Including Road Transport into the EU-ETS?

A agent based meso analysis for Germany

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Abstract

To reach the Kyoto target the European Union has been implemented the European Emission Trading Scheme for CO_2 emission allowances (EU-ETS). So far, the transport sector, which contributes around 28 % of European CO_2 emissions, has been exempted from the EU-ETS, although it is the only sector that increased (and will further increase!) its emissions. Economically this exclusion is not efficient. For post 2012 an inclusion of road transport into the ETS could be feasible. In this article a behavioral partial meso model is used to assess the impact of a CO_2 emission trading scheme in German road transport.

Key words: CO_2 emission trading, Germany, road transport, multi-agent.

INTRODUCTION

The most recent IPCC (Intergovernmental Panel on Climate Change) report shows that the increase in global average surface temperature is very likely due to the observed increase in anthropogenic greenhouse gas concentration (*1*). Additionally, the former Chief Economist of the World Bank, Sir Nicolas Stern, advised against the huge costs resulting from global warming which will be incurred towards the end of this century. He maintained that investing 1 % of GDP today in reducing carbon dioxide (CO_2) emissions would prevent losses of more than 20 % of GDP for adaptation costs and remaining damage costs in future decades.

In the Kyoto Protocol, Germany has pledged within the burden sharing agreement of the European Union (EU) to cut 21 % of its CO_2 emissions until 2010 with respect to the base year 1990. Up to now, Germany has already reduced its emissions by about 17 %. The sectors which have already made major contributions include industrial processes (-4.5 %), energy generation and transformation (-12.1 %), manufacturing and construction (-35 %) (in particular due to the breakdown of the industry in the former GDR), as well as others (a. o. households) (-21 %). One notable exception is the transport sector, which has actually increased its emissions by 8.2 % – from 158.1 million tons CO_2 in 1990 up to 171m t in 2004 (*2*). Recently, emissions have started to show signs of decline since only aviation and freight road traffic are still growing rapidly (*2*). Overall, the share of national transport in total CO_2 emissions in Germany increased from below 16 % to 19 % in 2004. Beside the huge growth in national aviation, this increase is mainly caused by an almost constant amount of CO_2 emissions from passenger cars (especially due to the expansion of passenger car density in the Eastern part of Germany) and road freight transportation (+20 %) due to the enlargement of the European Union to include many countries of Eastern Europe as a result of which Germany has increasingly become the centre of important trade flows.

For this reason it is desirable (both for fairness and for ecological efficiency) that traffic participants should also contribute to the national (and international) emission targets. Since it is unlikely that traffic participants will reduce their CO_2 emissions voluntarily, the government should intervene by introducing mandatory legislation. One possibility could be to incorporate the transport sector into the European Trading Scheme (ETS); but so far there are only vague ideas on how to do so. An interesting question is which policy instrument (taxes, prohibitions, charges etc.) or certificate market design is the most efficient and most suitable with respect to impacts on traffic participants. For this question, road transportation is crucial because it is responsible for 92.3 % of the overall (direct) CO_2 emissions from transport. These emissions can be reduced by higher fuel efficiency, fuel substitution based on renewable energies, or by changes in the modal split (*3*).

Most studies forecast a further increase in transport emissions until at least 2010 (*4*, p. 60). Considering the long-term (necessary) CO_2 emission targets for industrialised nations such as Germany (around -30 to -40 % until 2030 with respect to 1990 or -80 % until 2050 (*5*)), the current CO_2 emissions in the transport sector are far too high – particularly when looking at the high potentials for emission reductions (especially in road traffic) (*6*, p. 25, *7*, and *8*). This is valid even if the mitigation costs in this sector (or better expressed as "willingness-to-pay") are also high given the consumer preferences for heavy, safe and high-performance vehicles (*9*). Nevertheless reductions of about 14m t CO_{2e} are even profitable (*10*). A demand shift to more efficient cars brings a double dividend: cars (still suitable for driving from A to B) are much cheaper and use less fuel. But as long as preferences remain unchanged, Goodwin et al. (*11*) points out that the price-elasticity of total transport demand is about -0.6 in the long term whereas the income-elasticity of demand is higher by a factor of 1.5 to 3. Thus the cost of transport should increase much faster than income in order to avoid sales of more upsized cars.

