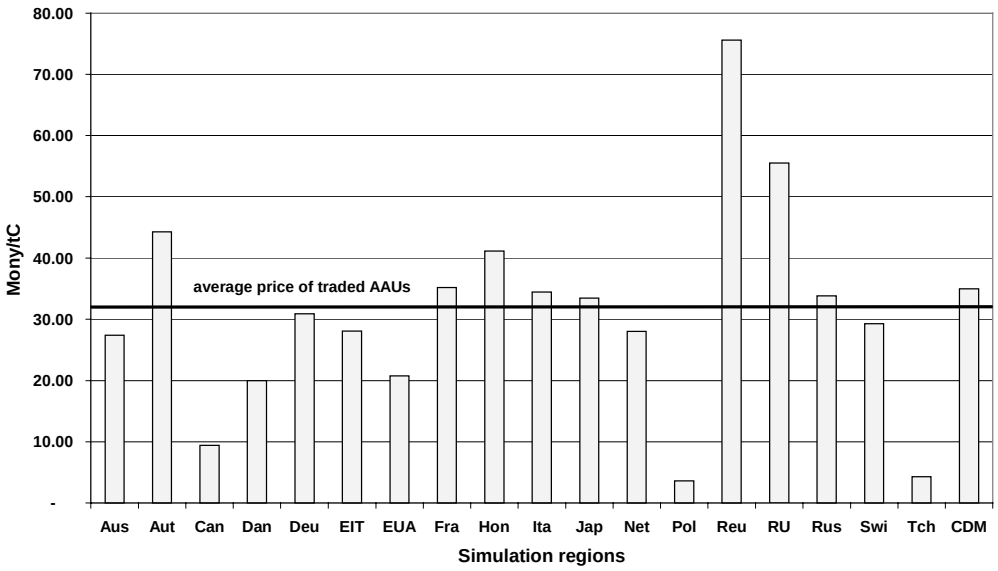
A typology of strategies

Not all participants optimised their domestic strategy to align their internal abatement cost with the price of traded AAUs. Figure 5 shows marginal costs compared with the average price of traded AAUs. Some participants kept their abatement cost quite low (CAN, DAN, EUA) and acquired AAUs at a higher cost than that of domestic reductions, while others paid a lot for domestic reductions (AUT, REU, RU) in spite of the availability of cheaper compliance alternatives in the form of AAUs. Figure 5 therefore gives the straight economic performance of participants. The closer their marginal cost to the traded AAU price, the more efficient they were.

It is useful to recall at this stage that participants were free to undertake strategies of their choice, and that no particular incentives were given for them to try and optimise their behaviour in the simulation. In fact, the differences between the international price and the marginal cost of domestic emissions can be justified by the following strategies.

- *Steady policy course*: Some participants decided early on a given level of domestic cost and kept to it throughout the simulation, relying on trading to offset emissions above the original assigned amount. At the two extremes, we find a private entity that did not apply any constraint on its emissions and relied entirely on trading – CAN2, which is reflected in the overall marginal cost for CAN –, and REU which achieved almost all its reductions internally. A steady policy may be explained by a variety of factors: the difficulty in negotiating domestic policies, and the high cost of undoing them; at the private-firm level, the potentially high cost attached to changing practices and physical capital; or the expectation of future commitments that would require a steady and increasing level of domestic effort.

