Energy and Carbon Markets

Jong, Thijs

Energy and Carbon Markets
Empirical Law and Economics Studies

Thijs Jong

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by

Thijs Jong

Supervisor
Prof. O. Couwenberg

Co-supervisor
Dr. E. Woerdman

Assessment committee
Prof. C.J. Jepma
Prof. M. Mulder
Prof. D.P. van Soest

To my parents

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CHAPTER 1
Energy and carbon markets in transition

Energy and carbon markets are in transition. Whereas utilities used to have steady businesses, their opportunities and threats have undergone dramatic changes – not only in the last decades, but even from the start of this research project. These have been unleashed through regulatory changes (e.g., the liberalization of markets), technologies (e.g., breakthroughs in information technology, geology, and materials science), and their interactions through market behavior forces (e.g., finance and logistics). The available variety in the generation, transmission, and usage of energy have become unprecedented compared to mere decades ago. For example, ever more households produce (solar-powered) electricity themselves, electricity may soon be transmitted from Norway to the Middle-East and back (e.g., via the European Union (EU) Ten-Year Development Plans), and nuclear fusion may arrive within a decade (Economist, 2014).

These achievements are astonishing given the nature of the energy business itself. Demand is by the millisecond (although gas molecules move slower than electrons). And this demand needs to be met with an exact equal supply to prevent malfunctions or breakdowns, requiring both predictive capacities and available installations with varying lead times. Energy provision is considered essential (i.e., a basic necessity), and EU-wide 'public service obligations' guarantee energy for every household. It is delivered primarily through fixed networks, requiring tight coordination in terms of its transmission, construction, and maintenance. And because demand has been large and is still growing, sufficiently powerful fuel sources are required (i.e., mostly fossil-based). Given that these sources are not spread equally across the world, they are paid for dearly, and typically involve state-level politics. The prevailing approach to secure supply while saving costs has therefore been to increase the scale of production and transportation, to vertically integrate at least the coordination-prone industry links, and to have the host governments involved to obtain the (fuel) resources.

From the end-1980s, policymakers became convinced, through breakthroughs in technologies and theoretical insights, that markets can have a complementary role in the energy value chain (e.g., Talus, 2013). With integrated energy firms, this market orientation led governments to question the sector's openness to competition and the related pressure to innovate. Among others, tariff regulation has been imposed in preventing monopoly prices. Gas and electricity sectors have been gradually opened to competition, among others through 'unbundling', where firms or governments are either to own the energy to be transported or to control the grids, but not both (see e.g., Pollitt et al., 2007).[1] Several EU Member States decided to (partly) privatize the (non-grid) generation and retailing segments, and have the grid segment state-owned to guarantee public interests (e.g., the security of supply).

The resulting market processes allowed for multiple stakeholders and their interactions, where no single player controls the system. Even if interactions may be brought about by developments outside grid operators' scope of competences (e.g., other geographical markets), these operators (jointly) need to guarantee the safety for both security of supply and flexibility purposes. This has become complicated, for example, because trade is not only physical but also virtual, and because supply is increasingly provided through short-term (spot) contracts.

Besides the resulting complexity from these market processes, energy firms also need to reckon with resource depletion. One 'resource' is the carbon budget, or the maximum amount of carbon-equivalent emissions below which anthropogenic interferences with the climate system will be prevented. The majority of energy processes release such emissions. Because of the European Union's signing and ratifying of the 1997 Kyoto Protocol, it has introduced the EU Emissions Trading Scheme (EU ETS) in 2005, which has put a price on carbon since then. Other resources being depleted are the non-'renewables', such as nuclear and fossil fuels (e.g., gas, coal, oil). Regulations require and/or facilitate the production of renewables, such as wind, solar, and bio-based energy. This challenges energy systems management even further, because many renewable supplies are intermittent by nature and are thus less predictable.

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[1] Minimum requirements for distribution grids are less strict than for transmission grids.

2.1 Research question

Given the increasingly complex design and performance of energy and carbon markets, it is important that public interests (e.g., limiting market failures) are aligned with private ones (e.g., profit or output maximization). Specifically, it is in the interest of consumers, firms, and policymakers that supply of energy is guaranteed while its production, trade, and consumption occurs efficiently (e.g., at the lowest possible transaction costs), and that scarce resources are optimally used (e.g., that resource depletion matches its accumulation). It therefore makes sense to find out if regulation-market connections are economically rational, both separately and jointly, because spillovers may affect 'neighboring' regulatory regimes.

This Ph.D. research applies Law and Economics, a sub-discipline of both law and economics, which analyzes the economic causes and effects of laws and regulations. Hypotheses are derived from property rights theory and tested using econometric techniques. The overall research question is: Are property rights regarding EU carbon and energy markets valued, used and traded, and restricted in an economically efficient way? To that end, three EU-wide empirical studies have been conducted: 1) how shareholders value the EU ETS impact on firms, 2) how energy firms used and traded carbon allowances, and 3) whether the legal competences of National Regulatory Agencies (NRAs) are aligned to the public interests of the energy markets they supervise.

This Ph.D. research is part of a larger project granted by the Energy Delta Gas Research (EDGaR) consortium: 'Understanding Gas Sector Intra- and Inter-Market Interactions'.[2] Its objective is to explore such regulation-market connections, and find out how energy and carbon markets can be improved upon from an integrated perspective. Since the project partners apply diverse tools and assumptions, these research findings are complementary to their contributions in meeting the EDGaR project targets.

[2] The project partners are Delft University of Technology and Energy research Centre of the Netherlands (ECN). DNV GL is an associate partner with a role in providing advice and information.

2.2 Thesis outline

This thesis is organized as follows. Chapter 2 explains the economics of property rights and transaction costs, the applicability and limitations of this approach, and how the three empirical studies fit into this framework. Because the first two studies are based on the same data source of EU ETS transactions, the European Union Transaction Log (EUTL), Chapter 3 elaborates on data problems when applying the EUTL and comes with recommendations on how these can be mitigated. Chapters 4 to 6 contain the aforementioned three EU-wide empirical studies. The conclusion, policy and research recommendations are provided in the final Chapter 7.

CHAPTER 2
Property rights theory

The connecting theoretical thread between the studied cases in this research is ‘property rights theory’.[3] A crucial element of property rights is for them to internalize ‘externalities’. External effects (or: 'externalities') occur if actors, due to significant transaction costs, will not account for the benefits or damages of their property rights usage, which positively or negatively affect the property rights they do not own, respectively.[4,5] For example, the Intergovernmental Panel on Climate Change provides increasingly significant evidence that mankind emits greenhouse gases, and thereby cause the climate to change. By and large, these climate effects have adverse impacts on people’s property globally. If few private actors are involved with these climate effects, transaction costs are low for them to bargain and/or to contract who is allowed to pollute and who is excluded from polluting. Yet, with carbon emissions being a global pollutant, transaction costs are too high due to the many actors involved, rendering it difficult to establish the exclusivity of who is allowed to pollute.[6]

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[3] Foss (2010) extensively reviews the literature about the similarities and differences between property rights and transaction costs approaches. The evidence is inconclusive which one is superior from conceptual and empirical viewpoints. The choice for one approach or a combination thereof should ultimately depend on the research question posed. However, property rights theory is relatively strong in analyzing the multifaceted nature of property rights, their economic incentives, and the institutional barriers and opportunities for moving towards more efficient outcomes (e.g., Kim and Mahoney, 2005).

[4] Indeed, the Hohfeldian paradigm (Hohfeld, 1913) implies that “a legally enforceable right presumes a corresponding legally enforceable duty” (Cole and Grossman, 2002). Hence, the existence of property rights is secure if non-owners respect the property of the owners.

[5] Transaction costs are, for example, the costs of information, the search for contractual partners, the bargaining, the drawing up and upholding of contracts. This concept has been introduced by Coase’s classical paper on the Nature of the Firm (Coase, 1937).

[6] Given the Hohfeldian paradigm of footnote 4, for property rights it is necessary to being able to exclude others from its usage as input (e.g., resource) and as output (e.g., theft) (e.g., Hotte et al., 2013). As to sanctions and enforcement and their expectations function toward exclusivity, the legal base can rely on codified law but also on societal customs and mores (Demsetz, 1967).

As argued by Demsetz (1967), “when net gains from exclusivity are positive” (Müller and Tietzel, 2005), existing property rights can be adjusted for this exclusivity, for example, who will be restricted in pollution terms.[7] Also new exclusive property rights can be introduced. An application hereof is the European Commission’s launch of the European Union Emissions Trading Scheme (EU ETS) in January, 2005, which introduced EU Allowances (EUAs). These are tradable property rights, each representing one metric tonne of carbon-equivalent emissions. This new property right lowered the transaction costs on the carbon emissions attributes of property subject to the EU ETS.[8] The lower transaction costs enable these owners to bargain who will own the right to pollute and who will not (e.g., via exchanges or over-the-counter).[9] Because the total number of EUAs declines every year (i.e., the ‘cap’), the scarcity of these rights forces firms to weigh up whether or not to produce and to emit, and/or to invest in low-carbon production processes. According to the Coase theorem (Coase, 1960; Stigler, 1966), with negligible transaction costs the efficient allocation of legal entitlements will become observable which, if carried out through allowance trades, will imply that the *non*-owners of EU allowances will be most efficient at abating the carbon emissions.[10]

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[7] According to Calabresi and Melamed (1972), three ownership rule types affect the compensation of damage. With 1) the property rule, only those owning the right may cause harm, for example, to pollute. Only state intervention is required to decide upon and enforce the initial entitlement of rights, while subsequent bargaining realizes the final ownership allocation. With 2) the liability rule, damage may be allowed or prevented only in exchange for an objective compensation (i.e., through the judiciary). And with 3) the inalienability rule, other actor’s rights may not be tampered with, for example, human rights. With low (high) transaction costs, the property (liability) rule should lead to efficient outcomes – if the judiciary adheres to the efficiency principle.

[8] There are multiple selection criteria for property to be part of the EU ETS. The industry sector is one, for example, the New-Zealand ETS includes the transport sector while the EU ETS does not (it does include aviation). Another criterion is the installation size; the EU ETS imposes a total thermal input minimum of 20 MW (EC, 2009a: Annex I).

[9] Firms in aggregate would trade until the net value of reallocating the abatement of pollution is zero. Stavins (1995) shows that the deadweight losses from transaction costs make the initial allocation of rights relatively more important toward the efficient allocation of abatement.

[10] With the setting in Pigou (1932), such situation is also realized with an emissions tax equal to marginal damages. However, his framework implicitly assumes that polluters are exactly those which are most efficient at abating pollution. Coase

In essence, with the zero-transaction costs benchmark by Coase, for everything carrying a non-zero value the efficient allocation will be observable. Individuals will all measure, restrict, and bargain about any value flowing to and from their individual property. Coase's Nature of the Firm (Coase, 1937) implies that, through such bargaining, infinite hybrids of efficient collaborative relationships will dynamically evolve – which may be substantially different than the more rigid and typical entities as 'firms' and 'markets'. Moreover, these efficient allocations concern not only the attributes of property, but also the multiple rights attached to it (e.g., Merrill and Smith, 2011). Property consists of 'bundles of rights' which generally define what you can and cannot do with it. In general, they consist of: the right to transfer some or all of the rights to others (*transferability*), the right to use the assets (*usus*), the right to its returns (*usus fructus*), the right to change their form and substance (*usus abusus*), the right to exclude others (*excludability*), and the right to sell or lease some or all of these rights to others (*alienation*) (e.g., Müller and Tietzel, 2005).[11]

Moving toward a situation of positive transaction costs, impacts on property are less measurable, and restrictions on property cannot be perfectly determined or enforced. To prevent adverse externalities and encourage beneficial ones, governments should 1) establish the default set of property rights restrictions, and 2) given these property rights restrictions, secure the contractual restrictions which parties agree upon (e.g., MacKenzie and Ohndorf, 2013). In such setting, and given the imperfect measurability of the value flowing to and from the property's attributes, the proposition as advanced in Barzel (1997) is that those contracting parties which are best able "to affect the mean outcome [of the

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showed that this polluter-pays asymmetry excludes cases where 'pollutees' may be more efficient at limiting the damage. Coase emphasized that property effects are mutual, and that they are borne through the allocation of rights. By applying economics to law, he contributed toward the foundation of Law and Economics.

[11] For example, only under certain circumstances are operators in EU gas and electricity sectors allowed to exclude access to their transmission and distribution grids, restricting their 'right to exclude'. And since the EU ETS is not 'linked' to the U.S. Regional Greenhouse Gas Initiative (RGGI) scheme, for instance, the 'right to use' of the assets is restricted.

value flows] will tend to assume the associated variability [i.e. the known and unknown risks]" (Barzel, 1997).[12]

For example, in an energy supplier-customer relationship, the best measurable unit of energy is its transmitted quantity. It is not (yet) completely measurable which customer consumed the energy from which source, because electrons or gas molecules cannot be directed in a network with multiple connections (e.g., Kirchoff's law).[13] If energy firms have exact estimates of energy consumption at the district level but not at the household level, households are incentivized to consume more and thereby externalize these costs to the energy firm and/or the other district's households. One way in limiting such energy variability is the restriction that customers regularly need to convey their energy usage.[14] Also the timing of energy consumption can be variable and involve costs. Uniform household demand generally peaks during mornings and evenings, for example, when people are not at work. During non-uniform hours, peak demand (e.g., the afternoon) can be costly if expensive backup-capacity needs to deliver this energy. If the timing of consumption is not exactly measurable, contracts (and dual energy meters) can therefore charge peak and base-load tariffs to discourage the externalities arising from such non-uniform demand.[15]

Moreover, since the quantity of energy is a per time-unit product of the number of charged elements times their charge, energy generators are expected to benefit by varying these two elements (i.e., while meeting demand). The scope thereof is limited because systems need to be in balance: 1) across time where, at least for now, especially electricity is difficult to store, and 2) across space, where transmission and distribution

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[12] A caveat is that it depends on how risk averse the parties are. For example, parties are less risk averse with softer budget constraints (e.g., state-owned) and when input and output risks of their generating business offset one another (Meade and O'Connor, 2012).