Therefore there is an imperative need for action. Besides technical innovations, a rethinking in the demand is also necessary. The latter can be supported by political instruments such as regulatory (obligations or prohibitions), information, voluntary (among others self obligations), and economic policies (taxes, charges, and certificates). How far these instruments can be economically legitimised can be evaluated using the criteria compiled by Rennings et al. (*12*), i.e. aim- and system conformance, cost efficiency, as well as institutional controllability. Certificates seem particularly convincing with respect to three of those criteria: the actors are free to make decisions (system conformance), actors with low marginal abatement costs have the highest incentive to reduce their emissions and innovative behaviour is rewarded (cost efficiency) and the objective is reached (aim conformance). However, empirically, these theoretical advantages may emerge as drawbacks if transaction costs arise. Furthermore main influences remain unclear as so far no experience has been gained in Europe with trading certificates in the transport sector (*13*) thus simulation models might give deeper insights concerning the institutional controllability.

The remainder of the paper is organized as follows. After a short introduction of multi agent modelling, certificate trading and German transport the following section describes the main features of the developed agent based partial meso model. Finally, the outcome of the model is presented and the main results are summarised in the conclusion.

MESO ECONOMIC ANALYSIS OF GERMAN ROAD TRANSPORT

The developed meso economic model includes some characteristics form multi agent modeling compiled by Wooldridge and Jennings (*14*). The concept of multi-agent based simulation seeks to overcome some of the weaknesses of conventional modeling approaches by constructing a simulation from a player's perspective which helps to integrate aspects like individual player strategies, learning, imperfect information or subjective decisions. The approach of agent-based simulation draws on concepts from several disciplines such as economics/game theory, the social and natural sciences and software engineering (*14*). The different approaches to agent-based simulation have resulted in a variety of definitions concerning the term "agent". One definition which is often quoted in the field of multi-agent systems or distributed artificial intelligence is given by Wooldridge and Jennings (*15*) stating that agents are characterized by *autonomy* (ability to operate on their own), *social ability* (ability to interact with other agents), *reactivity* (ability to respond to a perceived environment) and *pro-activeness* (ability to act on their own initiative in order to reach envisaged goals). However, a review of multi-agent based simulation platforms shows that the agents used in these simulations apply weaker definitions of the term "agent" in many cases (*16*).

Recent multi agent models in transportation are network-based (among others by Axhausen and Nagel, e.g. (*17*)). It is obvious that not all questions concerning traffic behaviour are dependent on network decisions. This is also true for modeling the topic of this paper. Thus a behavioral approach is adequate and the focus should be seen in modeling modal split decisions and the reaction functions of households and freight forwarders and how they cope with the implemented CO_2 emission trading scheme.

These reaction functions are generally difficult to estimate because individuals react differently to policy instruments and there are so many factors of influence involved. Additionally in Germany there has been no significant (real) price raise in the last decades (except the late 70s), which could be used to calibrate the model (*18*). Probably data from the price drop in the autumn 2008 might bring some new findings. In the developed model the statistically estimated reaction functions of households reflect group specific characteristics. Due to this group specific reaction function the model might be considered as a meso economic model.

Main Agents

As already mentioned in this article a behavior-based model is used for assessing the impact of a hypothetic CO_2 emission trading scheme in the German road transport. Therefore an overview of the corresponding four markets included in the considered model is given. In passenger transport, participants can reduce their CO_2 emissions by changing their personal modal split or reducing their mileage (i). In German freight transport, participants can reduce CO_2 emissions significantly by changing mode (ii) – due to the heavy duty charge on highways logistics are already at a high level in Germany. I.e., in the long run all traffic participants could also buy more efficient vehicles (iii). Furthermore the CO_2 certificate market (iv) should not be forgotten. Agents comprise first of all households (demanding fuel and new passenger cars), shippers, hauliers and carriers (demanding fuel and new freight vehicles), carmakers (providing new cars) and fuel companies (selling fuel and trading certificates).

With regard to the reaction patterns of households it is difficult to identify the main influences on decisions regarding traffic behaviour. In Germany some studies found attitudes and social networks to be main influences (*19*, *20*, *21*, and *22*).

Agents in road freight transport are subsumed to one agent class. This means that shippers, hauliers and carriers act (concerning their mode choice) according to the nested logit model of Bühler (*23*). In the model the fleet of the carriers is represented by a car pool of equal lorries which upgrades every year its efficiency by 0.2 litres per 100 km (less than 1 %).