FIGURE 5. MARGINAL COST AND PRICE OF TRADED AAUS

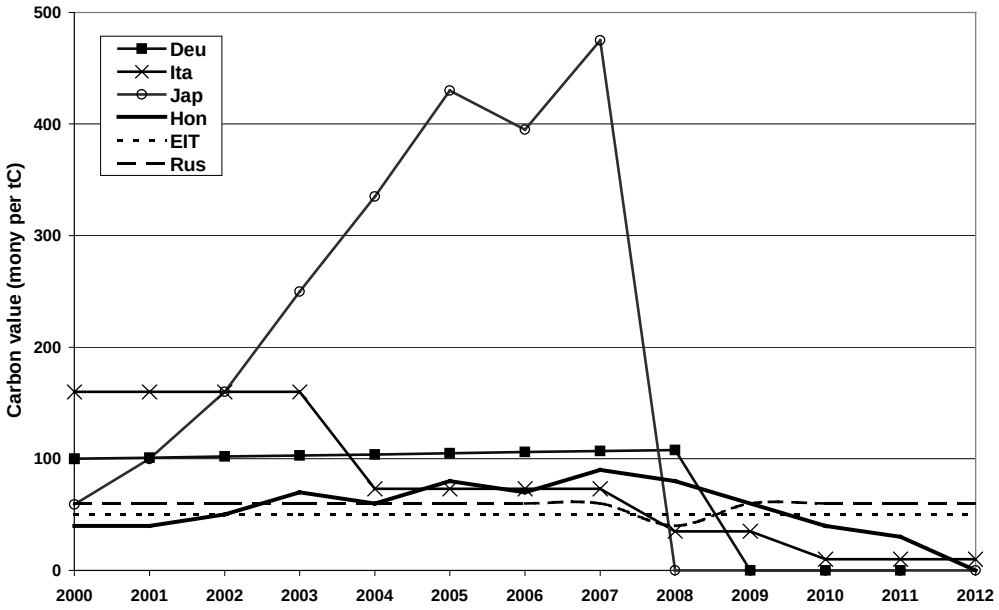


- *Adjusted policy*: A number of participants applied a more cautious approach, making aggressive reductions early on and then adjusting their domestic mitigation strategy to the international price of traded AAUs. One participant (DEU) simulated a radical policy change in 2009, bringing its domestic carbon value to 0. Its marginal cost ended up being very close to the average AAU price, the sign of a highly efficient compliance strategy. JAP and ITA followed similar strategies, albeit ITA's was less pronounced (see Figure 6). By 2004, ITA had acquired the majority of what it needed to comply, so that it was no longer necessary to put pressure on domestic sources. The price reduction observed in 2008 encouraged JAP to halt its domestic policy and ITA to reduce its domestic cost still further.

- *Rational sellers*: Figure 5 also shows the cost applied by EIT, HON and RUS. These three sellers of AAUs tried to keep their marginal cost of abatement close to the price of the AAUs that they sold on the market – HON sold AAUs at an average price of 40 mony per tonne. This assumes, in fact, that selling countries would be very much attuned to the international market price: their

domestic policy would be adjusted to reflect the international price. For instance, a higher price would trigger more reductions at home. This would probably require a rather extensive *domestic* trading system, open to the IET regime. A domestic tradeable-permit market would directly relay the price signal given by the international regime to companies covered by the domestic regime. Other policy instruments such as regulations or taxes may not be as flexible in that respect.

FIGURE 6. EVOLUTION OF POLICY COST (CARBON VALUE) APPLIED TO DOMESTIC SOURCES – ILLUSTRATIONS FOR VARIOUS PARTICIPANTS



Note: These costs are not equal to the marginal cost of reductions for the country as a whole; they indicate a form of "tax" that would be paid by emission sources in these years.

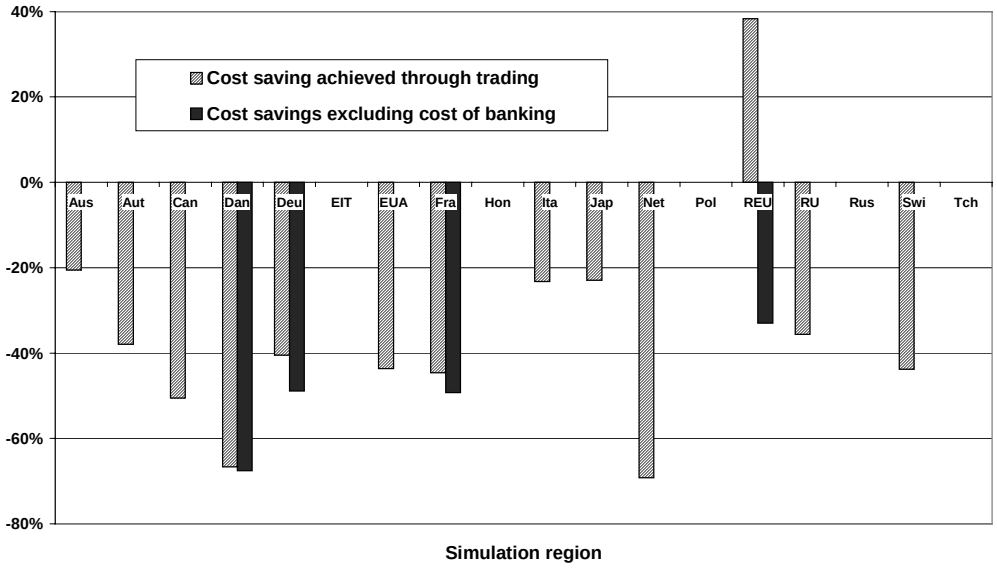
- *Banking AAUs*: The extent to which reductions were banked was a crucial factor in participants' cost of compliance. Because the second period was not played out, some participants assumed that all costs were to be borne in the first budget period. Using this assumption, REU ended up spending a lot more for compliance than was necessary. However, it could have made sense to bank AAUs to alleviate the burden in the second commitment period, if costs were expected to climb significantly. Figure 7 indicates the cost savings achieved through trading with and without the cost of banked units, for those players who did bank them.