[13] The timing of energy consumption will be measurable with 'smart meters'. The EU's aims that, "where roll-outs of smart meters is assessed positively, at least 80% of consumers shall be equipped with intelligent metering systems by 2020" (EC, 2009b).

[14] Energy firms' inspectors will then occasionally come by to validate this information.

[15] These sources of variability can be categorized under the technological element of energy. In essence, "each party prefers a contract that follows their own load profile [i.e., the supply-side, including outages and fuel risks] and demand swings" (Meade and O'Connor, 2012).

bandwidths are narrow because overheated lines or over-pressured pipes increase asset depreciation and raise safety concerns. This generally explains why consumer appliances or installations are restricted with standard energy quality settings. Large energy consumers such as aluminum manufacturers, however, may value energy quality differently. For meeting their continuity of supply, considered a quality by itself, they may install their own specialized energy transformers or facilities and, thereby, opt for different contractual restrictions.[16,17]

These examples show that valuations and restrictions mutually affect property rights. First, "the more valued transactions are, the more attributes are expected to be priced" (Barzel, 1997). Second, "the more valued transactions are, [...] the more comprehensive the restrictions [and the units of exchange] are expected to be" (ibid.).

1. Case I: Property valuation

The first study, Jong et al. (2014), provides an evaluation of carbon property attributes and restrictions. Its aim is to test whether theoretical expectations on the effects of property rights changes are actually to be found in share prices, because prices and property are intrinsically related:

> "*When* [private property] *rights are well defined and enforced, property is exchanged at prices reflecting its highest-valued use. Through these market prices people communicate clear, accurate, and constantly updated information to each other on the values they place on the resources they own and those owned by others*" (Lee, 2004).

We conducted our empirical analysis with respect to regulatory impacts on the value of the shares of energy and other carbon-intensive firms. The value of shares reflect the discounted future profitability of exchange-listed firms as expected by shareholders. Indeed, "property rights have an inherently forward-looking dimension [as to] how actors value their expected opportunity set of property rights" (Foss, 2010).

[16] Industry consumers can get discounts on their energy supply costs, for example, through backup-capacity for purposes of 'peak-shaving', 'valley-filling', or interruptible energy delivery (i.e., less than full continuity).
[17] Conversely, households and small enterprises are legally safeguarded against non-continuous supplies via Public Service Obligations (e.g., EC, 2009b).

This study's focus is on the April 2006 news that EU ETS industries had received too many environmental property rights, referred to as emission allowances. This 'over-allocation' effect is not only directly discounted in the price of CO_2 and other commodities, but also had an effect on the companies' market values. The study finds that firms with relatively high carbon-intensities and lower allowance holdings were 'punished' with lower share prices. EU ETS property rights are therefore valued as a restriction on pollution.

2. Case II: Property use and trade

One of the main property theory propositions on property use and trade originates from Coase's 'Nature of the firm' (Coase, 1937). Firms exist to lower transaction costs among their production factors, including workers and capital. The activity of these production factors is coordinated through (employment) contracts and management fiat, and the resulting output value is shared through, for example, profits, wages, bonuses, and company shares.

Yet, as mentioned above, valuations and restrictions mutually impact property. Productive capital or workers are more likely to be employed outside firm boundaries to prevent that their larger-than-average productivity gains are captured by the less productive counterparts. However, such (new) contractual setting raises transaction costs, since specific contractual agreements need to be made for the risks which were previously internalized in the firm. This trade-off is referred to as the 'make-or-buy decision', because transactions take place within firm boundaries (i.e., 'make') when transaction costs are lower vis-à-vis the market (i.e., 'buy').

The second empirical study, Jong and Zeitlberger (2017) parallels this firm-market interaction. Examined is whether firms behave self-sufficiently by first allocating production, emissions, and, hence, allowances within firm boundaries before opting for the carbon market. Contrary to our expectations, we find that self-sufficient firms conducted less allowance trade across their subsidiaries than on the carbon market. Pollution abatement capacity outside firm boundaries may therefore be less expensive and/or more cost-effectively coordinated through the market. The allowance trades of self-sufficient firms also point to carbon risk hedging, which allows them to reap further cost savings. Altogether, self-sufficient firms may therefore depend more on the EU ETS market than less self-sufficient firms.

3. Case III: Property restrictions

Finally, as postulated above, firms take restrictions of their property rights into account when contracting for the known and unknown risks (e.g., of their outputs). From the institutional economics literature the 'alignment hypothesis' comes forth, which states that the more transactions are frequent, uncertain, and involve sunk costs, the more these should be shifted away from market-based mechanisms toward those that involve vertical integration, long-term contracts, and/or public ownership (e.g., Williamson, 1979; Mulder, 2011).[18] In other words, ownership structures will change from private via common to public ownership.

The 'hold-up' problem is a key example on the necessity of such ownership changes (e.g., Klein et al., 1978). Parties can contract *ex-ante* that investments by one party will be reimbursed through cost-markups, for example, for fixed assets or labor specialization. Yet, *ex-post*, these investment returns or sunk costs can be creamed off by reneging on the contract.[19] Because if ownership in asset-specific investments is private and the counterparty's (unilateral) objective is to maximize profits, contracts may not prohibit the counterparty from behaving opportunistically in trying to capture the investment value.[20]

To overcome such issue, property can be shared and/or made less exclusive (i.e., by changing the ownership structure). Since objectives are then *multilaterally* determined, property usage will be optimized across

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[18] Künneke (2008), Couwenberg and Woerdman (2006), and Woerdman (2004) elaborate on this framework for the electricity, gas, and carbon markets, respectively.

[19] Through backward induction, it is not (game-theoretically) optimal to commit to such investments.

[20] The literature is extensive how commitments can be made credible to sustain investment incentives. For example, Miceli (2014) suggests to let 1) a property rule govern the transaction, 2) contracts avoid "the holdup-problem under ordinary circumstances" (Miceli, 2014), and 3) a liability rule to govern breaches of contract in case a contracting party reneges. In containing the hold-up problem, contracting parties can decide on commitment devices, such as 'bonding' (Davis, 2015) and 'hostages' (Williamson, 1983). There is an additional risk when contracting with government-affiliated entities, namely that governments can capture rents through property rights changes (e.g., Spiller, 2013).

the involved parties so that property investments and returns can be shared. This explains why pipelines and transmission lines are often realized through shared property settings such as joint-ventures (e.g., Garcia et al, 2014; Boffa and Panzar, 2012; Energy Charter Secretariat, 2014). The safeguarding of public interests is also a case where objectives are multilaterally determined, hence, where property is made less exclusive. For example, EU regulations require the energy sector to account for the public interests of energy security, competitiveness, and climate change (Haney and Pollitt, 2013).[21] However, accommodating qualitative and/or more public aspects will come at the cost of industry performance such as profits (e.g., Schmitz, 2000).[22] And, property rights which are less private bring in additional coordination costs since parties will become incentivized to capture the property value.[23]

In relation to this, the third empirical study, conducted by Jong and Woerdman (2016), focuses on an increasingly important element of EU Member States' energy regulations or property rights restrictions, namely the legal competences of National Regulatory Authorities (NRAs). These include the extent to which NRAs have the power to intervene in contractual freedoms such as price setting, sales and investment decisions. Specifically, the study examines whether legal competence differences in European gas and electricity sectors are significant, whether they are aligned to the corresponding countries' divergent levels of 1) security, 2) competitiveness, and 3) carbon-neutrality of energy supply. Although more secure, competitive, and carbon-neutral energy supply levels should reduce the need for regulatory intervention and thus legal competences, it appears that this does not hold for most policy objectives. This result is not

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[21] The EU ETS can be considered a privatization (i.e., into tradable rights) from a resource which had been publicly-owned before (Cole, 1999). These exclusive rights aim at preventing the 'Tragedy of the Commons' (e.g., Hardin, 1968), where the incentive is to deplete the fully-accessible resource before others prevent them from doing so through their 'rivalrous' consumption (i.e., my consumption decreases yours).

[22] Profits maximization is usually considered the prime objective if property rights were purely private.

[23] This trade-off is mentioned in Cole (2012). In fact, the first and third element correspond to 'non-exclusivity' and 'non-rivalry', respectively, from which four (classical) goods classifications can be set up: rival goods are labeled as 1) private (exclusive) and 2) common (non-exclusive), while non-rival goods are labeled as 3) club (exclusive) and 4) public (non-exclusive).

intuitive, because NRAs should be less ‘equipped’ with legal competences when energy supply criteria are (sufficiently) met. Furthermore, the intrusiveness of legal competences varies substantially among NRAs. Intrusive competences may be effective, but they are also costly to exercise. Rescaling the legal competences according to this trade-off may therefore result in a more cost-effective enforcement of property rights.

4. Property rights theory limitations

This subsection discusses several limitations on the property rights methodology. A first limitation relates to the targeting of efficiency rather than equity by the property rights framework. Despite that redistributions of property will not affect the efficient allocation (e.g., Stigler, 1966), there will be distributional and, hence, equity effects among those demanding the same resources.[24] For example, the Coase framework is more consequentialist than deontological (Roberts, 2014). Some transactions may then be deemed contrary to moral or societal norms, for example, when efficiency requires firms to violate human rights in order to improve productivity. Such distribution issues can be mitigated by changing the above mentioned ‘bundle of rights’, for example, by curbing the transferability or alienation of property rights (cf. footnote 7).

Second, when transaction costs are high and/or valuations on property attributes are low, there are always some attributes which will not be perfectly included, leaving some externalities unaccounted for. Parties may actually be incentivized to create and thereby redeem valuable externalities by increasing transaction costs. For example, this enables them to deplete funds or resources they should ordinarily be excluded

[24] Among the attempts with *positive* transaction costs to “replicate the outcomes of [zero transaction costs] hypothetical Coasean bargaining” (Parisi, 2008) is the ‘single owner test’ by Epstein (1993). The idea is that the legal arrangement should [...] “mimic the solution that would be chosen by the single owner of interfering resources” (ibid.). Yet, relying on such checks exposes the regulator to asymmetric information issues (i.e., the regulated may not truthfully reveal their property valuations) and/or to rent-seeking behavior. The resulting sub-optimal regulation may end up impacting transaction costs differently among property owners, again raising distributional concerns. For example, Lawson-Remer (2012) shows that countries may secure resource rights differently among indigenous inhabitants and foreign and elite investors. It typically results in adverse income consequences for the indigenous inhabitants.

from.[25] In addition, externalities that *have* been contracted for may not yield welfare-optimal allocations. For example, sub-optimal institutional designs might become locked-in as a result of path dependence (North, 1990). Lock-ins appear when sub-optimal rights or contracts prevail in the presence of a superior alternative. Increasing returns, learning effects, sunk costs, and switching costs, for instance posed by legal inertia, may all cause such lock-ins.[26] An example is the exclusive entry of GasTerra, the trade branch of former Dutch company Gasunie, to the Groningen gas field in the Netherlands, which was given to Gasunie in the form of a legal concession in the 1960s and to some extent still limits competition today.

Third, welfare sub-optimal allocations may also persist if property restrictions unintendedly introduce new (perhaps more costly) externalities. For example, since the gas and electricity's network structures are subsets of one larger energy network, restrictions could have upstream as well as downstream consequences (i.e., from the gas sector towards the electricity sector, *et vice versa*) (Meade and O'Connor, 2012). This may be the case if price regulations on grid segments differ between the gas and electricity sectors, as is the case for the Netherlands.[27] On the face of it, this is understandable as the two products are different. However, such differences may affect the gas-electricity chain, thereby contributing to the sub-optimal organization of firms with respect to ownership, fuel mix, security of supply, and sustainability.

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[25] For example, when drawing up contracts, lawyers may structure a financial product to be a (near) substitute of the income or risk transfer which would normally have involved (higher) regulatory costs (Fleischer, 2010). Through the transaction costs they increase (e.g., through vague and/or lengthy contracts), value can thus be captured between the explicit restrictions and the 'spirit' of the law.

While the typical objective for regulators is to limit transaction costs, another option at their disposal is to lower property valuations. For example, Allen (2002) names dehorning of rhino's as an example of mitigating hunting incentives.

[26] According to Hovenkamp (2011), with sunk costs the efficient allocation does not only depend on zero transaction costs. Even if transaction costs are zero and bargaining is costless, resources locked in investments cannot easily be redeployed to the allocation where these resources were more efficiently used.