Trading strategies of companies for fuel imports and fuel production (in the following they are denoted as "oil companies") are hard to capture. Nevertheless a survey was carried out where current ETS industries are asked about their trading strategies (*24*).

As pointed out above the focus here is on road transport because it has an increasingly large share of CO_2 emissions. It contributes about 94 % of the CO_2 emissions in the German transport sector, whereas rail (1.4 %), aviation (fast rising 4 %) and inland waterways (0.5 %) are almost negligible (*25*). But besides freight road transport, aviation is also contributing to the rising emissions in the transport sector. Despite the fundamental improved efficiency of aircrafts, its CO_2 emissions increased by 73 % between 1990 and 2003 in the EU-25 (*26*). The forecast that these emissions will double in the following decade makes the problem significantly worse (*27* and *28*), especially as the impacts from emissions in the tropopause are twice to four times as severe as emissions in the lower troposphere (*27* and *29*). Therefore the European Commission decided to include aviation and international shipping in the ETS in the third phase (after 2012).

Comparison of an Open vs. a Closed Emission Trading Scheme in the German Transport Sector

As fuel consumption is directly correlated with CO_2 emissions (*30*, pp. 59) it is equally effective to introduce a downstream (liability of e.g. car drivers) midstream (liability of e.g. car producers) or upstream (liability of e.g. fuel companies) approach. Transaction costs are much lower when using an upstream approach which is why this is chosen in this model where the oil companies are liable for holding certificates for every gallon of fuel sold. There are many other possibilities for liable agents considering the dimensions of market participants, the energy consumption of modes and mobility purposes; more than 36 possibilities could be identified by Stronzik et al. (*13*). But no possibility does really affect fuel consumption and concern at the same time so few agents (about 100 oil companies in Germany).

Concerning the tradability of certificates it is assumed that the willingness-to-pay for fuels in transport is very high, thus this also applies to CO_2 emissions. It is obvious that, on the one hand, without a big change in the demand structure of motorized road users, the certificate prices in a closed trading scheme would be enormous. On the other hand, in an open trading scheme, the transport sector would not change its emissions but rather use the high willingness-to-pay to buy certificates in other sectors ('cross-financing of mitigation') which conforms to economic efficiency. When introducing a certificate market it is useful to refer to the already implemented ETS. For this reason, all other above mentioned decisions are made in accordance with ETS rules to avoid a bias between different companies. Thus the certificate trading scheme in this model includes an absolute target (concerning the amount of fuels sold) and a (mainly) free allocation of certificates based on historical emissions (grandfathering).

THE DEVELOPED MODEL

A JAVA based model is designed, which includes only different households and freight carrier as traffic participants, preliminary carmakers and an open CO_2 certificate market (as described above). The households and the freight carriers are based on empirical data, but the CO_2 reduction path (number of certificates) and the duration (10 years) are theoretical and only basic structures are considered. This model focuses on individual impacts on households and freight carriers due to an implementation of a CO_2 certificate market. In demanding more fuel as certificates are applied, households and carriers force fuel companies to buy certificates on the CO_2 exchange (open market) or to higher the fuel price (closed market). In the open market case the resulting CO_2 price is marked up to the fuel price of the next day.

Global parameters are weekdays t (1-264 per year), years n (1-10), households i (1-50,000), fuel types j (super 95, super plus 98, gasoline 91 and diesel), fuel companies m (1-80), trips r (1-2000), lorries l (1-610), freight forwarders q (1-610) and vehicles in households k (1-6).

The root of the model consists of a loop which represents an average exchange market day and which is repeated 264 times a year. On such a day, traffic participants may arrive at the petrol pump and take a look at the current prices. As a result, they may adjust their mileage (equation 7). In the model fuel prices increase only by a very few percent (<<10%) each year thus only minor changes are assumed. Once a year they decide whether to buy a new (or used) car or continue to drive the old one. Usually the decision is to reject the purchase for more than six years before the next car is bought. Carriers get a trip (transport order) from the database which can be accomplished by lorry or combined transport and carry them out by lorry or combined transport (equation 8). Transports by train or inland waterways (IWW) are neglected. Carriers are assumed to refill their tank every day. Some trips are directly allocated to rail and water transport (heavy goods) others directly to lorries (distances less than 50 km, 31 mi). In the open market, oil companies decide every evening whether to buy certificates or not (equation 4). In doing so they are free to decide the number – except on the last day in the year when they have to balance their certificate account (as the trading period is one year). If fuel companies sell their certificates, the CO_2 certificate price of the other markets (industry and energy) declines (due to a surplus of certificates); if they buy certificates (zDemand>0) this will raise the price for others (shortage of certificates); and if no transaction is conducted the CO_2 price in the ETS remains constant (equation 5 and 6). This surplus of the CO_2 price is added to the fuel price for the next day (equation 3). In the closed market oil companies raise fuel prices in case of shortage of CO_2 certificates and reduce fuel prices in case of a surplus of CO_2 certificates in the market (equation 1). This adjustment is conducted by estimating the fuel price elasticity (equation 2) of the corresponding agents (households and carriers).