- *Traders & risk takers:* Some participants engaged in pure trading activity, buying and selling AAUs at a profit, beyond the acquisition of AAUs for straight compliance purposes. This turned out to be a successful strategy for some participants, who managed to greatly reduce the net cost of AAUs acquired for compliance. With profitable trades taken into account, it cost FRA and SWI only 23 and 4 monies respectively to acquire an average AAU, to be compared with the average price of 31.3. This trading activity can be

distinguished from the acquisition of AAUs for straight compliance by a simple observation. 2.9 Gtc were *traded*, yet in the end only 2.1 Gtc were *transferred*.

How do all these mitigation and trading strategies translate in terms of compliance cost? Figure 7 shows the savings achieved by participants, when their strategy in the simulation is compared with the total cost of a purely domestic mitigation scenario. The biggest savings were made by those countries with the largest gaps between domestic costs and the market price – which was a function of the initial size of the gap between projected emissions and target levels, and of the cost curves of domestic reductions.

FIGURE 7. COST SAVINGS ACHIEVED THROUGH TRADING IN THE SIMULATION



Note: The figure shows savings with and without the cost of banked units, assuming that the most expensive reductions pertain to the compliance cost for the second commitment period.

It is not possible to produce a savings figure for net sellers. Because they had emission objectives below their business-as-usual emission trend, most of them could have sold without incurring any domestic cost. Only HON had first to reduce its domestic emissions in order to be able to sell. Table 3 displays mitigation costs and trading revenues for these participants.

TABLE 3. MITIGATION COSTS AND TRADING REVENUES FOR NET SELLERS

Participant	Mitigation costs (Millions of mony)	Trading revenues (Millions of mony)	Revenues/costs (Ratio)
EIT	1,443	11,090	7.7
HON	189	365	2.45
POL	63	488	7.8
RUS	4,394	38,703	8.8
TCH	10.4	74	7.1

Companies trading

Two "country" participants devolved assigned amounts to "private companies" in the simulation. These companies largely acted independently of their governments. The governments, however, were faced with the following tasks:

- Inventories were required from all companies before a single, nation-wide inventory could be produced. This is similar to the real-word requirements to produce inventories under the UNFCCC. In fact, setting emission caps on domestic companies, which in turn necessitates close monitoring, can contribute to more timely and accurate inventories at the country level;
- Questions were raised about the policy coherence of the country. Would it make sense for a company to acquire tonnes from the international market when such tonnes may be available on the domestic market? The response of companies in the simulation was that they wanted to get the best possible price, and that the international market was the place where this was guaranteed in the simulation;
- Governments, not companies, are responsible for compliance with the Protocol's emission objectives. Countries did not control or limit their companies' trading activity in the simulation. But they had to consider the possibility of having to acquire AAUs from the market if the country were to be pushed to the fringe of non-compliance as a result of a company's mistake. Such risk emerged when one entity in AUS sold all its AAUs in a speculative move. While this risk was taken in a situation where the system was able to deliver these tonnes, this may not always be the case. Thus, while no control of private company activity proved necessary, there may be some merit in a government AAU "buffer" that would hedge the country against non-compliance – a possibility that was raised by some simulation participants.

4. BEYOND THE SIMULATION: INSIGHTS FOR POLICY-MAKERS

The simulation sought to mirror reality by introducing uncertainties on future emission levels, and by including some account of the inertia inherent to policy-making. However, as a simulation, it opened the door for participants to test strategies in a way that is unlikely to occur in a real IET regime. It is therefore difficult to extrapolate from this simulation to a full-fledged, operating emissions market. However, some conclusions can be reached.

What kind of market can we expect?

Policy inertia and the international trading regime

The simulation illustrated the various factors that would prevent an IET regime from delivering a perfectly optimal outcome. This does not, of course, alter the basic observation, confirmed in this exercise: Parties could significantly reduce compliance cost through trading.

By no means can all domestic policies be adjusted to reflect the price of internationally traded AAUs. Can a carbon tax – which is unlikely to be the unique climate policy option – be adjusted annually to reflect the price of traded carbon? Probably not, for political reasons, in spite of theoretical arguments suggesting that it should. Recent experience shows that energy users may not accept abrupt increases in the price of energy commodities. Many regulatory approaches involve a number of stakeholders and are designed to stimulate investment in technological progress; for such programmes, guaranteed policy stability may also be essential. Most of all, a number of policies could be motivated by objectives other than GHG emission reductions, so that a change in international prices would not necessarily entail a change in policy design.

Some participants in the simulation did not hesitate to implement radical policy changes to lower their domestic costs, an approach that may not be feasible in real world conditions. Some measures may look costly in the short run but prove very cheap in reducing emissions beyond 2012. These policies are not reflected in the simulation – except as they might show up in some participants' "banking" options.