[27] Examples are differences in the application and determinants of the benchmarks; that the level of tariffs can be location-dependent for the gas transmission system operator (TSO) but not for the electricity TSO; and that gas faces entry-exit tariffs for cross-border transport but not electricity, where congestion and thus scarcity determines costs.

Yet, any theoretical framework will be limited given the multidimensional aspect of property rights. Empirical analyses can facilitate less-than-multidimensional patterns (i.e., the error term captures the remaining dimensions), but data sources typically do not contain the realized transactions and contractual clauses because these are predominantly limited to the private sphere. This makes our second study, Jong and Zeitlberger (2017), relevant through a micro-economic analysis on the actual EU allowance transactions. Moreover, if empirical analyses focus on property rights restrictions, it may not necessarily imply that owners make complete use of their unrestricted rights (e.g., Voigt, 2013). For example, this holds for our third study, by Jong and Woerdman (2016). The legal competences of NRAs are analyzed here, rather than which competences have actually been applied.

Analyses on property rights can therefore only partially contribute to our understanding of inefficiencies in the regulatory system. This explains why case studies are applied in this Ph.D. research, and are empirical rather than theoretical.[28] Before discussing these cases, the next section elaborates on the data source of the first two case studies, the European Union Transaction Log (EUTL), namely what data problems will need to be tackled when applying this data source, and how researchers and policymakers can mitigate these issues.

[28] Case studies are also in line to what Coase advocated (Frischmann and Marciano, 2014), and he "critiqued the use of abstract models" (ibid.).

CHAPTER 3
Emissions Trading Registries and Data Problems[29]

1. Introduction

Registries are crucial for emissions trading. Any emissions trading scheme needs an emissions registry to record the allowance transactions and to check compliance of the regulated entities. But emissions trading registries are not problem-free. This chapter discusses the registry of the EU Emissions Trading Scheme (EU ETS). We focus on data problems that arise when monitoring transactions and checking compliance in this particular scheme. Particular attention is paid to the difficulty of linking data from this registry to other relevant data, such as firm ownership information. Some recommendations for improvement of the EU registry are also provided.

With the foundation of the EU ETS, all Member States had to set up their national emissions registries.[30] Regulated firms need to hold an account at these registries and to make sure that at the end of the annual compliance cycle (April 30th) their accounts contain the necessary number of allowances which are at least equal to the past calendar year's verified emissions – so that authorities can bring these allowances out of

[29] This section does not only draw on my first-hand experience with the EUTL. I am also indebted to my colleague-dataset researchers: Jurate Jaraitė, Andrius Kažukauskas, Aleksandar Zaklan, and Alexander Zeitlberger, and to stakeholders involved in the dataset project (in alphabetical order): Nicolas Berghmans, Raphael Calel, Denny Ellerman, Claudio Marcantonini, Vincent Martino, Damien Morris, Andrei Mungiu, Olivier Sartor, Raphael Trotignon, Ronald Velghe, and Stefano Verde. I am also grateful for the useful comments I received from presenting this research at the Dutch Energy Law Association membership meeting (26 October, 2015) and the FSR Climate 2015 Annual Conference (22-23 October, 2015).

[30] Not all Member States started on time with a registry. Among the countries which were part of the EU before the launch of the EU ETS, the first to have an operating registry was Denmark (Ellerman et al., 2007); the last was Poland in July, 2006 (Convery and Redmond, 2007).

circulation.[31,32] These allowance surrenders are subsequently subject to and constrained by the Kyoto Protocol, the international climate treaty to which the EU has committed itself.

The registry accounts are made available online at the EU Transaction Log (EUTL).[33] Information on these accounts can be downloaded in batches and, hence, empirically analysed. Next to the names and account codes (i.e., 'identifiers'), the EUTL provides the installations' annual number of allowances received (i.e., 'allocations'), their annual emissions (both 'surrendered' and 'verified', the latter of which is checked by independent verifiers), as well as the conducted intraday allowance transactions (the amounts settled, the timestamp, and the involved purchasing and selling parties' account identifiers). A 'simple' compilation from this data shows the *intraday* transactions at Member State level, and *annual* compliance figures at installation, industry sector, and Member State level.[34]

Whereas statistics at these levels may be insightful, a crucial yet unavailable level is that of the firm. Firms own and use these EUTL accounts and, as such, influence how the EU ETS is run. These accounts

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[31] Emissions not accounted for through allowances are financially penalized: € 40 Euro per tonne in Phase I (2005-2007), € 100 Euro per tonne in Phase II (2008-2012). As of 2013, the penalty increases annually with the Euro-wide rate of inflation. Next to paying the fine, the insufficient allowances still need to be surrendered the year after.

[32] From Convery and Redmond (2007): "The Emissions Trading Directive requires that installations participating in the trading scheme report their actual CO_2 emissions for the calendar year to their respective national authorities by March 31st of the following year. All emissions reports must be approved by an independent verifier. Installations are then given until April 30th to ensure that they have a sufficient quantity of allowances in their national registry accounts to cover their verified CO_2 emissions for the previous calendar year, which indicates their compliance with the EU ETS. The annual compliance cycle of the EU ETS closes with the publication of emissions data and surrendered allowance information on May 15th, together with the cancellation of surrendered allowances, which must occur by June 30th."

[33] The EUTL website is available at: http://ec.europa.eu/environment/ets/. The EUTL was previously named the 'Community Independent Transaction Log' (CITL). And as of 2012, some of the national registries' duties have been centralized at EU-level: the 'Union Registry'. National registries still have an important role, for example, for issuing emission permits, for supervising, and informing and advising on emissions trading.

[34] Compliance data is made available annually. Transactions data used to be online after 5 years, while nowadays it is 3 years (Regulation 389/2013).

can be, for example, owned by family-owned businesses, conglomerates, or government-affiliated agencies. Rather than the account level, it is likely that transaction decisions are made at the parent company level, or by entities holding controlling stakes. The data indeed shows many transactions taking place within rather than between co-owned entities (Jaraitė and Kažukauskas, 2014; Jong and Zeitlberger, 2017).

At its start, the EUTL did not provide details on account ownership. Prof. Denny Ellerman, at the time affiliated with the European University Institute (EUI), found and brought together researchers which immersed themselves in this challenge. Through their team efforts, they could cross-check EUTL account-to-firm linkages and realize a publicly available database: the 'Ownership Links and Enhanced EUTL Dataset' (Jaraitė et al., 2013b).[35] Those coordinated efforts were supported by the European Commission (DG Climate Action), and this dataset was provided by the EUI.[36] The societal aim of this end-result is to avoid further duplication of efforts by other researchers, and to enhance EU ETS *ex-post* research.

So far, documentation on how the EUTL works is limited.[37] A place to start is the EU Emissions Trading System section on the DG Climate Action website. Although it lacks a discussion on EUTL technicalities, this gap is partially filled through the European Environment Agency's EU ETS data viewer and manual. Further literature provides details, for example, Delbosc and Trotignon (2008) and Martino and Trotignon (2014), as well as our technical report (Jaraitė et al., 2013a) and YouTube video on the EUI's Ownership Links and Enhanced EUTL Dataset' website.[38] Additional information is available from emissions authorities and their websites, for example, the Netherlands Emissions Authority (NEa) section called 'CO_2 registry'.

Moreover, there are few specific evaluations on allowance registries. Lile et al. (1996) evaluates the EPA's SO_2 emission allowance tracking

[35] This database has already been taken up in several analyses: Jaraitė and Kažukauskas (2014), Betz and Schmidt (2015), Coria and Jaraitė (2015), Jong and Zeitlberger (2017), Naegele (2015), and the Enipedia database (available at: enipedia.tudelft.nl).
[36] The EUI dataset is not further maintained. Yet, with this accounts-to-firms list, identifying new accounts or account name changes is much easier.
[37] For example, EUTL website links to the Frequently Asked Questions and Help section are broken.
[38] The website is:
http://fsr.eui.eu/EnergyandClimate/Climate/EUTLTransactionData.aspx

system. McGuinness and Trotignon (2007) assess the EUTL, and their aim is aligned with this chapter's. They focus on three deficiencies, namely that: 1) power sector installations cannot be precisely separated from the EUTL industry category 'Combustion of fuels' category – a point which we confirmed in Verde et al. (2016), 2) EUTL allocations do not reflect New Entrant Reserve allowances or other allocation adjustments, and 3) the EUTL-specific industry categorization can attribute installations to industries different than those of their parent companies.

The setup of this chapter is as follows. Section 2 explains the online EUTL information and how it is exactly categorized. Section 3 discusses issues in determining EUTL account ownership by firms. Section 4 presents topics on interpreting EUTL transactions: Section 4.1 explains how they are recorded how they need to be regarded with derivative transactions; Section 4.2 illustrates that, due to the closure of EUTL accounts, different statistics can be obtained on the same time period; and finally, Section 4.3 demonstrates that applying daily transactions or annual installations data will matter when analysing compliance. Section 5 provides suggestions for improvements on the current EUTL structure. Section 6 concludes this chapter.

CHAPTER 3
Emissions Trading Registries and Data Problems

Table 1: Categorization of EUTL information

	EUTL compliance		EUTL transactions
	Allocations to Stationary (1) and Aircraft (2) Operators	**Accounts (1), Operator Holding Accounts (2), Compliance (3)**	**Transactions**
1		Year[2,3]	transactionDate
2	NationalAdministrator	NationalAdministrator(Code[2])	acquiringRegistry(Code)
	NationalAdministrator	NationalAdministrator(Code[2])	transferringRegistry(Code)
	NationalAdministrator	NationalAdministrator(Code[2])	originatingRegistry
3	ETSPhase	CommitmentPeriod[1]	applicable(original)PeriodCode
4	InstallationName[1]	InstallationNameOrAircraftOperatorCode[2,3]	
	InstallationID[1]	(Related[1])InstallationAircraftOperatorID[2,3]	
	AircraftOperatorCode[2]	InstallationNameOrAircraftOperatorCode[2,3]	
	OperatorID[2]	(Related[1])InstallationAircraftOperatorID[2,3]	
	PermitOrPlanID[1]	PermitOrPlanID[2,3] (Date[2])	
	MonitoringPlanID[2]	PermitOrPlanID[2,3] (Date[2])	
5	AccountHolderName	AccountHolderName[2,3]	acquiring(transferring)Holder
6	AccountStatus	AccountStatus	
		AccountOpeningDate[1,2]	
7		MainActivityTypeCode[2] (Lookup[2])	
8		AccountType[1,2](Code[2])(Lookup[2])	acquiring(transferring)AccountTypeCode(Lookup)
9			acquiring(transferring)AccountIdentifier

10			transactionID blockSize (supp)unitTypeCode (supp)transactionTypeCode(Lookup)
11	Allocation	ComplianceCode[2,3] Allowance(In[2])Allocation[2,3] Free(Reserve[2])Allocations[2] (TotalOf[3])AllowancesSurrendered[2,3] UnitsSurrendered[2] CumulativeSurrenderedUnits[2] (Total[3])VerifiedEmissions[2] CumulativeVerifiedEmissions[2]	
12	AddressCity	Name[1,2] Main(Secondary)AddressLine[1], Address[2] City[1,2] ZipCode[1,2] CountryCode[1,2](Lookup[2]) RelationshipType[1,2](Lookup[2]) CompanyRegistrationNo[1,2] EPRTRIdentification[2] Parent(Subsidiary[2])Company[2] Latitude[2], Longitude[2]	

2. How EUTL information is categorized

The reason for creating Table 1 is to show how the EUTL website and its data elements can be categorized. The upper row shows the two main EUTL 'data pillars': 1) compliance, namely on the greenhouse gas emitting installations, and 2) transactions from and to all accounts, including those not linked to installations.[39] The second row of Table 1 'folds out' these pillars into the main underlying EUTL website sections, for example, 'Allocations to Stationary Operators'.

Specifically, this table shows which of these EUTL sections share the exact same information contents. In a couple of categories all three sections do so. For example, row number 2 shows that in all EUTL sections and, hence, with all downloaded data the national registry's Member State is provided. In most cases, however, there is an empty cell which implies that this information is not provided. For example, in row number 11 the compliance-related EUTL sections contain information on allocations. Given the empty cell in 'Transactions', allocation information is not provided when downloading transactions data.

The shaded rows in Table 1 show which sections overlap between the compliance and transactions pillars. However, the shaded rows 1-3 and 8 are not specific enough to bring about unique links between the two pillars (more details are provided in this section below). Most specific is 'AccountHolderName' from row 5. Given its pivotal status, much of Section 3 discusses issues with this identifier in determining EUTL account by firms.