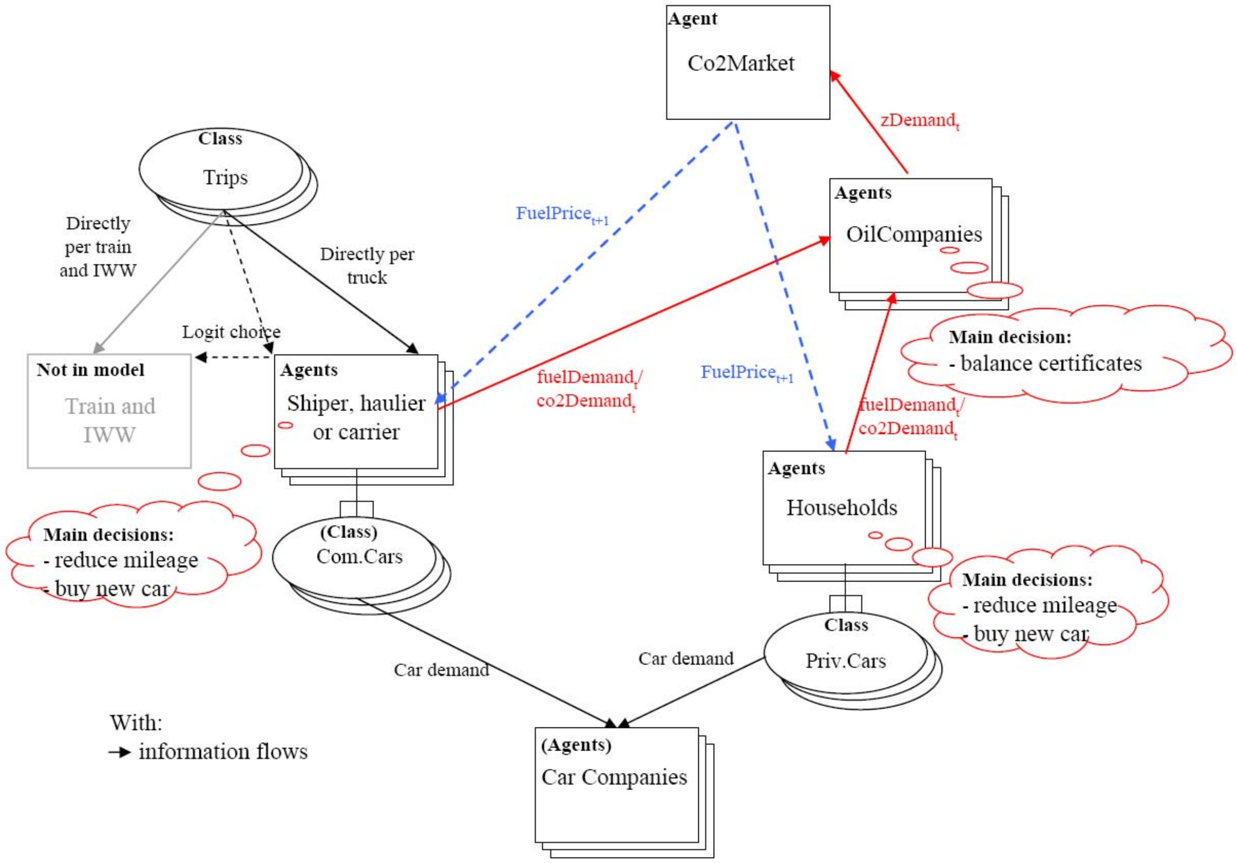

FIGURE 1 Class diagram of the model

The multi-agent specific Java library RePast (*31*) helped to coordinate the agents and to deliver proper results. An overview of the model is given in Figure 1 where quadrates illustrate agents, ellipses objects and clouds for possible decisions of agents. Agents without clouds have no decision – they act deterministically. Arrows reflect the exchange of information.