One policy instrument that would react quickly to an international trading regime is the domestic trading of greenhouse gas emissions, provided private firms interested in such trading have direct access to the international market. Indeed, some companies – notably power facilities with dual-firing capacity – could adjust behaviour based on the international price. But private sector activities are also based on medium- to long-term strategies and cannot veer as quickly as is sometime assumed.[11] However, the access of companies to the international market also raises domestic policy issues about the need for governments to control trading by their companies, especially transfers of AAUs. No conclusion can be drawn from the simulation on this particular point, beyond the observation that all five "entities" ultimately complied with their domestic emission objectives.

The timing of inventories

In the simulation, it was optimistically assumed that inventories would be available at the end of each calendar year, or no later than one year after the simulation ended. In fact, governments may be in the dark with respect to their emission levels when they have to make trading decisions. Currently, the preparation of inventories lags behind actual emissions by at least two years – and in some cases by as many as five years. In such cases, Parties and companies may still find themselves trading in 2013 and 2014 for the first commitment period. At that time, the price signal would of course have no effect on emissions in the 2008-2012 period, as only banked AAUs could be traded in that timeframe. This may have a negative impact on the overall efficiency of the IET market. Uncertainty observed in the early years of the simulation, and the related price variations, could continue beyond what has been observed here. Adjusting policies to international prices would be even more challenging in such circumstances. Of

11. See IEA-ParisBourse-EurelectricUnipede (1999) for a discussion of the crucial role of investment decisions in the compliance of private companies in a trading regime.

course, private services may become available to project inventory levels, much as current oil production levels are assessed. However, while these services might provide an indication of quantities to the market, they could not substitute for official compliance determination – or the ultimate need to true-up emissions.

Beyond 2012

Most participants in the simulation did not incorporate potential future commitments in their mitigation and trading strategies, and indeed, no clear indications were given to them to encourage such inclusion. It is worth noting however that as a result of their ability to rely on trading for compliance, buyers have had the opportunity to emit more greenhouse gases.

The question to ask is whether the market will be able to deliver enough AAUs to allow Parties to emit greenhouse gases above their targets at reasonable cost. If the overall prospect is for a tightening of the regime, acquisition and mitigation policies undertaken in the first commitment period may be more aggressive. Banking may become a much more attractive strategy and prices would come to reflect the expected cost of compliance in the second commitment period, as AAUs banked from the first period would be valid for compliance in the second.

This argues in favour of an accelerated process to negotiate the obligations for future commitment periods. Uncertainties on that front could otherwise hamper the efficiency of the first commitment IET market.

Domestic policy issues

Ambitious mitigation policies in countries with economies in transition

The simulation showed two distinct behaviours on the part of principal sellers, the economies in transition. These may reflect real options for countries with economies in transition in the actual IET regime.

First, these countries may be encouraged to reduce emissions beyond what they would be in a business-as-usual scenario for the purpose of selling reductions on the market; this is the case that was observed in the simulation.

Alternatively, economies in transition may be discouraged from engaging in aggressive mitigation policies since their citizens know that compliance with Kyoto emission goals is almost certain without any effort. Although countries in transition are assumed to have significant potential for energy savings and CO_2 emission reductions at low or even negative cost[12], exploiting that potential would require a proper regulatory framework and significant investment. Thus, while the emergence of a trading regime with clear price signal could foster such actions, it may not be adequate to ensure any more reduction.

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12. Russian economist Igor Bashmakov once described Russia is "the Saudi Arabia of energy efficiency" (Chandler, 2000).

A central question on decision-making for IET

How could governments implement a system like the one simulated here? This exercise used an extremely simple decision-making tool, where the marginal cost of reduction was reasonably easy to determine. Some sectors with devolved assigned amounts will probably develop such tools of their own to evaluate mitigation costs – in itself a complex task given the many uncertainties that drive these costs: energy prices, interest rates, market developments, etc.

For governments, assessing the marginal cost of GHG mitigation will be a daunting analytical challenge, all the more as they look beyond 2012. Some domestic policy goals may be estimated at specific costs in 2008, but they may well become more (or less) expensive over subsequent years. Governments will also need to take into account such factors as potential ancillary benefits from reducing emissions domestically, or from having companies investing in new technology and encouraging national firms to produce climate-friendly technology. These decisions may affect a country's international competitiveness in a climate-constrained environment – a factor which a simple cost analysis may not make clear. Most analytical tools (macro-economic models or models based on technology inventories and optimisation) are ill-equipped to evaluate such phenomena.[13]

On rules for IET

The simulation was not designed to test rules related to eligibility, market design, liability, non-compliance measures, registries or supplementarity issues, although some observations can be drawn on the options chosen for the simulation.

The design adopted in the simulation encouraged price competition on both the buying and selling side of the IET market. The fairly stable market signal that resulted was used by most participants as an indicator of the "pressure" to be put on domestic emissions. The system was efficient and compliance costs were reduced in the process.