To further elaborate on Table 1, the variables are superscripted with (1), (2), or (3). These numbers coincide with the EUTL sections (i.e., those mentioned in the column's second row). And, if the variable contains some text in brackets, it implies that both the variable with and without this bracketed text can be found. For example, with NationalAdministrator(Code) the EUTL section provides both NationalAdministrator (e.g., the Netherlands) and the

[39] This overview is applicable to the EUTL as in mid-June, 2015. Left out from EUTL section 'Allocations to Stationary (1) and Aircraft (2) Operators': 'International Credit Entitlements', 'LatestUpdate' (i.e., when the record is updated) and 'Status' (i.e., if the permit is active or revoked). Left out from EUTL section 'Operator Holding Accounts': 'CallSign' (i.e., the Aircraft Registration code).

relatedNationalAdministratorCode (e.g., NL). To provide some row-specific information:

- Information contained in row 1 relates to time: through Year (i.e., annual) and transactionDate (i.e., daily);

- Row 2 refers to the Member State of the installation. For example, OriginatingRegistry indicates where the allowances have originated. Also countries outside the EU ETS can be mentioned here (e.g., for the Clean Development Mechanism (CDM));

- Row 3 refers to the EU ETS Phase. It is possible that the applicable period differs from the original one (e.g., banked Phase II allowances can be used in Phase III and later);

- Row 4 refers to the installation or aircraft identifiers. These identifiers are Member State-specific;

- Row 5 provides what names the owners assigned to their accounts. These are called 'AccountHolders', and will be further discussed below;

- AccountStatus in row 6 classifies whether accounts are open or closed;

- With row 7, 'MainActivityTypeCode' refers to the installation's EUTL industry category (e.g., 'Combustion of fuels', 'Refining of mineral oil'). As mentioned above, McGuinness and Trotignon (2007) shows that this EUTL industry categorization does not allow unique identification of the power sector installations (i.e., from the 'Combustion of fuels' EUTL industry category);

- AccountType in row 8 refers to the EUTL account type – of which there are several. For every installation there should be an 'Operator Holding Account' (OHA: registries assign these with number 120). OHAs are the 'main' accounts which operators use for compliance purposes. As provided on the Netherlands Emissions Authority (NEa) website 'Account types' section:[40]

> "*Every Dutch company that has to participate in the EU ETS must have an OHA in the CO_2 registry. This is the account into which NEa will transfer the allocated emission allowances and from which the company must surrender sufficient allowances. Furthermore, the OHA can be used for doing transactions with emission allowances from and to other accounts.*"

[40] Available on: http://www.emissionsauthority.nl/english/eu-registry/accounts

OHAs can be used for allowance trading, as mentioned in the above quote, but the EU ETS also introduced private *non*-installation accounts or 'Person Holding Accounts' (PHAs: registry code 121):[41]

> "*A Person Holding Account (PHA) can be opened by organisations that want to trade emission allowances, [and by] operators and aircraft operators which are obligated to participate in the EU ETS. A PHA can only be used to trade or to voluntary cancel allowances. A company cannot use this account to surrender allowances.*"[42]

Not only EU ETS regulated firms made use of these accounts (e.g., to trade with these accounts). The PHA-group also consists of entities which acquired permits to trade allowances (e.g., brokers and banks). Finally, the remaining accounts are government-affiliated, the main category of which is called 'Holding Accounts' (registry code: 100). Through government-affiliated accounts, allowances are issued, allocated (e.g., free allocations, auctions and/or installations openings or closures through the New Entrants Reserve), cancelled and/or retired (for the emissions) (main registry codes: 230 and 300).

- Per EU Member State there are many OHAs and PHAs. For unique identification within national registries, an extra AccountIdentifier is therefore introduced, as shown in Table 1 row 9;

- Row 10 contains transaction-specific information. It includes the unique (country-specific) transaction identifier (i.e., transactionID), the exchanged number of allowances (blockSize), and the transaction's type

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[41] I do not further discuss 1) Aircraft Operator Holding Accounts, which are similar to OHAs, but specifically for aircraft operators, 2) Trading accounts, which are similar to PHAs but facilitate quicker transfers of allowances, and 3) Kyoto accounts, which are similar to PHAs but configured specifically for Kyoto allowances, such as Assigned Amounts Units (AAU) which countries need to meet their Kyoto targets, Certified Emission Reductions (CERs) from the Clean Development Mechanism (CDM), and Emission Reduction Units (ERUs) from the Joint Development (JI) mechanism).

[42] As mentioned above (footnote 33) as of 2012, accounts moved from national registries to the Union Registry. Since not all allowances could be automatically moved over to the Union Registry (essentially the CERs and ERUs), accountholders got a 'duplication' of their accounts. This explains the labels of 'Former' Operator Holding Accounts and 'Person Account in National Registry'. While these accounts may create some confusion, the intention is to prevent that allowances got lost when old accounts were cancelled.

(e.g., an allowance issuance, whether the transaction is within or between registries, an allowance cancellation);

- Row 11 is related to compliance. ComplianceCode categorizes whether: the total of surrendered allowances is more (code: A) or less (code: B) than the verified emissions, whether reports on verified emissions were *not* entered until April 30th (code: C), whether verified emissions were corrected by the competent authority after April 30th and decided to be (code: E) or not to be (code: D) in compliance, and whether accountholders could not enter their verified emissions and/or surrender allowances until April 30th (code: X). Moreover, note that there are two ways to check the compliance of firms. The first is via Table 1 row 11, namely via the verified emissions and the allocated and surrendered allowances. The other is to select the transactions transferred between the OHAs and the national registries' accounts. If such allowances are received by OHAs (national registries) they can be characterized as allowance allocations (surrenders) (more in Section 4.2 and 4.3 below);

- Row 12 includes CompanyRegistrationNo, the national company register code.[43] This information is important for linking the transactions and compliance-related EUTL pillars, as will be explained next.

3. Issues in determining EUTL account ownership by firms

As mentioned above, the pivotal identifier in linking compliance with transactions is the 'AccountHolderName' from row 5. When looking into the EUTL data, a quick glance over the accountholder names will reveal that several are affiliated to the same company, for example, as with 'RWE Power Aktiengesellschaft' and 'RWE Energiedienstleistungen GmbH'.[44] But in many cases the accountholder names do not point toward an affiliation, apparently since EU ETS users are given leeway in naming their EUTL accounts and their installations. Next to the company names, accountholder names may also include those of cities, simple digits, abbreviations, or even simply 'CHP plant'. Clearly, this complicates assigning firm ownership to the EUTL accounts. For example, the

[43] In row 12, E-PRTR stands for the 'European Pollutant Release and Transfer Register' which, for each industrial facility, provides information on air, water, and land pollutants. As with Parent(Subsidiary)Company, this information is not fully one-on-one available through the EUTL.

[44] And, apparently many transactions are conducted among them.

accountholder 'Lazzerini' is affiliated to many Operator Holding Accounts (OHAs) named 'Dalkia France'.[45] 'Lazzerini' is one of many EUTL accounts where the name refers to the (likely) employee's surname controlling it. Google searches often reveal such people's names and their (emissions trading) professions (e.g., on LinkedIn profiles). However, there are several OHAs which had 'untraceable' accountholder names. Some were later renamed to their operators'. For example, OHAs of the former accountholder name 'Harish Mistry' were later renamed to 'District Energy Limited' and 'EDF Energy (West Burton Power) Limited'.

By tracing firm ownership, issues relating to accountholder and operator name differences can be overcome. For example, with 50-50% joint ventures, 50% of the installation's or account's activity can be allocated to either party (e.g., the Dutch 'Nederlandse Aardolie Maatschappij' joint venture of ExxonMobil with Shell). Drawing boundaries along firm ownership may then be a better solution than considering it to be a separate entity.

Firm ownership information can also facilitate linking multiple (different) accountholder names with multiple OHAs. Firm-level analyses will also be possible on the affiliated installations (e.g., on allocations and emissions), at higher levels of controlling shareholders, and on transactions since also PHAs can be easily included in the firm ownership structures. In Jaraitė et al. (2013a) we show that many firms control multiple PHAs.

However, adding ownership to the equation introduces several difficulties. First is the identification of ownership in itself. On the one hand, the operator names can be obtained by looking up the AccountHolderName from the Accounts section (i.e., Table 1 column 2) and CompanyRegistrationNo, the national company register code. Although the latter category was not available when the EUI team and I were identifying the EUTL accounts operators, these national company registration codes are not available for all accounts: the majority of codes are not provided (e.g., due to administrative law reasons) or cannot be found in the Bureau van Dijk (BvD) company database 'Amadeus' or

[45] These OHAs can be found when looking up this accountholder in the EUTL transactions search option 'AcquiringAccountHolder' or 'transferringHolder'(cf. Table 1).

'Orbis'.[46] Moreover, firm ownership details are provided at the European Commission DG Climate website (e.g., the MS Excel files in the Documentation section).[47,48] Yet, these details are only provided for a few EU Member States, and on EU ETS installations (i.e., OHAs) but not for the Person Holding Accounts (PHAs). PHAs are frequently used for conducting transactions, for example, by energy firms and the financial industry.

Hence, and especially given the above mentioned time-inconsistent and/or incomplete ownership details and ambiguous accountholder names, automation of ownership identification is effectively hindered.[49] Inserting a text in the Orbis search function provides multiple results which resemble the requested phrase; company names may be registered in Orbis through different accentuations, abbreviations, or parts of the company names are missing or wrongly spelled.[50] It was more the exception than the rule that EUTL company names exactly matched those from Orbis. Hence, a sizeable share of accounts needed to be manually looked up to codify these with their unique Orbis-identifiers (i.e., BvD

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[46] A plain lookup of these national IDs through the Orbis national ID lookup function results in only 227 Global Ultimate Owners (i.e., these are the parent companies: more in Section 3) over all EU ETS accounts as available in mid-June, 2015. In contrast, with the EUI team we found around 3,646 Global Ultimate Owners.

[47] These online available Excel sheets relate to the National Allocation Plans (NAPs). For EU ETS Phase I (2005-2007) and II (2008-2012), EU Member States had to provide these plans for approval to the European Commission. These plans contained the allocation methodology including the installations selection criteria, the subsequent list of regulated installations, and the allocations they were supposed to receive during the concerned EU ETS Phase. As of Phase III, there are no NAPs anymore since allocations are determined at the EU level (and through EU-wide benchmarks).

[48] Instead of these Excel files, installation-level data may better be downloaded from the online registry (from 'Operator Holding Accounts' > 'Details All – All periods' > 'Export'). This data is directly obtained from the online registry so it is more recent and, through identifiers, better linked with the remaining registry data.

[49] Helpful, although soon withheld for privacy purposes, was that the EUTL used to provide the e-mail addresses of the persons responsible for the accounts. Most had the company name in their e-mail address, for example, @rwe.com.

[50] Online search engines were also consulted. For example, (as a non-Germany resident) I would not have known that HEW could stand for Hamburgische Elektrizitätswerke.

codes).[51] Especially for the non-automated work, the cross-checking of the researchers' account-to-firm linkages contributed toward identifying the links and completing the unidentified ones.[52,53]

A second reason why including ownership introduces difficulties is that ownership depends on how it is exactly defined. Ownership does not necessarily imply control, since these two aspects can be separated.[54] The EUI dataset applies ownership as provided in Orbis.[55] Orbis accounts for both direct and indirect ownership (e.g., via 50%+1 shareholding-cascades) but does not distinguish control from ownership. In our application of the ownership data, operators' control is therefore implicit in ownership. For example, we assume that the French Engie (formerly GDF SUEZ) not only owns but also controls Electrabel (Belgian) and International Power Limited (UK).

[51] A possible quicker route would have been to request from BvD all firm names and identifiers, and to use a lookup function (e.g., in MS Excel). Yet, this approach is unfeasible with Orbis 60 million registered 'firms' in the EU28 and its limit of 100,000 per download, as well as Excel's row limit of about 1 million. Moreover, Excel's lookup function is not useful as it requires perfect matches, and other approaches I found online were not user-friendly or useful either.

[52] The resulting 'Ownership Links and Enhanced EUTL Dataset' includes all available OHAs until spring 2013, excluding the aircraft OHAs: we identified 13,217 out of 13,512 OHAs. The dataset further includes all PHAs which conducted at least one transaction between 2005 and December, 2007: we identified 679 out of 725 PHAs. Among the unidentified accounts, several were not registered in Orbis (i.e., company-related information was lacking). For example, this applies for universities, hospitals, district heating, or private individuals. And the reasoning behind the Phase I emphasis (i.e., on PHAs) is that, when working on the EUI data project, EUTL transactions data were publicly available 5 years after the closing of calendar years (currently after 3 years). The identifying, cross-checking, and finalizing of the dataset were the further time-consuming elements.

[53] It further appears some installations' accounts prevail in the transactions data but not in the NAPs, or the other way around. One reason is that NAPs registered installations and their allocations *ex-ante*, while the EUTL website subsection 'Allocation / Compliance' provides *ex-post* data. For example, installations may be shut down or may have received opt-outs from the EU ETS (e.g., the Dutch greenhouse sector). And especially at the start of the EU ETS, discussions were looming on the regulatory definition of an 'installation', thereby determining whether installations opted into the EU ETS or not.

[54] The Economist Special report on 'Family companies' (April 18th, 2015), for instance, shows that statistics on family-owned businesses can differ given ownership and control assumptions.

[55] More ownership details are provided in the Bureau van Dijk's (BvD) Orbis help section.

Third, accountholder names may change.[56] This is what happened with the above mentioned case of the 'Harish Mistry' accountholder which controlled several OHAs. Later on, new separate accountholder names were introduced for these OHAs which matched their operator names. The trickiness with such accountholder name changes is that these also have retroactive impacts on the data, while the EUTL does not exactly specify what changes are introduced when EUTL updates take place. For instance, Orbis specifies that not all OHAs affiliated to the 'Lazzerini' accountholder name were owned by the same 'predominant' owner (i.e., Dalkia France).[57] With such cases, I decided to let the accountholder labels overrule the operator ownership indications. For example, I let 'Lazzerini' be 'owned' by Dalkia France including the OHAs which, according to Orbis, are not affiliated to Dalkia France.[58] And, it cannot be deduced whether accountholders which control multiple accounts, use one account to conduct transactions for another account. Such linkages may get broken if a 'strict' ownership pattern is followed.