Oil Companies in the Closed Certificate Trading System

The 100 companies for fuel imports and fuel production ("*oil companies*") in the model are the concerned agents in the illustrated up-stream certificate trading scheme. They have to balance the amount of circulated CO_2 certificates (which are reduced by 1 % per year) with the CO_2 emissions resulting from the fuel demand of households and carriers. In the model it is assumed that they balance their account on a daily basis. In the closed system the reduction must be achieved by road transport itself. Thus the only possibility is raising fuel prices to lower fuel demand. If at day t certificates suffice to balance fuel demand (*co2demand* ≤ *co2Supply*) no change for the CO_2 surplus (*co2Price*) for fuel is needed. If the fuel demand exceeds the certificate supply the CO_2 surplus is raised (equation 1) according the estimated price elasticity η.

$$co2Price_{t+1} = \begin{cases} co2Price_t\,,\ for\ co2demand_t \le co2Supply_t \\ \dfrac{co2Price_t \cdot (co2Supply_t - co2Demand_t)}{co2Demand_t \cdot \eta_t} + co2Price_t\,,\ for\ co2demand_t > co2Supply_t \end{cases} \tag{1}$$

The price elasticity is estimated according the price reactions of agents of the last day (equation 2).

$$\eta_t = \begin{cases} -0{,}1\ \ for\,(co2Price_t - co2Price_{t-1}) = 0 \\ \dfrac{\dfrac{co2Demand_t - co2Demand_{t-1}}{co2Demand_{t-1}}}{\dfrac{co2Price_t - co2Price_{t-1}}{co2Price_{t-1}}}\,,\ else \end{cases} \tag{2}$$

The certificate price is added to the base fuel price ($baseFuelprice_j$), which is constant for the entire simulating period for each fuel type j. Hence, according to Equation 3 the fuel price of the next day ($fuelPrice_{t+1,j,i}$) includes the certificate price. As the amount of emissions differs for the fuel types a corresponding factor ($co2Factor_j$) for each fuel type $_j$ is considered in the equation.

$$fuelPrice_{t+1,j,i} = CO2Price_t \cdot CO2Factors_j + baseFuelprice_j \tag{3}$$

Oil Companies in the Open Certificate Trading System

In the open market oil companies can balance their certificate account also by buying certificates in the existing ETS. The daily demand for CO_2 certificates by the oil companies m ($zDemand_{t,m}$) is given by the difference of the daily certificate allocation (*co2Supply*) with the CO_2 emissions resulting from the fuel demand of households and carriers (*co2Demand*) (equation 4).

$$zDemand_{t,m} = co2Demand_{t,m} - co2Supply_{t,m} \tag{4}$$

The ETS shows specific (forecasted) base CO_2 certificate prices. According the real abatement cost curve from BDI (*10*), specific (higher) CO_2 prices resulting from the additional certificate demand from the transport sector could be estimated (see equation 5 with λ = 0.0002).

$$co2PriceTransp_t = zDemand_t \cdot \lambda \tag{5}$$

Where *co2PriceTransp* is the surplus of the certificate price in the ETS (see equation 6).

$$co2Price_t = baseCo2Price_{ETSt} + co2PriceTransp_{t-1} \tag{6}$$

As in the closed market, a rise of certificate price increase fuel prices according equation 3.

Households

The (about) 700 real households in the model, which represent the 40 million of the German households, are representative and defined by the following attributes: the *monthly kilometers driven*, the *monthly fuel consumption*, the *fuel efficiency* of their cars, paid *fuel prices*, *age* of their cars, their *fuel type* (diesel or not), whether their car is an *luxury car*, their *household size*, their number of household members with an *high school diploma*, the number of *employed* household members, the number of *children* below 10 years old in the household and whether they made an holiday trip during the survey.