A number of private exchanges have positioned themselves to administer such trading, at least at domestic or regional level, and one can expect that they will be effective in delivering a clear price signal to the international market. Their success is likely to depend not only on the market design but on the nature of the participants. Trades by private firms will be driven mostly by economic considerations, while governments may neither have the right information to price their trades, nor be strictly limited to cost issues when engaging in international transactions. The participation of private companies is essential to assure the efficiency of the IET regime.

The exchange used here kept track of all transactions in the equivalent of a registry, so that the balance of the overall IET regime could be evaluated immediately. This is clearly an ideal (and possibly unrealistic) regime, as it

13. See IEA (1998) for a discussion of energy modelling and climate change policy.

combines financial transactions and the transfer of AAUs from the seller's account to the buyer's. The links between a system of national registries and the commercial transactions of AAUs will require some careful thinking before such an airtight regime can be replicated.

Issuer liability – the rule adopted here for reasons explained above – would help to generate an active trading regime. It guarantees that all traded AAUs are valid for compliance, so that their price becomes the only discriminating factor in any transaction. But the simulation provides no information on the risk of over-selling in IET, which is the danger of an issuer liability regime without strong penalties for non-compliance, or a limit on the transfer of AAUs by Parties.

5. KEY MESSAGES FROM THE SIMULATION

- Emission trading as envisioned in the Kyoto Protocol can work and can significantly reduce the overall cost of meeting emission goals.
- Inertia in domestic policy, uncertainties in inventories and variations in the price of traded units may reduce the predictability of the market price, but they do not offset its significant cost-effectiveness.
- The developments of markets encourage all Parties including economies in transition to undertake policies at home as they gain from making – and then selling – additional reductions.
- Full inventorying and reporting of greenhouse gases and net trades is critical for the market. Timely information is a must.
- Trading by private companies can work in an international regime. While it raises questions regarding domestic monitoring and oversight, it offers countries the capacity to adjust domestic cost rapidly and offsets the potential for the negative use of "market power" by large sellers or buyers. Competitive markets also help alleviate that risk.
- Future commitment periods will affect current decisions. An early decision of emission objectives for these periods will be important to set appropriate price signals.
- Participants in the simulation applied a wide variety of policy approaches. Both the simulation and a real world regime are likely to accommodate this diversity while keeping the overall system in compliance.

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ANNEX X. THE EMISSION / COST MODEL

Projecting greenhouse gas emissions

The model was based on simple energy demand relationships, in which demand was driven by GDP growth and energy prices, including a carbon value. Energy demand was then translated into CO_2 emissions. The model was not meant to replicate any country's exact situation, but to provide a rough estimate of emissions. CO_2 emissions from fossil-fuel combustion were used as the underlying statistical basis. Table 2 shows each participant's Assigned Amount for the commitment period; cumulative emissions in 2008-2012 had participants taken no action to lower them. This is the so-called "business-as-usual" (BAU) scenario. The table also shows the percentage difference between the two. The ranking of countries with respect to the domestic cost of bringing emissions down to Kyoto levels was similar to that of the modelling literature.

Emissions were subject to uncertainty, as the simulation rules allowed for four different potential "surprises". These surprises could lead to a change in the gap between a participant's emission goal and its business-as-usual emissions by as much as 40 percent – even when cumulative emissions over the 2008-2012 period increased by a mere six percent. While participants did not know which kind of surprise would occur, they could test each beforehand, and were encouraged to do so.

The model allowed participants to test strategies to reduce CO_2 emissions internally, the better to evaluate the relative merits of domestic action versus international emissions trading. Domestic policies and measures were represented with a simple cost applied to domestic emissions, not unlike a carbon tax. A one-year delay was introduced between the time a policy decision was taken and its effect on emissions. Of course, a determination that domestic action was more costly than international purchases did not necessarily lead participants to engage in trading. Such decisions were based on a complex set of criteria, some of which are described in the main body of the text.

The calculation of the relative costs of domestic versus international action was further complicated by the fact that the magnitude of the domestic effort could vary through time, and that the overall cost of compliance depended on the price of AAUs acquired from (or sold to) the international market. On the domestic front, participants could choose to reduce emissions early, with cost applied from 2000 onward, or wait for a few years, observe the international price and make necessary domestic emissions reductions based on this information. Note, however, that the model was designed so that early action was a less costly strategy overall than delaying reductions. This reflects the common view that over the time frame simulated here (2000-2012), drastic reductions near the end would be much more difficult to achieve than a progressive change leading to the same outcome.

The simulation participants were therefore faced with a rather complex set of choices, including the amount of domestic action, the possible need for adjustments if the international market price diverged from the participant's expectation and the potential for surprises.