A fourth issue in determining account ownership is that ownership itself may change over time. This affects the identification of EUTL account-to-operator links in two aspects. The first aspect is that the EUTL-provided operator names may change retroactively. For example, Gaz de France (GDF) and SUEZ merged in 2008. Yet, the majority of OHAs indicate GDF SUEZ rather than either GDF or SUEZ.[59] As a result, it becomes impossible to find out whether allowance transactions before 2008 are actually conducted by GDF or by SUEZ. So by updating account names which are linked to historical transactions, the EUTL thwarts the correct indication of ownership.

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[56] Less prone to EUTL changes is 'AccountIdentifier', the unique identifier for each nationally registered EUTL account (cf. Table 1). These codes may thus facilitate identifying accountholder name changes.

[57] Other tricky cases are where accounts are owned by one conglomerate while only one or a few are owned by foundations – although these foundation-owned accounts share the conglomerate's name.

[58] The reason is that it is unlikely that 'independently' owned operators (e.g., Dalkia and non-Dalkia) pool from the same accountholder (e.g., 'Lazzerini'). CEC (2008) argues that, at least over EU ETS Phase I, allowance pooling has hardly been used by operators. "This may relate to the need of having a legal entity to take responsibility for all pooled emissions" (CEC, 2008).

[59] Four of its OHAs have only GDF in its name.

A second aspect on ownership changes affecting EUTL account-to-operator links is that, if empirical analyses *also* include the parent companies and/or the firm networks of operators, information on such *past* ownership is also required. Since EUTL data is historical by definition (i.e., it can only be acquired ex-post), past parent companies need to be looked up, for example, due to possible mergers and acquisitions. The Orbis parent company type we selected for the 'Ownership Links and Enhanced EUTL Dataset' (Jaraitė et al., 2013b) is called the 'Global Ultimate Owner' (GUO). These controlling units are the operators owning the 'ultimate' 50%+1 of shares.[60] However, Orbis only provides the GUO which currently owns an operator, not the past ones. Besides providing the account-to-firm linkages and the 'current' GUOs, the joint dataset's other innovation lies in how we constructed such 'past' GUOs.[61,62] Our Technical Note provides more details on how we looked up the historical owners of these operators (Jaraitė et al., 2013a).[63]

In general, the GUO or ultimate owner can be found by finding the 50%+1 owner of the 50%+1 owner, until no further 50%+1 owner can be found. Orbis does provide the *past* shareholders which control 'the first' 50%+1 shares but not the 'ultimate' 50%+1 shares. We therefore created *past* GUOs from *past* shareholders ourselves.[64,65] Moreover, by mapping shareholder hierarchies ourselves, a good circumstance is that we could check when we reached shareholder levels of individuals, families, or of public organizations such as governments.[66] The database information of

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[60] In Orbis' records there is, by definition, always just one GUO controlling 50%+1 of the controlling owner, via both direct and indirect ownership. If no GUO is mentioned, the firm in question is the GUO – implying that it owns 50%+1 of its shares.
[61] The 'current' ones refer to the firms' GUOs acquired from the Orbis database in spring 2013 (i.e., when the dataset was constructed).
[62] This approach may be promising for future research to allow for dynamic rather than static ownership analyses.
[63] Another limitation is that Orbis only provides past shareholder information at a monthly basis. With the EUI team, we traced the GUOs based on the month being in the middle of EU ETS Phase I (2005-2007), namely December, 2006.
[64] We encountered shareholder hierarchy-layers which reached in the tens before ending up at the ultimate owner. Moreover, for 6,197 and 5,384 OHA accounts, current and past GUOs were found, respectively. For 4,907 OHAs we found both current and historical GUOs, whereas for 3,111 OHAs no GUO-change took place.
[65] We fine-tuned this algorithm by first creating the *current* GUOs from the *current* shareholders.
[66] We called this penultimate layer the top-1 ownership level.

these entities is generally limited. For example, the GUO of Volkswagen AG is the Porsche/Piech family for which clearly no company information is available. Another benefit, of using the shareholder level just below the GUO, is that this may prevent that characteristics of state-owned entities will be conflated with other owned assets subject to the EU ETS. For example, assets of EDF, Dong Energy, or Vattenfall are then mixed with the remaining ownership of the French, Danish, and Swedish governments, respectively. In such occasions, the penultimate owner as the controlling unit will better represent the entities' compliance and transactions.

4. Interpreting EUTL transactions

When downloading and/or analysing the transactions, it becomes clear they consist of multiple blocks. For example, transaction number AT3683 shows there are two allowance blocks: 21,278 and 3,722.[67] The sum or the total transacted amount, however, is exactly 25,000. Indeed, allowances can be split up into any tradable amounts, clearly a feature making them tradable. This aspect is made clear with the following text from a report prepared for the City of London Corporation:[68]

> *"Each tonne of CO_2 equivalent in a unit is represented by a unique serial number, giving information about the country of issue, the type of unit, year of issue, project information (if a CER/ERU) and a number representing which actual tonne of CO_2e it represents. So, for example, if CERs are created representing a saving of 100,000 tonnes of CO_2e, are issued, the 100,000 tonnes are represented by a single entry in the register of a block having a start block value of 1 and an end block value of 100,000. If 50,000 units are then transferred, the block is broken into two new blocks, one having a start block value of 1 and an end block value of 50,000, the second having a start block value of 50,001 and an end block value of 100,000. These blocks can further be broken down by subsequent transfers, but blocks can never be increased in size by subsequent amalgamations. Over time, the blocks get*

[67] This transaction can be found via the EUTL 'Transaction ID' search option, and then 'Details All'.

[68] CO_2e stands for CO_2-equivalent. Given equal volumes, methane, perfluorocarbons or nitrous oxide have larger impacts on the greenhouse effect than CO_2 (i.e., the benchmark).

smaller and smaller. In order to make a large transfer, several transactions may need to occur to meet the value of the transfer". (Bourse Consult, 2010, p. 35)

Since 2012, the EUTL does not show the start and end-block values anymore (primarily due to privacy concerns) but the difference between these values, which thereby constitutes the number of allowances exchanged. Yet, the pattern of ever smaller exchanged allowance blocks is clearly observable when more recent EU ETS transactions are considered. This also implies that, when downloading the transactions, the files become ever larger and smaller time periods need to be selected given the EUTL download limit on the number of observations.[69]

Quite a few transactions show that accountholders acquire from or transfer allowances to accounts with exactly the same name. Among government-held accounts (i.e., all accounts not coded 120 or 121) such transactions are often categorized as allowance issuances, whereupon national administrators allocate allowances to EU ETS installations. And among private accounts, such transactions may take place to move allowances from one national registry to another, for example, if exchanges require allowances to be nationally registered before they can be transferred. From a total perspective, however, there is thus no real exchange. This is why we left out such identical-counterparty transactions from our analyses (e.g., Jong et al., 2014; Jong and Zeitlberger, 2017).

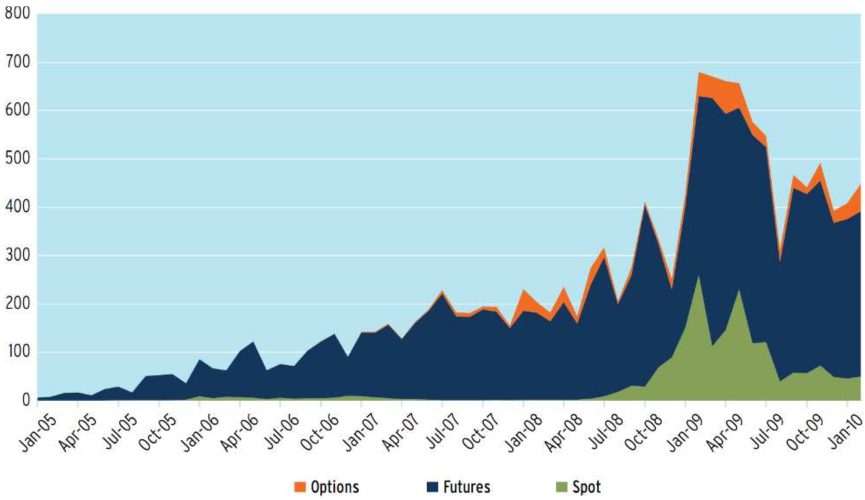
4.1 No derivatives but spot trades[70]

Transactions from the EUTL are the settlements as recorded in the EU ETS allowance registries. A limitation is that the EUTL only provides the names of the purchasing and selling parties, the amounts settled, and the time-stamp of the settlement, but not the underlying price and the nature of the contract. This makes it almost impossible to distinguish spot transactions from Over-the-Counter (OTC) or exchange-based derivatives

[69] For example, XML-files containing all EUTL transactions from 2005 to the most recent available data (i.e., until April 30th, 2012) require 4.2 GB of hard disk space.
[70] This subsection cites Jong and Zeitlberger (2017: footnote 22), but which excludes Figure 2.

which initiated, intermediated, and finalized the EUTL settlements.[71,72] From a research point of view this is regrettable. Figure 2 shows that during Phase I (2005-2007) allowance derivatives, the middle line, made up the largest share of trades in the EU ETS.

Figure 2: Monthly volumes (in millions) per contract modality: options, spot, and futures



Source: Kossoy and Ambrosi (2010)

Forwards and futures allow firms to flexibly upgrade or downgrade the exposure they consider optimal. For example, exposure can be lowered by adjusting it with the corresponding derivative positions (e.g., going long while maintaining an overall short position) whereby exchanges of allowance ownership can be cancelled. EUTL transactions are allowance ownership exchanges, which must have been beneficial to both transacting parties. With Chapter 5, or Jong and Zeitlberger (2017), we therefore consider EUTL transactions to be spot trades – although they may well

[71] An indication on the delivery of futures can be obtained by identifying the trade activity of EUTL exchange clearing accounts (Martino and Trotignon, 2013), but since most Phase I trade took place OTC, this identification would capture a small share of futures trades).
[72] NASDAQ OMX (which took over Nord Pool) and EEX derivative deliveries are 1) at the last exchange days of November, and in mid-December, and 2) at the last Mondays of March, June, September and December.

originate from derivatives.[73] However, without the initiated and intermediated transactions, the 'unobserved' observations (i.e., the latent demand) cannot be estimated. The observed transactions are thus where the net benefits are positive for both purchasers and sellers to exchange ownership.[74] As inferences on the firms' decision to trade are difficult to make, Jong and Zeitlberger (2017) is limited in using the volume and sign of the observed transactions only.

4.2 Closure of EUTL accounts

In the EUTL 'Accounts' section it is shown whether accounts are closed or not. It is understandable that accounts get closed (and opened) given the EU ETS scope across EU Member States and, hence, the many involved firms and their accounts.[75] Yet, due to (retroactive) EUTL updates not all historically closed accounts are provided, and so not all past transactions are shown. Before showing what impacts this can have on the data, this subsection explains how the EUTL transactions are selected.

Transactions from two different download-vintages are compared. The first is downloaded on September 24th, 2013, and are labelled as 'Old transactions'.[76] The second is downloaded on May 27th, 2015, and are labelled as 'New transactions'. The transactions are considered on the same time period, namely the start of the EU ETS or January 1st, 2005, until April 30th, 2008. Specifically, it is checked whether transactions with the same TransactionIDs appear in the other dataset (i.e., these are unique transaction-specific identifiers, cf. Table 1).

73 Parties take on derivatives to cover for their expectations on future prices, but it is then still unknown with respect to which day in the past a company had this price expectation (relative to the then prevailing spot price).
74 Hence, if the net benefits were negative for either of the two, the contract would have been cancelled.
75 Also non-EU countries joined the EU ETS: Iceland, Liechtenstein, and Norway.
76 These transactions are applied in Jong and Zeitlberger (2017).

Table 2: Categorization of national registry transactions

#	(code)transactionType	(code)suppTransactionType	Category
1	(1) Issuance - Initial creation of a unit	(0) no supp	Intra-registry
2	(3) External - External transfer of unit between registries	(0) no supp	[accountType]
3	(3) External - External transfer of unit between registries	(21) External transfer (2005-2007)	[accountType]
4	(4) Cancellation - Internal transfer of unit	(3) Retirement (2005-2007)	Intra-registry
5	(10) Internal - Internal transfer of unit/supplementary program transaction	(0) no supp	[accountType]
6	(10) Internal - Internal transfer of unit/supplementary program transaction	(1) Allowance cancellation (2005-2007)	[accountType]
7	(10) Internal - Internal transfer of unit/supplementary program transaction	(2) Allowance surrender	Surrenders
8	(10) Internal - Internal transfer of unit/supplementary program transaction	(52) Allowance issue (2008-2012) onwards	Intra-registry
9	(10) Internal - Internal transfer of unit/supplementary program transaction	(53) Allowance allocation	Allocations
10	(10) Internal - Internal transfer of unit/supplementary program transaction	(55) Correction to allowances	Intra-registry
11	(10) Internal - Internal transfer of unit/supplementary program transaction	(93) Correction	[accountType]

In order to compare the two download-vintages, it is useful to understand the two 'main' ways that transactions are categorized. First is via the main and supplementary (i.e., 'supp') transactionTypes (for transactionTypes see Section 2). The second and third columns of Table 2 provide these along with their EUTL codes (i.e., between brackets) and which prevail on the selected time period. Based on these transactionTypes, some but not all transactions can be categorized. For example, the 10-0 category in Table 2 row 5 is rather ambiguous (i.e., 'Internal - Internal transfer of unit/supplementary program transaction' and 'no supp'). A second way to categorize transactions, and which explains why [AccountType] is mentioned in Table 2 column 3, is by utilizing the direction of allowances between acquiring to transferring accountTypes (e.g., the 100 and 120 codes). For instance, allowances transferred from 100-accountTypes to 120-accountTypes are most likely allowance allocations (or related).