Inputs into the model are transport panel data from a mobility survey (German Mobility Panel (GMP), *32*), which include some characteristics of more than 20,000 German traffic participants. For the reaction function of households to different prices an existing econometric model by Frondel et al. (*33*) is used. Their estimated function is depicted in the following equation 7.

$$ln(km_{it}) = 8.12 + 0.582 \cdot ln(\mu_{it}) - 0.615 \cdot ln(pe_{it}) + \alpha_x \cdot x_{it} + \xi_i + \upsilon_{it} \tag{7}$$

Where *ln(km)* is the log of the monthly VMT of households, *ln(μ)* is the log of the fuel efficiency of the car, *ln(pe)* is the log of the fuel price, and α_x are the other estimated parameters of all other household specific variables *x* depicted above. ξ denotes an unknown individual-specific term and υ is a random component that varies over individuals and time. This price reaction by households is accomplished every day, thus they can adopt their VMT according to the fuel prices at the pump (which include the CO_2 prices). Besides the daily VMT change, once a year the household can decide whether to buy a new or used car. This is accomplished by a Logit-Model. The model shows that households buy similar cars during their lifecycle. Thus if the household bought a used car with a small engine the following car is again a used car with a small engine, and so on. Furthermore, it is seen that households confronted with high fuel prices buy more fuel efficient cars, but the rebound effect is marginal; i.e. lower operating costs of cars do not boost VMT significantly.

Freight Road Carriers

In the model about 500 real freight road carriers where implemented, which represent the German freight road sector. The features where taken from a representative survey by Bühler (*23*). These are *ost*, when the company is located in the eastern part of Germany, *employee*, number of employees, *clerkShare*, share of clerks in the company, *lkwKmLkw*, kilometre to accomplish an order by lorry, *trailer*, whether the loading unit is an trailer, *transpVolume*, transport volume of the origin-destination relation, *dangGood, perishGood fragGood*, whether the good is an dangerous, perish or fragile good, *stockLog*, wheter it is individually regulated that the stocking and logistics should be accomplished by the carrier, *tracking liability*, whether a possibility for tracking the transport is regualted, *priceVolume*, the price and the volume is regulated in the contract, *pairing*, whether it is a round trip, *partnerAtDest*, whether the carrier knows carriers at the destination, *numberOfTransports*, number of transport at the origin-destination relation, *timeForScheduling*, time between receipt of the order and the pickup at the shipper, *justInTime*, whether the transport is an just in time transport, *pulsing*, pulsing of combined transport at the (potentially) used origin destination relation, *directTransport*, whether the combined transport is accomplished directly, *durationKV*, the duration of the combined transport, *durationLkw*, the duration of the road transport, *costsKVPerKm*, costs of the combined transport per kilometre the specific order, *costsLkwPerKm*, costs of lorry per kilometre for the specific order, *delayKV*, average delay on the origin-destination relation by combined transport, *delayLkw*, average delay on the origin-destination relation by lorry, and ε, an error term.

The heart of the freight model is the discrete choice model (nested logit) of Bühler (*23*) where the decision how to carry out the order is made: solely by road transport (*kvLkw* <0) or combined transport (usually road-train-road) (*kvLkw* >0) (see Equation 8).

$$kvLkw = \begin{cases} -2.401 - 0.092\ ost + 0.0000298\ employee + 0.509\ clerkShare + 0.003 \\ lkwKmLkw - 1.412\ trailer + 0.049\ transpVolume - 0.133\ dangGood - \\ 0.091\ perishGood - 0.38\ fragGood + 0.371\ stockLog - 0.831\ tracking - \\ 0.193\ liability + 0.4\ priceVolume - 0.24\ pairing + 0.046\ partnerAtDest \\ + 0.001\ numberOfTransports + 0.005\ timeForScheduling + 0.002 \\ justInTime + 0.083\ pulsing + 0.675\ directTransport - 0.021\ durationKV \\ - 0.027\ durationLkw - 2.081\ costsKVPerKm + 1.473\ costsLkwPerKm + \\ 0.009\ delayKV - 0.038\ delayLkw + \varepsilon,\ for\ lkwKmLkw > 50 \\ -1,\ for\ lkwKmLkw \leq 50 \end{cases} \tag{8}$$

The *kvLkw* variable can be transformed the dummy variable *kvLkwD* (see Equation 9).

$$kvLkwD = \begin{cases} 0\ for\ kvLkw < 0 \quad (road) \\ \\ 1\ for\ kvLkw \geq 0 \quad (CT) \end{cases} \tag{9}$$

A change in the fuel price due to the increase of CO_2 certificate price influence the *costLkwPerKm* variable in the equation 8 above by the following correlation.

$$costLkwPerKm_{t,r} = costsLkwPerKmTAB_{t,r} + (fuelCombustion/100) \cdot (fuelPrice_t - 1.14) \tag{10}$$

This equation 10 consists mainly of the variable costsLkwPerKmTAB $_{t,r}$, which depicts a lorry maintenance cost factor per kilometre – including fuel prices – (about 0.75 Euro/Km, *23*). The subsequent summand include changes of the CO_2 certificate price.