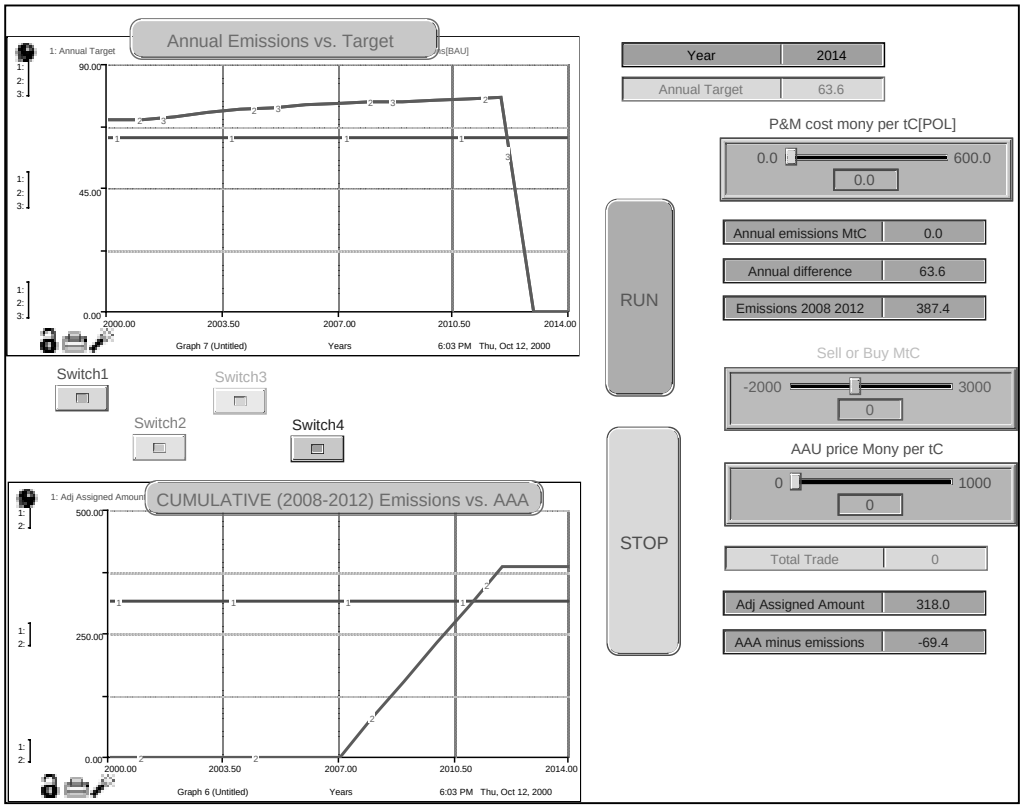
Participants were of course free to test any strategy of their choice, even if it were not strictly motivated by the minimisation of the cost of compliance in the first commitment period. It was made clear at the outset that the relative economic performance of participants would not be measured nor ranked.

Various strategies based on the model are illustrated below.

Figure A.1 shows the model's screen for a business-as-usual emission scenario. No cost was added to energy prices to reflect CO_2 emissions and no reductions were obtained. The

model accounts both for annual emissions (upper graph) and cumulative emissions (lower graph). It also keeps track of the participant's assigned amount and its emission gap, as reflected in the box labelled "AAA minus emissions" – AAA stands for Adjusted Assigned Amount, i.e. the original assigned amount plus acquisitions and minus transfers of AAUs. The four switches in the middle-left section are provided to simulate potential "surprises" in emissions. Participants were asked to activate these at various points during the simulation.

FIGURE A.1. **AN ILLUSTRATION OF BUSINESS-AS-USUAL EMISSIONS**



Reducing emissions with "policies and measures"