Hence, in order to compare the two download-vintages, the transactions are categorized and labelled as follows. Next to applying the transactionTypes, 'Intra-registry' are transactions between government-owned accounts (i.e., mainly registry codes: 100, 230, 300), 'Allocations' are transactions from governments to private accounts (i.e., registry codes: 120, 121), 'Surrenders' are transactions from private to government accounts, and 'Transactions' are transactions among private accounts.

Table 3: Comparing transactions data across two different vintages but over the same time period

	2005 -- April, 2008		Intra-registry	Allocations	Surrenders	Transactions
(1)	Old transactions		9,138.22	6,067.34	6,524.24	3,653.88
(2)	Deleted transactions	-	3,059.98	6.15	957.09	52.71
(3)	Added transactions	+	5,337.44	269.13	289.48	29.09
(4)	Amounts differences	+	-344.20	-26.06	-62.13	-324.29
(5)	New transactions	=	11,071.47	6,304.26	5,794.49	3,305.97

Table 3 shows the categorization across the two vintages of transactions.[77] Row (2) shows the deleted totals, namely those appearing in the old but not new transactions. Row (3) show the added totals, hence, which appear in the new but not old transactions. And row (4) captures the difference in totals over the same selection of transactions. Table 3 suggests that transactions can differ substantially across different download-vintages. Proportionally, 'Intra-registry' transactions show largest changes (i.e., row 1 vs. row 5, or +21%), then 'Surrenders' (-11%), 'Transactions' (-10%), and 'Allocations' (+4%).[78]

This example emphasizes the importance to be transparent when data has been downloaded (i.e., its 'vintage'). A cautionary note is that replications of analyses will be possible when possessing the exact same data, for example, if the acquired data has the same EUTL update timestamp, or if it is made available by the researcher. Moreover, advisable

[77] Only excluded are transactions when 1) the accountType (e.g., OHAs and PHAs) is missing from both the acquiring and transferring parties, and 2) the transaction purpose cannot be deduced from transactionType.

[78] We double-checked this analysis with newly downloaded data (downloaded at October 30th, 2015), and found the new transactions still diverge from the old transactions: 'Intra-registry' +37%, 'Allocations' +4%, 'Surrenders' -5%, and 'Transactions' -9%. Part of the problem can be that the website does not completely transfer the data from the EUTL archive to the files to be downloaded. When we randomly checked separate transactions, the EUTL did show these transactions.

for EU ETS analyses on compliance is therefore to use or (at least) double-check with the annual compliance or installation level data (i.e., hence, Table 1 row 11 rather than row 10). The next section provides further discussion on the transactions versus annual allocations and emissions data.

4.3 Using transactions or compliance data?

When comparing transactions with compliance data, we need to account for the fact that 1) firms receive their allocations no later than end-February, and 2) that at end-April, allowances need to be surrendered in accordance with the verified emissions from the *previous* calendar year. And since the annual EUTL statistics on Phase I (2005-2007) were approved in 2009, also the transactions until end-April, 2009, need to be considered for possible allowance corrections.

In the selection of transactions, we first exclude those among private parties, and to or from non-EU ETS countries. Generally, the latter type of allowances originates from CDM projects, but CDM credits are not necessarily used for compliance purposes. This selection leaves us with only national registry and, hence, compliance-specific transactions.

Table 4: Selection of transactionType from the national registry transactions

#	(code)TransactionType	(code)suppTransactionType	In/exclude?
1	(1) Issuance - Initial creation of a unit	(0) no supp	fully excl.
2	(1) Issuance - Initial creation of a unit	(52) Allowance issue (2008-2012 onwards)	fully excl.
3	(10) Internal - Internal transfer of unit/supplementary program transaction	(51) Allowance issue (2005-2007)	fully excl.
4	(10) Internal - Internal transfer of unit/supplementary program transaction	(0) no supp	excl. missing AccountType
5	(10) Internal - Internal transfer of unit/supplementary program transaction	(41) Cancellation and replacement	excl. missing AccountType
6	(3) External - External transfer of unit between registries	(0) no sup	excl. after Apr. 30, '08
7	(3) External - External transfer of unit between registries	(21) External transfer (2005-2007)	excl. after Apr. 30, '08
8	(10) Internal - Internal transfer of unit/supplementary program transaction	(0) no supp	excl. after Apr. 30, '08
9	(10) Internal - Internal transfer of unit/supplementary program transaction	(53) Allowance allocation	excl. after Apr. 30, '08
10	(4) Cancellation - Internal transfer of unit	(0) no supp	excl. after Apr. 30, '08
11	(4) Cancellation - Internal transfer of unit	(3) Retirement (2005-2007)	fully incl.
12	(10) Internal - Internal transfer of unit/supplementary program transaction	(1) Allowance cancellation (2005-2007)	fully incl.
13	(10) Internal - Internal transfer of unit/supplementary program transaction	(2) Allowance surrender	fully incl.
14	(10) Internal - Internal transfer of unit/supplementary program transaction	(55) Correction to allowances	fully incl.
15	(10) Internal - Internal transfer of unit/supplementary program transaction	(92) Reversal of allowance surrender	fully incl.
16	(10) Internal - Internal transfer of unit/supplementary program transaction	(93) Correction	fully incl.

As with Table 2, Table 4 shows which transactions are further in or excluded, based on the main and supplementary (i.e., 'supp') transactionTypes and the accountTypes of the acquiring and transferring parties. Allowance issuances or rows 1-3 are excluded, since they do not affect compliance per se. Also excluded are transactions when 1) the accountType (e.g., OHAs and PHAs) is missing from *both* the acquiring and transferring party, and 2) the transaction purpose cannot be deduced from transactionType (cf. footnote 77). These cases are specified in rows 4 and 5. With row 4, for example, 'supp' in suppTransactionType does not tell whether the transaction concerns an allocation or surrender.

Moreover, when looking into the transactions with row 5 (i.e., '(41) Cancellation and replacement') will reveal that all have missing accountTypes as well (i.e., OHAs and PHAs). Allowance cancellations and replacements are likely to be among national registry accounts only, and are therefore 'safe' to exclude (i.e., they also do not affect compliance per se).[79]

Further excluded are the transactionTypes from rows 5-8 for allowances after April 30th, 2008. It cannot be deduced from the transactionTypes whether these allowances are conducted for Phase I (2005-2007) or Phase II (2008-2012). After April 30th, 2008, allocations are excluded since they are likely for Phase II (i.e., '(53) Allowance allocation' or row 8). Transactions with '(4) Cancellation - Internal transfer of unit' or row 9 are also excluded; the data specifies these are all voluntary cancellations, and are deposited at national registry accounts with 2008-2012 labels. Finally, transactions with '(2) Allowance surrender' (i.e., row 12) and with '(92) Reversal of allowance surrender' (i.e., row 14) are still included after April 30th, 2008. These are likely to be conducted for Phase I.

As with Table 2, the transaction purpose could be further deduced from the accountTypes of the acquiring and transferring parties. When national registries receive (hand out) allowances, Table 4 considers these as allowance allocations (surrenders).[80] This applies to '(92) Reversal of allowance surrender', which are labelled as allocations, and to '(1) Allowance cancellation (2005-2007)' and '(55) Correction to allowances', which are labelled as allowance surrenders. Finally, '(3) Retirement (2005-2007)' and '(55) Correction to allowances' are only intra-registry. These are considered to have no impacts on allocations and surrenders.

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[79] All transactions with AccountTypes and '3) Retirement (2005-2007)' or row 10 are among national registries. For transactions where AccountType is *missing* we therefore assume these are also among national registries.

[80] If possible, this is also applied for transactionTypes which are not specific enough (e.g., 'no-supp').

Table 5: EU ETS Phase I (2005-2007) allocated allowances per EU Member State. Numbers are in million tonnes of CO_2-equivalents, and based on data obtained in June, 2015, and compliance data obtained in August, 2015

Country	initial: 2005	ultimate: 2005	initial: 2006	ultimate: 2006	initial: 2007	ultimate: 2007
AT	8.04	32.41	41.74	65.06	103.37	97.79
BE	45.86	58.31	118.30	118.26	179.73	178.69
CY	0.00	n.a.	11.08	n.a.	16.98	n.a.
CZ	88.79	96.92	194.07	193.84	291.51	290.76
DE	0.23	493.48	506.99	988.97	1038.13	1486.27
DK	0.09	37.30	31.23	65.21	85.58	93.11
EE	16.74	16.75	35.13	34.95	66.28	56.29
ES	124.70	172.16	337.16	338.37	675.34	498.11
FI	0.10	44.67	45.77	89.28	127.80	133.90
FR	77.70	150.41	232.28	300.38	387.92	450.15
GR	0.00	71.16	142.27	142.32	213.43	213.49
HU	0.00	30.24	62.13	60.47	94.52	90.71
IE	19.15	19.24	43.91	38.47	66.97	57.71
IT	0.00	216.15	409.59	421.20	669.17	624.46
LT	13.50	13.50	24.91	24.08	36.79	34.39
LU	0.00	3.23	6.47	6.46	9.71	9.69
LV	4.07	4.07	8.70	8.13	13.36	12.16
MT	0.00	n.a.	0.00	n.a.	6.54	n.a.
NL	0.11	86.45	87.06	172.84	177.88	259.32
PL	0.00	237.56	341.35	475.12	714.84	712.66
PT	18.29	36.91	73.80	73.82	113.82	110.73
RO	0.00	0.00	0.00	0.00	74.34	74.34
SE	2.62	22.29	25.65	44.77	48.67	67.62
SI	9.14	9.14	17.94	17.83	26.28	26.08
SK	24.16	30.47	60.97	60.96	91.50	91.44
UK	9.91	206.07	228.83	412.08	464.03	627.95

Table 6: EU ETS Phase I (2005-2007) surrendered allowances per EU Member State. Numbers are in million tonnes of CO_2-equivalents, and based on data obtained in June, 2015, and compliance data obtained in August, 2015

Country	initial: 2005	ultimate: 2005	initial: 2006	ultimate: 2006	initial: 2007	ultimate: 2007
AT	33.37	33.34	65.76	65.12	100.29	97.52
BE	55.42	54.91	110.11	110.10	168.90	162.65
CY	5.08	n.a.	10.34	n.a.	15.73	n.a.
CZ	82.48	6.34	166.17	165.92	254.51	253.62
DE	485.59	465.95	984.18	950.29	1568.66	1431.52
DK	26.48	35.24	60.71	69.65	90.53	87.54
EE	12.62	12.61	34.35	15.04	49.68	40.06
ES	184.02	159.63	363.06	362.55	550.90	546.63
FI	33.20	33.03	77.90	77.74	121.38	115.81
FR	131.53	19.27	258.62	257.56	389.00	384.32
GR	142.66	71.32	282.55	141.22	359.19	213.84
HU	26.06	25.39	51.93	51.44	79.40	76.81
IE	22.40	22.40	44.16	44.12	66.64	66.44
IT	227.29	90.35	453.60	438.34	699.51	672.94
LT	6.64	6.63	13.15	13.02	19.14	19.13
LU	2.60	2.60	5.32	5.32	8.56	7.88
LV	2.83	2.85	5.78	5.80	10.01	8.61
MT	0.00	n.a.	3.96	n.a.	5.98	n.a.
NL	80.35	80.14	157.28	155.50	236.98	236.60
PL	137.61	204.42	414.22	412.33	620.65	617.91
PT	36.43	34.09	69.49	69.59	100.98	100.79
RO	0.00	0.00	0.00	0.00	69.70	69.70
SE	19.41	19.38	39.25	38.26	58.48	58.44
SI	8.74	8.72	17.58	17.43	26.62	26.50
SK	25.24	0.60	50.87	50.99	77.92	75.35
UK	242.95	241.29	494.55	493.48	755.88	749.66

Table 5 and 6 provide the EU Member State-specific annual tCO_2 amounts of allowances allocated and surrendered for Table 5 and 6, respectively. Per Phase I year, the columns provide the 'initial' and 'ultimate' tCO_2 amounts. The 'initial' numbers are based on the EUTL transactions. For Table 5, 'initial' represents the amounts transferred from national registries to installation accounts (i.e., allocations), and the transfers are opposite for Table 6 (i.e., surrenders). 'Ultimate' tCO_2 amounts are instead taken from the annual statistics, or the EUTL compliance section.[81] Furthermore, the amounts in Tables 5 and 6 are cumulative. This cumulative view allows for a more balanced view toward the end of Phase I (more below). Such cumulative view is also in line with EUTL statistics (e.g., see Table 1 row 11).[82]

For the majority of cases, the transactions-based (i.e., 'initial') and compliance-based (i.e., 'ultimate') columns deviate from one another. Table 5 shows all Member States except Lithuania start with less 'initial'-allocated amounts than 'Ultimate' amounts in 2005. In all cases, differences between 'initial' and 'ultimate' decrease or (even) switch sign from one year to the next. About two-third (one-third) of the Member States ends up in 2007 with more (less) 'initial' than 'ultimate' allocations. For the surrendered amounts, Table 6 shows that almost all have more 'initial'-surrendered than 'ultimate' amounts in 2005. In 2007, all end up with more. Half of the Member States increase (decrease) the difference from 2005 to 2006, while about two-third (one-third) increase (decrease) the difference from 2006 to 2007.