But in the open system also the train transport is affected by rising CO_2 certificate prices. This is considered in the cost per km variable of the combined transport, costKVPerKm, accordingly (see equation 11).

$$costKVPerKm_{t,r} = costsKVPerKmTAB_{t,r} - 0.01 + (co2Price_t / 25) \cdot 0.01 \qquad (11)$$

As there are some more possibilities to reduce CO_2 emissions in road freight transport a further reduction possibility is sketched. This includes implicitly the renewal of lorries (efficiency increase) or an improvement of logistics. The simplified mechanism assumes that the fuel efficiency of lorries increase every year (see equation 12).

$$fuelCombustion_{n,t,l} = fuelCombustion_{n-1,l} \cdot (1/1.016)^{n+t/264} \qquad (12)$$

The mileage carried out by a carrier by road transport can be calculated according equation 13. It is assumed that the transport demand volume increases by 1.6 % per year (*34*) whatever fuel costs. Thus without the certificate trading scheme CO_2 emissions of freight transport would stagnate as the fuel efficiency of lorries decreases by 1.6 %.

$$mileage_{t,q} = [\sum_{l=1}^{L} lkwKmKV \cdot kvLkwD + lkwKmLkw \cdot (1-kvLkwD)] \cdot 1.016^{n+t/264} \qquad (13)$$

Finally, the daily CO_2 demand of all freight forwarders *co2DemandQ* can be calculated by multiplying their mileage ($mileage_{t,q}$) with their fuel efficiency per kilometer ($fuelCombustion_{l,n} / 100$) and by the corresponding emission factor of diesel $co2Factors_5$.

$$co2DemandQ_t = co2Factors_5 \cdot (fuelCombustion_{l,t,n} / 100) \cdot mileage_{t,q} \qquad (14)$$

Concluding, the java based meso economic model is empirically calibrated, uses empirical data (from *23* and GMP) and follows some characteristics of multi agent models as heterogeneous agents, learning and proactivity of agents.

RESULTS

The output can be described by the CO_2 demand resulting from the fuel demand of the households and carriers, the CO_2 supply (i.e. the number of certificates allocated to the transport sector), the exchanged CO_2 certificates and the corresponding CO_2 certificate price. This can be depicted for an open certificate market (see Figure 2) and a closed market (see Figure 3). It is most obvious that CO_2 prices are much higher in the closed trading scheme than in the open trading scheme.

FIGURE 2 Simulation results: reactions of households facing limited CO_2 certificates in periods 1 to 10 (open market).

In the open system the CO_2 certificate prices may raise to 40 Euros per t CO_2. When adding this amount to the actual fuel price a surplus of 0.08 Euro per liter are thinkable. This means an average surcharge of about 0.6 % p.a. for the next 10 years which is not much for German fuel prices and should not affect the households' driving habits as long as their current attitude persists. Thus the impact of the decisions of households is small if households do not change their preferences for small and efficient cars. It is possible to argue that the open certificate system only gets the transport sector to pay for its emissions and does not really contribute to reducing emissions here.

In the closed trading system the certificate is very likely to be much higher than in the open system, as the willingness to reduce CO_2 emissions in the transport sector is very high (much higher than in other sectors). The model displays certificate prices of more than 60 Euro per ton, which is not to unrealistic (*35*).

Looking at the impacts on households due to the closed certificate trading scheme it is noticeable that car owner on the country side are in average by 3 Euros more affected than households in metropolitan areas, which accept a surplus of about 20 Euros per month. However, freight transport is more affected. A surplus of about 20 Euros per trip needs to be paid. Since margins are low the impact on the road freight transport is much too high. This argues for an open trading scheme or a different political instrument.