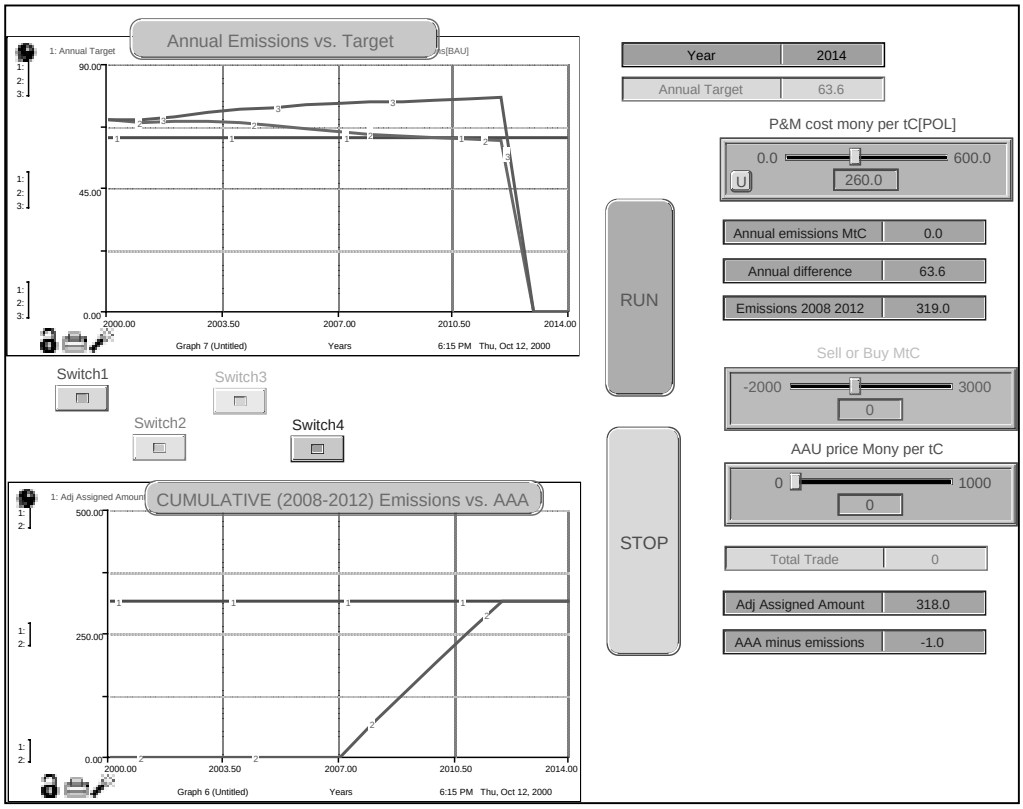
The model was designed so that a certain level of domestic effort would bring reductions in national emissions (or sectoral emissions, for companies). This was performed via the addition of a carbon cost to energy – using the slider "P&M cost – mony per tC" on the upper-right section of the figure. It was assumed that any policy would only affect emissions one year after it had been introduced. That meant that any policy taken in 2012 would have no effect on emissions for the first commitment period.

Figure A.2 shows emission reductions that would result from a carbon value starting at 20 mony per tC and growing every year by 20 mony, reaching 260 mony by 2012. This particular pattern would bring the participant almost into compliance through domestic measures only. The model computes the total cost of this strategy to be equal to BnM 2.04 (Billion mony) – not shown here.[14]

14. The total cost is the sum of annual costs, computed as the integral of the marginal cost curves for every year.

The marginal cost of this pattern can be easily derived from an example where one additional mony is applied to emissions throughout. By dividing the additional cost by the additional reductions, one obtains the marginal cost of bringing emissions to the desired level. In this example, the addition of one mony to the previous strategy would reduce emissions by an additional 230,000 tC at a cost of 19 MnM, hence a marginal cost of 82 mony per tC.[15]