Some caution is needed before interpreting these results. As shown above with the selection of transactions (e.g., Tables 2 and 4), the EUTL does not always label for which administrative purpose transactions were conducted. Transactions to and from national registries may be 'late' allowance surrenders, ex-post emissions adjustments, or voluntary allowance surrenders. An issue is therefore how to allocate the intra-Phase transactions, hence, which transactions pertain to which Phase I calendar year (2005-2007) and/or if transactions may actually belong to Phase II (i.e., possibly 2008). Even if these transactions are properly allocated, it is the question whether all transactions are taken into account. Table 3 from Section 4.2 shows that the EUTL does not show (anymore) a substantial number of public transactions. When analysing EU ETS compliance, transactions data can thus give a distorted picture.

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[81] Moreover, these statistics are from a closed EU ETS Phase. These numbers are further *ex-post* checked and formally approved. For Phase I this approval is timestamped in 2009.

[82] Moreover, allowance surrenders for calendar year *t* take place in *t*+1, which is applied in Table 6.

Furthermore, 'inconsistencies' may be handled differently since the interpretation of requirements concerning verifiers can be different from one EU Member State to another.[83] For example, some national authorities may penalize every tonne of insufficient emissions imbalances, while others may allow imbalances to be settled with the next annual compliance round. Such imbalances can occur if monitoring reports, upon which verifiers base their approval, may not have adequately covered the installations' production processes. These above issues may be mitigated through the cumulative view in Table 5 and 6, although it cannot be determined how much so. For example, it is well possible that the 2007 imbalances in Table 5 and 6 are actually incorporated in 2008.

That the 'initial' and 'ultimate' statistics converge over 2005-2007 may relate to the start of the EU ETS when not all national registries were operational – but steadily became so as time progressed.[84] Yet, in 2007 most Member States ended up with deviating numbers. With allocations in Table 5, the average is that 'initial' is -1.41% less than 'ultimate' (calculation not shown). With surrenders in Table 6, the average is that initial' is +6.82% more than 'ultimate'. The overall view is, hence, and compared to transactions (i.e., 'initial'), that compliance-based (i.e., 'ultimate') allocations are *ex-post* 'upscaled' and surrenders are *ex-post* 'downscaled'. Compliance-based data are checked and formally approved after EU ETS Phases are closed. This *ex-post* rescaling therefore appears twice favourable to firms (i.e., both higher allocations and lower surrenders). Also Table 3, which compared the data from two download vintages, shows this upscaling and downscaling of allowance allocations and surrenders, respectively. But with the information as provided by the EUTL it is impossible to pinpoint whether ex-post corrections were actually on the part of the firm (e.g., by being non-compliant) or the national registry (e.g., by a reinterpretation of monitoring reports) and, hence, led to *ex-post* benefits or losses for firms. This also implies that if transactions-compliance differences are found negligible in next EU ETS

[83] As Article 16 par. 3 of EU Directive 2003/87 (EC, 2003) could conflict with Article 12 par. 3. We are grateful to the Dutch Emissions Authority (NEa) for pointing this out. Verschuuren and Fleurke (2014) evaluate EU ETS enforcement differences across Member States.

[84] Cyprus, Greece, Hungary, Italy, Luxembourg, and Poland had their first government-initiated transaction in 2006. For Malta this is 2007, and 2008 for Romania.

Phases (i.e., expected, given that Phase I (2005-2007) is considered the pilot or start-up Phase) it may be too quick to conclude that compliance was really flawless.

To err on the 'safe' side, most researchers opt for the formally approved data (e.g., Verde et al, 2016; Jong and Zeitlberger, 2017).[85] The implicit trade-off is that, indeed, these ex-post readjustments are taken into account when analysing EU ETS impacts, for instance, on the installations. In fact, the transactions may in fact better reveal firm behaviour since these allowances were truly acquired or transferred.

5. Recommendations for improving the EUTL

This chapter concludes with suggestions for improvements on the current EUTL structure. Mainly, these improvements will be conducive to transparency, enable third-party monitoring, and in so doing, improve the integrity of the scheme. The recommendations are the following:

1) Besides this text, some additional guideline(s), Frequently Asked Questions (FAQ), and/or website Help-functionality will be useful for EUTL users;

2) Allowance transactions are made in increasingly smaller batches. This is less an issue with standard download queries, since these only provide the total amounts of allowances exchanged. It is an issue with detailed queries given the EUTL's download limit. Fewer transactions can then be downloaded since the files become ever larger. Research on EUTL data will be facilitated if, for example, the total exchanged amounts can be enabled with detailed queries. With other allowance aspects, standard and detailed EUTL queries also differ, for example, on allowances from Joint Implementation (JI) or Clean Development Mechanism (CDM) projects. Simple enable-disable information options in the search criteria will thus be useful for cross-validating purposes;

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85 The literature's preference for the 'formal' numbers is also expressed through the choice of verified emissions rather than the surrendered allowances. At Phase I totals, out of the 11,563 installations there are 22 where verified emissions were 'Not Calculated' and 133 where either verified or surrendered emissions were missing. Excluding these cases (i.e., with 11,408 installations), 92.83% have equal verified-surrendered emissions, 6.38% with more surrendered allowances (average: 15,171 surplus), and 0.78% with less surrendered allowances (average: 51,733 shortage). Within Phase I, 29% and 3% of installations have insufficient surrendered allowances in 2005 and 2006, respectively, while 3% and 4% of installations surrendered too many allowances in 2005 and 2006, respectively.

3) The EUTL has its own industry categorization. The European Commission regularly updates the list of industries subject to carbon leakage, but these industries rely on other industry categorizations: mainly the NACE Rev. 2 industry classifications, and the Prodcom-classification for a handful of specific products.[86] EUTL data will be more in accordance with national and EU-wide statistics (e.g., Eurostat) if these industry classifications are adopted additionally or instead;

4) A related aspect, as McGuinness and Trotignon (2007) and Verde et al. (2016) indicate, is that, while installations are categorized into EUTL industries (e.g., 'Combustion of fuels'), its operator may actually be active in a different industry. The EUTL does not provide the operator's industry;

(i) However, identification of ownership is also effectively hindered, due to its time-inconsistent and/or incomplete ownership details and ambiguous accountholder names;

(ii) Operator and accountholder names may change with EUTL updates. Such changes can also affect the names designated to be behind *historical* transactions. The EUTL should therefore record the previous names and the time periods these were active. With merged entities, for example, it will otherwise be impossible to trace which of the previously separate branch conducted transactions (e.g., GDF or SUEZ before their merger in 2008);

(iii) Moreover, the EUTL subsections on compliance and transactions should have more overlap in terms of variables and/or identifiers. One way in which linking will be improved is if AccountIdentifier, currently only provided in the transactions subsection, is also made available in the compliance-based subsections;

(iv) And not all firms can be identified via CompanyRegistrationNo, primarily because most EU Member States supply a limited selection of company identifiers. The EUTL may hence provide an additional identifier to indicate which installations are company-affiliated across the EU;

(v) Tracing ownership will be necessary in order to validate whether firms are actually subject to carbon leakage. The efficiency or distributional effects from the EU ETS can also be estimated, for example, if EU ETS markets can be manipulated (e.g. Hintermann, 2015);

[86] The first four Prodcom-digits correspond with the NACE code, while the remaining four allow for the detailed product specification.

5) Currently, it cannot consistently be found out whether and how transactions with registries add up to the compliance-based allocations and surrenders. It cannot equivocally be pinpointed which allowances refer to which EU ETS Phase or to which calendar year within an EU ETS Phase. For example, for many transactions, transactionTypes are not specific enough (e.g., with the supplementary code: 'no supp') and details on the acquiring and transferring entities are not sufficient (e.g., lacking accountType codes). It is also uncertain whether deviations are on the part of the firm or of the registry. This can be mitigated if the EUTL provides details on the extent to which transactions with national registries had compliance-deviating or corrective impacts. With ComplianceCode (cf. Table 1), compliance statuses can be deduced but this is on an annual basis only – not per transaction. EUTL transactions do not have an analogous label yet;
6) Besides these necessary details, this chapter has shown that the EUTL registry may not show transactions from accounts which have been closed by now. These transactions can be disclosed, for instance, via an extra identifier on the accounts closure dates.

At the 2015 FSR Annual Climate Conference, we were told that the EUTL is limited in providing information and identifiers in the following two ways. First, EU Member States can decide how detailed and specific the information needs to be that they submit to the EUTL (e.g. whether AccountHolder names have to contain the official company names or not). The EUTL thus acts as an information intermediary. Second, the EU ETS registry regulation (Regulation 389/2013, Annex 13 and 14) outlines the identifiers (not) to be provided. For example, this explains why AccountIdentifier is mentioned in the transactions-based EUTL section but not the compliance-based one.

The recommendations of this chapter are therefore primarily relevant for the European Commission and the EU Member States. They are in the position to change the regulations which determine what information the EUTL can provide.

6. Conclusion

Emissions trading registries are not problem-free. The registry of the EU Emissions Trading Scheme (EU ETS), the EU Transaction Log (EUTL), is a case in point.

We have demonstrated that the EUTL suffers from various data problems. One issue is that it cannot consistently be found out whether and how transactions with registries add up to the (annually provided) statistics on allowance allocations and surrenders. Another is that transactions downloads do not reveal historical transactions from accounts which have been closed by now. Moreover, this chapter focuses particularly on firm ownership. Firms are the actual owners and users of EUTL accounts and, therefore, influence how the EU ETS is run. But company information from the EUTL is both inconsistent and ambiguous.

The issues have their roots in one main aspect: the EUTL lacks crucial variables or identifiers. For example, the previous names of the installation operators and of the accountholders, the (country-specific) identifier of the installations accounts, or the date when accounts have been closed. Moreover, for some identifiers, such transactionType and accountType, the value is either generic ("no supp") or not available, making it equivocal by whom or for what purpose the transaction was conducted.

Not only can extra information via such identifiers mitigate the above mentioned issues. It can also make the EUTL robust against its recurring updates, which have resulted in retroactive data changes. This chapter provides several suggestions for these identifiers.

Although emission registries, such as the EUTL, suffer from design imperfections and data problems, their role remains undisputed in providing crucial information on the past performance of the corresponding emissions trading scheme. Experiences with registries, such as our study of the EUTL, as well as recommendations for improvements that follow from such experiences, may help to overcome similar problems in current and emerging emissions trading schemes around the globe.

CHAPTER 4
Does EU emissions trading bite? An event study[87]

1. Introduction

To meet its greenhouse gas emission targets, the European Union (EU) has introduced in 2005 the EU Emissions Trading Scheme (EU ETS).[88] This scheme is based on 'cap-and-trade' regulation. The total amount of emissions is 'capped' and the EU emission allowances, which make up the subsets of that total amount, are tradable. In Phase I (2005-2007) and Phase II (2008-2012) of the EU ETS, the total domestic supply of allowances was determined through National Allocation Plans (NAP). However, at the end of April, 2006, the first EU Member State annual reports were published. These reports showed that national demand for allowances in 2005 was much less than supply. The resulting carbon price drop was the main signal that market participants revised their expectations on the shortage of allowances.

But while supply was larger than demand, the carbon price did not immediately fall to zero. And while one can expect investors to put a lower valuation on cleaner rather than dirtier firms, the statistics (to be shown later) suggest that dirtier firms instead received a lower valuation. Yet, if the carbon price drop lowers firms' valuations, it does not suggest that the EU ETS is costly. Since share prices reflect the firms' *future* profitability, the EU ETS 'bite' is in the market's expectation of its *future* related costs. The aim of this chapter is to find out whether investors consider the EU

[87] This is the author final version (i.e., the post-print) from the article which previously appeared in Jong et al. (2014). We are grateful for the useful comments we received from Denny Ellerman, Aleksandar Zaklan, Jurate Jaraitė, Zofia Lukszo, and from the participants at the IEA International Energy Workshop (19-21 June, 2013), the EUI RSCAS Seminar Series (October 15th, 2012), the BAEE Research Workshop on Energy Economics (September 28th, 2012), and the University of Erfurt 25th Consecutive Workshop in Law and Economics (April 5th, 2012). Any remaining errors are our own.

[88] We refer the reader to Böhringer (2014) for a recent, more general overview on EU ETS developments.

ETS as relevant for polluting firms, and how this is related to the firms' allowance allocations and transactions.