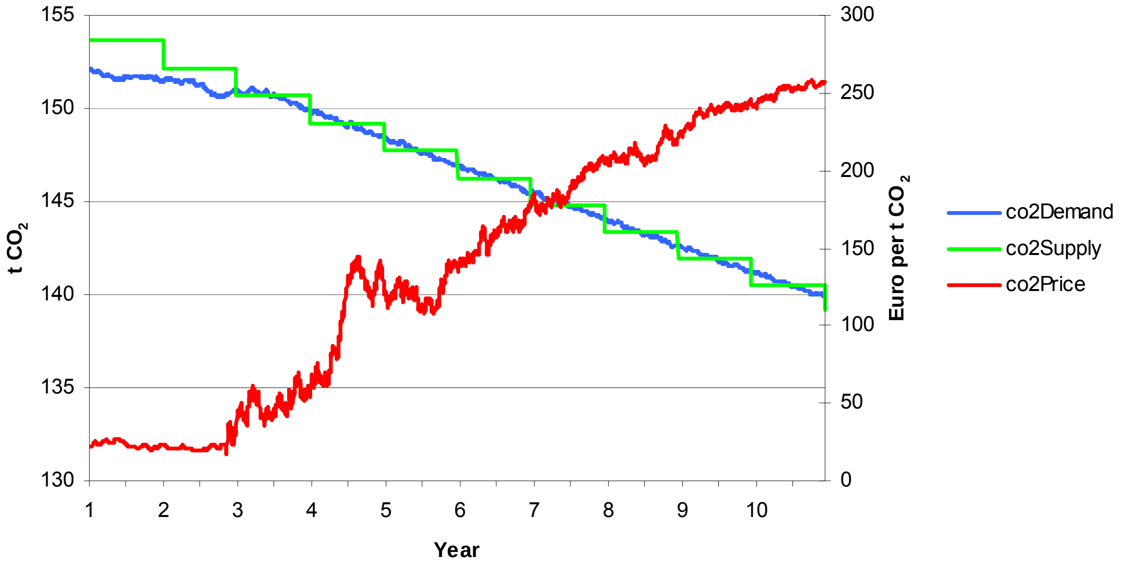

FIGURE 3 Simulation results: reactions of households facing limited CO_2 certificates in periods 1 to 10 (closed market).

CONCLUSIONS

Due to the dangers of global warming and the commitments undertaken in the Kyoto Protocol, policy instruments to reduce CO_2 emissions in the German transport sector are now unavoidable. This is especially urgent as the transport sector is the only one which has increased its CO_2 emissions over the last decade and now contributes almost a fifth of total German emissions. New instruments should be considered to combat transport emissions as existing instruments have so far failed to achieve the crucial reversal of the emission trend in this sector. This applies particularly to road transport. One such possible instrument is an emission trading scheme for the transport sector. As a result of the direct link between emissions and fuel consumption, emission trading does not have to be applied to the emission source – here vehicles – but can target any point in the energy flow chain of fuel (e.g. oil company, petrol station, etc.). As in those (up-stream) schemes only 100 agents are affected, its implementation is much easier.

An emission trading scheme fulfils the first three of the four criteria of system and aim conformance, efficiency and institutional controllability. A suggestion for a certificate trading scheme is illustrated in a behavioural based partial meso economic model for German transport which includes households, shippers, hauliers, carriers, carmakers and fuel companies. An upstream model charging fuel companies in an open system (trade with the existing ETS is allowed), with free allocation of certificates and an absolute reduction target is implemented in the model. For comparison a closed system is illustrated. The model (working with empirical data) was demonstrated and applied. The results confirmed firstly the expected CO_2 prices for a trading scheme at the level of 0.04 Euro per liter today which could rise in an open certificate trading scheme to 0.08 Euro per liter (as CO_2 certificate prices quintuple) and up to about 0.40 Euro per liter for a closed certificate trading scheme. The model shows that if the current attitudes of traffic participants persist, two outcomes occur for the different trading schemes. In the open scheme the mileage and fuel consumption will remain constant and the transport sector will act as a net payer in the emission trading – i.e. the reduction of other sectors will be paid for at the petrol pump. In the closed scheme only very high fuel costs reduce mileage by households and carriers. In summary, the impact in the open system on the business-as-usual scenario is rather small and further political instruments should be implemented in parallel to lead to a much higher reduction potential (*36*). If, however, transport demand would change and more fuel efficient cars are bought, a double dividend could be expected: Despite people would still travel from A to B, cars are then less expensive, cause cheaper operating costs and produce less CO_2 emissions. This ignores however the human want of social prestige, comfort issues etc.

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