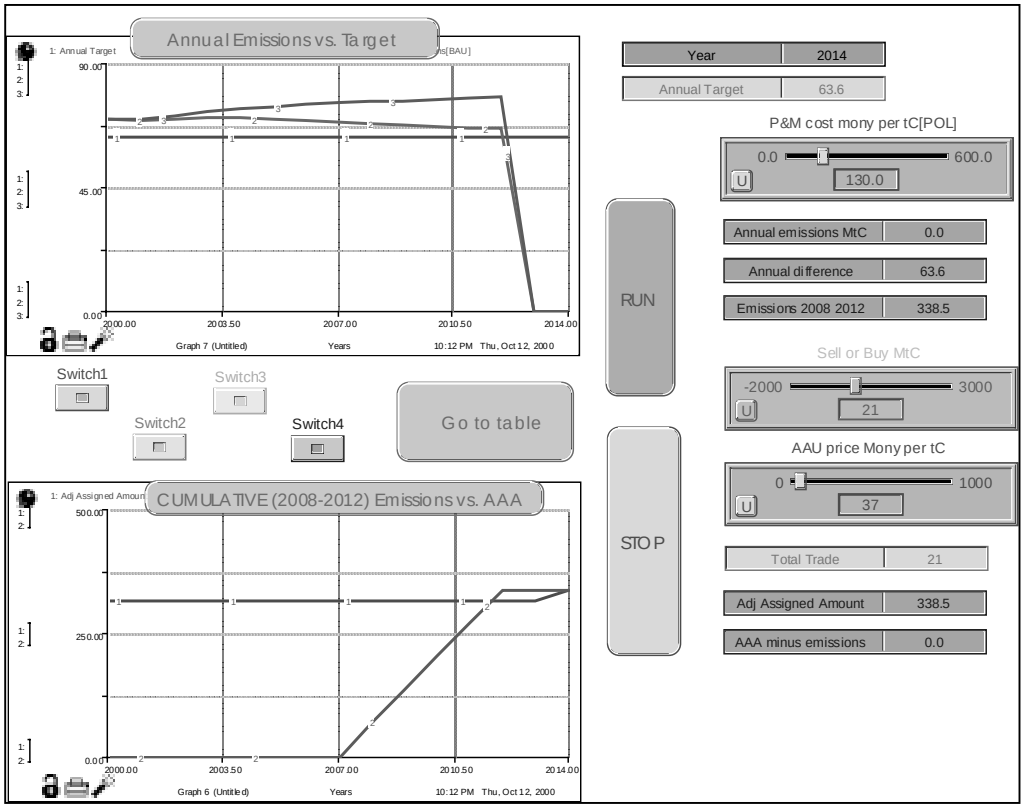
FIGURE A.2. **ILLUSTRATION OF A DOMESTIC EMISSION REDUCTION STRATEGY**



The model can also be used to evaluate the economics of strategies relying on trading. Let us assume that the international price of AAUs is stable at 37 mony per tC. The participant in our illustration could define a domestic strategy matching that level of effort (a marginal cost of 37 mony per tC). Such a strategy would not suffice to meet the emission goal domestically, but the country could comply using AAUs (20.5 MtC) acquired from the market. Based on the model, the total cost of domestic reductions would be MnM 754, and the participant would need to acquire an extra 20.5 million tonnes from the market at 37 mony, for a total amount of MnM 758.5. The total cost of this strategy is BnM 1.5, while an "autarchic" strategy that would cost more than BnM 2. Through trading, this participant could cut overall compliance cost by more than 25 percent. This strategy is illustrated in Figure A.3, where we assume that the participant would acquire 20.5 MtC from the market at 37 mony during the true-up period (2013). This is reflected in the lower graph, where cumulative emissions are matched exactly by the AAA at the end of the period.

15. *I.e.*, MnM 19 divided by 230,00 tonnes of additional reductions.

FIGURE A.3. **ILLUSTRATION OF A STRATEGY BASED ON DOMESTIC REDUCTIONS AND AAU ACQUISITIONS**



ANNEX Y. THE TRADING TOOLS: EXCHANGE AND BILATERAL MARKETS

The exchange

The exchange used in this simulation was based a double-auction mechanism in which only best-priced offers could lead to a transaction.

The exchange also recorded other less attractive offers in its order book, so that if an offer to buy or sell were to be taken up, the next best offer would come on line. An example is given in the next table: At time 1, someone is offering to buy 2.5 million tonnes (or 2.5 AAUs) at 30 mony per tonne, the highest price at this time. The best offer to sell is for 50 million tonnes at 32 mony per tonne. At time 2, someone has acquired 5.5 million tonnes at 32 mony, so that only 44.5 million tonnes remain from the previous offer. At time 3, someone is offering to buy 5 million tonnes at 31.5 mony per tonne, which outbids the previous best buy offer of 30 mony per tonne.

TABLE A.1. ILLUSTRATION OF THE EXCHANGE

	Best BUY offer	**Best SELL offer**
Time 1	2.5@30	50@32
		event: sale of 5.5 units at 32
Time 2	2.5@30	44.5@32
	event: higher buying price is offered	
Time 3	5@31.5	44.5@32

Note that there need not be a perfect match for a transaction to take place. Traders only need to agree on the price, not on the quantity. This guarantees that the best possible price can be obtained at any given time by whoever is willing to buy or sell.

Bilateral markets

Bilateral markets were running in parallel with the exchange. Transactions on these markets were known only to the two parties (a potential buyer and a potential seller) and therefore not open for competition by others.

The next table indicates what a potential seller would see if a bilateral transaction (an offer to buy) was issued on its bilateral market. The first line indicates information available on the exchange, the second indicates the bilateral market information.

Table A.2. THE EXCHANGE AND BILATERAL MARKET (1)

Market	**Best BUY offer**	**Best SELL offer**
Exchange	2.5@30	50@32
Bilateral market	10@31	--

As a seller, we may be inclined to accept the private offer to buy 10 AAUs at 31 mony per tonne, since the best buy offer on the public market is for 30 mony per tonne. But why would the buyer not go on the public exchange instead and outbid the best buy offer with a price only slightly higher than the current best offer of 30 mony per tonne, which is lower than the 31 offered on the bilateral market?

Hence, there was no *a priori* interest in relying on bilateral markets in this simulation. Participants nevertheless tried to obtain better prices than what was available on the market, and they sometimes succeeded. This could happen when the participant offering the transaction did not follow the public market development and failed to change its bilateral offers accordingly. This is illustrated in Table A.3.

TABLE A.3. THE EXCHANGE AND BILATERAL MARKET (2)

Market	Best BUY offer	Best SELL offer
Exchange	12@29	25@30
Bilateral market	10@31	

Here, we assume that the public market has evolved since the potential buyer made its offer to buy ten AAUs at 31 mony per tonne. As a seller, we can only hope to sell at 30 or below, as the best SELL offer is now at that level. If we were to have 10 AAUs for sale, we would rush to conclude the transaction at 31 mony per tonne on our bilateral market. The buyer would obtain 10 AAUs at 31 mony, where it could have acquired them for 30 on the exchange.

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