The central question of this chapter is therefore: Did EU ETS firms' shareholders interpret the April 2006 carbon price drop as significant and, if so, how did the event's impact differ among firms' allocations and transactions?

This chapter is organized as follows. In Section 2, the literature will be reviewed on the EU ETS how the impact of the EU ETS differs through the related allocations and transactions. In Section 3, hypotheses are formulated on the share price responsiveness through which the carbon price drop impacted the EU ETS firms. The methodology will be discussed in Section 4. The empirical results and a discussion thereof will be presented in Sections 5. Section 6 concludes the chapter.

2. Literature review

With an abundant supply of allowances one may expect the regulation did not affect the firms' management or share prices. For example, Anger and Oberndorfer (2008) showed for a sample of German firms that allocations did not impact revenues and employment. Kettner et al. (2008) concluded it was unlikely that abatement had taken place.

However, ex-post research shows the EU ETS did have an impact on firms. Anderson and Di Maria (2011) showed there were both 'under-allocations' as well as 'over-allocations' and that some firms did reduce emissions. Abrell et al. (2011) found that the profit margins of over-allocated firms were positively affected, *et vice versa*. Furthermore, the market valuations of firms were responsive to the carbon price. For example, Oestreich and Tsiakas (2012) analyse the 'carbon premium', defined as the share price return difference of dirty versus clean firms. They find that this premium is higher for dirtier firms. However, when focusing on energy companies in the EU, Koch and Bassen (2013) find the opposite, namely that dirtier firms have higher costs of capital due to carbon related risks and thus a lower equity value. Moreover, through an event study on the April 2006 carbon price drop, Bushnell et al. (2013) shows that the market values of dirtier *non-energy* industries declined more, i.e., dirtier firms were more heavily penalized, as was found for the *energy* industry in Koch and Bassen (2013).[89] Among energy firms, however, the impact was the opposite, i.e., being cleaner will be penalized, as with Oestreich and Tsiakas (2012).

This study contributes to the literature through the inclusion of the firms' allowance purchases and sales from the EU ETS database: the European Union Transaction Log (EUTL). Only three studies have analysed these EU ETS transactions. Both Jaraitė and Kažukauskas (2012) and Zaklan (2013) examine determinants in purchasing and selling allowances. Yet, to our knowledge the impact of these transactions on share prices has not been analysed yet.

Bushnell et al. (2013) also conduct an event study on the same allowance price fall in the EU ETS. However, this chapter is different from theirs. First, where Bushnell et al. (2013) make an industry comparison by focusing on power versus non-power industries, we use a more specific categorization of industries to test the effect of the allowance price fall on share prices. Second, contrary to Bushnell et al. (2013) we bring the buying and selling of allowances, which is the very essence of emissions trading, into the analysis, by incorporating such purchases and sales into a number of hypotheses. Third, as a result our conclusions partly reproduce but also partly differ from theirs, which enhances the validity of both studies and adds new insights to this carbon market event.

The literature thus shows that the ex-post results are mixed on the impacts of over-allocation and of carbon-intensive production, and that there is a literature gap regarding the effects of allowance trade on share prices. This chapter fills these gaps by incorporating allowance trade with the allocation and the product market in determining the EU ETS impact on share prices. In the next section hypotheses are formulated on the interplay of these three factors.

3. Theoretical framework and hypotheses

Several related effects on firms' market values occur simultaneously with a change in the carbon price. The three main effects, discussed below, are: (1) carbon leakage and carbon-intensity effects, (2) exposure and borrowing effects, and (3) trade effects.

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[89] There are more event studies on the EU ETS, e.g., Mansanet-Bataller and Pardo (2007).

3.1 Carbon leakage and carbon-intensity effects

Carbon-intensive production becomes less attractive in an emissions trading scheme. 'Carbon leakage' refers to the consequential relocation of companies, and thus emissions, to countries where restrictions on carbon emissions are weaker. Firms competing with firms from outside the system cannot or can partly pass on carbon-related costs in their product prices. This decreases their profit margins. Once the carbon price drops, the profit margins and thus share prices should increase of firms within the EU ETS. The first hypothesis H.1 is therefore:

Market values of firms with carbon leakage increase.
Increases are larger for dirtier firms, i.e., with a higher carbon-intensity of production, than for cleaner firms. (H.1)

Hence, if firms can pass-through less than 100% of their carbon-related costs, a drop in the carbon price increases the market value of such firms.

However, if firms can pass on at least 100%, i.e., they do not suffer from carbon leakage, the carbon price drop decreases product revenues, profits and thus their market values.[90] Indeed, Oberndorfer (2009) finds a positive share-price-to-carbon-price relationship for European power firms. The carbon cost margin, i.e., the carbon price times the emissions per unit of production, is higher for firms with a dirtier production. Product prices of dirtier firms will thus decrease more when the carbon price drops, lowering their profits and thus their share prices. Contrary to H.1, the impact for dirty versus clean firms is thus the opposite. As a result, the second hypothesis H.2 is that:

Market values of firms without carbon leakage decrease.
Decreases are larger for dirtier firms than for cleaner firms. (H.2)

3.2 Exposure and borrowing effects

Polluting firms in the EU ETS either receive their allowances for free or they have to buy them at auction. Auctioning or free allocation have similar economic costs (costs of buying allowances or the opportunity costs of using free allowances) but do effect accounting profits and the market values of firms differently. Firms receiving free allowances should thus have higher market values than comparable firms having to buy them at

[90] This relationship holds with grandfathered allowances. With auctioning the effect on market values is neutral. Allowance costs are then not only an opportunity cost but an out-of-pocket expense as well.

auction. Typically, the former is long on allowances, while the latter is short. The carbon price drop should thus have lowered the cost burden for firms that were short on allowances on an annual basis. The hypothesis is that investors see the accumulation of these lowered cost burdens into increases in market values. The third hypothesis is thus as follows:
Market values increase the more firms are short on allowances.
Market values decrease the more firms are long on allowances. (H.3)

However, in the short-term the price drop decreases the value of allowances held in stock. This negatively affects the market values of firms. One of the features of the EU ETS Directives (EC, 2003; EC, 2009a) allowing firms to manage short-term impacts is called 'borrowing'. In the EU ETS, firms receive their next year's allocation of allowances prior to the compliance date for their current year's emissions. Firms can thus 'borrow' these allowances to cover for their current year's emissions. But in case firms foresaw the carbon price drop they should *also* have sold any of their remaining allocation holdings. As such a strategy is a signal of market insight, firms with lower net stock positions should have higher market values. The fourth hypothesis is then as follows:
Market values increase the more firms decreased their net stock holdings by borrowing and selling allowances. (H.4)

3.3 Trade effects

If rational expectations are assumed, firms should trade for any discrepancies between allocations and emissions. However, firms do not only trade to eliminate these mismatches, they may also actively bet on carbon market developments. Active traders might know more about the workings of the market and thus have an information advantage. Investors might therefore positively value firms active at trading allowances, irrespective of whether they are buying or selling. The last hypothesis is thus as follows:
Market values increase the larger the firms' shares in the allowance trade. (H.5)

4. Methodology

4.1 Abnormal share returns

In order to estimate the market valuation effects around the carbon price shock, we use an event study. This approach was introduced by Fama et al. (1969) initially for corporate finance purposes, but has also been applied within the field of regulatory economics.

The event study methodology implicitly assumes the market is efficient: all available information impacting future profits of firms is discounted into the share prices. If an event is significant for a firm it should thus be possible to extract from its share price the firm-specific returns associated with the event.[91] Subsequently, these 'abnormal returns' can be analysed by relating them to these firm's characteristics. Here the firms' industry categories, revenues, allocations, emissions, and allowance purchases and sales will be considered.

For obtaining the market returns the Return Index (*RI*) was used from Datastream.[92] With *RI* the (simple log) returns $r_{i,t}$ can be calculated by first-differencing its natural logarithm:

$$r_{i,t} = \ln(RI_{i,t+1} / RI_{i,t}) = \ln(RI_{i,t+1}) - \ln(RI_{i,t}) \qquad (1)$$

where i stands for the company $i = 1,\ldots, N$ and $i = m$ denotes the market index. These market portfolio returns $r_{m,t}$ are proxied by the *RI* of the Morgan Stanley Capital International EU equity market index. The subscript t stands for the trading day.

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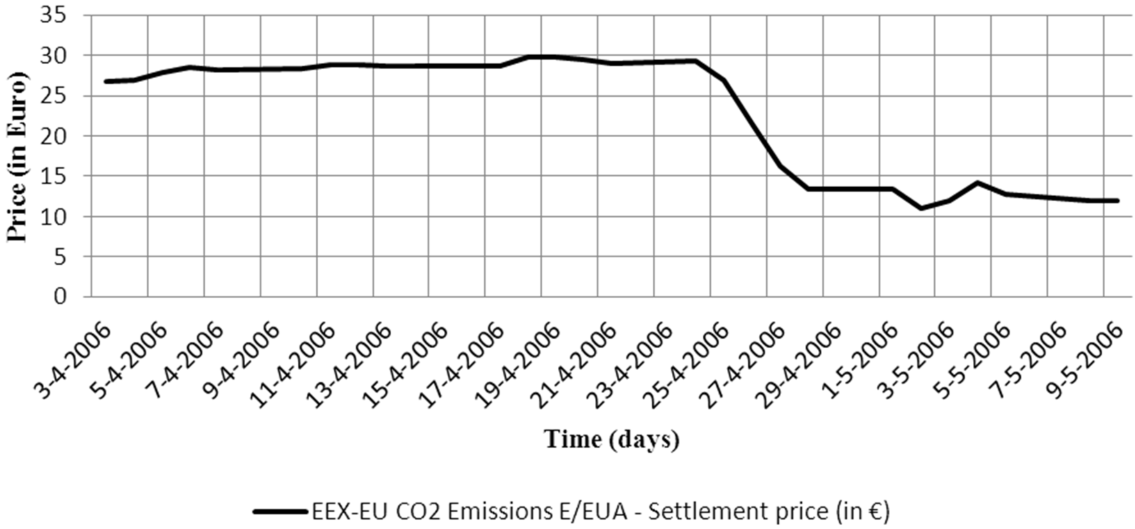
91 Regulatory changes are often gradual and expected. Event study estimates will then become biased if key dates in the regulatory process are ambiguous. However, the information on the excess amount of allowances came as a shock to the market (see e.g., Figures 1 and 2). Moreover, in the April 21st 2006 edition of *Carbon Market Europe* of Point Carbon, it was argued that the CO_2 price was too low (Ellerman and Buchner, 2008). The expectations before the event thus indicate a CO_2 price movement in the opposite direction.

92 In the calculation of the Return Index, dividends or share splits are corrected for.

Figure 1: EU Allowance unit settlement price around the 25th of April, 2006 (in €)



Source: Datastream

As Figure 1 shows, the start of the event window is to be pinpointed at the 24th as it is the last day the price moved upwards. And since the price fall took off from the 25th we consider it the day of the event, i.e., for which t = 0.[93] The inclusion of the 24th, i.e., for which t = -1, allows for the effects of prior information on the share prices. The event window should not encompass too many days as that may affect the degree of bias of the statistical analysis, but with too few days the impact of the event may not be captured (e.g., Campbell et al., 1997). We therefore devise three event windows: one with the 26th of April (t_1 = {-1,1}), one with the 27th (t_2 = {-1,2}), and one with the 28th (t_3 = {-1,3}).[94]

93 The disclosure of emissions by EU Member States did not take place on the same day. The shock can thus be more pronounced for firms from the countries that were first at disclosing their national demand for allowances.

94 Bushnell et al. (2013) take the 26th until the 28th of April as the event window. They stated that little information had leaked into the market and that, otherwise, the carbon price would have responded to that. However, as Figure 1 shows, the carbon price fall had already started between the 24th and 25th.

In order to estimate the 'abnormal' returns caused by the event a business-as-usual estimate is needed. This estimate was determined by running, for each firm, an Ordinary Least Squares (OLS) regression:

$$r_{i,t} = \alpha_i + \beta_i r_{m,t} + u_{i,t} \qquad (2)$$

These OLS regressions are run in a sufficiently large time period of 60 days *before* the event, the estimation window.[95] The next step is to calculate the abnormal returns ($AR_{i,t}$) through the *estimation* window intercepts ($\hat{\alpha}_i$) and beta's ($\hat{\beta}_i$), and the *event* window's realized firm ($r_{i,t}$) and market returns ($r_{m,t}$):

$$AR_{i,t} \equiv \hat{\alpha} + \hat{\beta} r_{m,t} - r_{i,t} \qquad (3)$$

It is standard to aggregate these abnormal returns over the event window. Since if these returns are *significantly* affected during the event window, they will not revolve around zero but maintain a new level. For t_1, for example, these cumulative abnormal returns (*CAR*) can be calculated by summing $AR_{i,t}$ from t = -1 to t = 1.

4.2 Carbon leakage and carbon-intensity effects

For the carbon leakage estimate we draw on three Commission decisions (EC, 2010; EC, 2011b; EC, 2012a). These include lists of product categories deemed exposed to 'carbon leakage'. As these product categories are provided in NACE codes, a dummy variable $carbleak_i$ is defined equaling 1 if a firm's NACE code appears in the three Commission Decisions' lists.

The carbon-intensity of production (called: $carbintens_i$) is estimated as follows[96,97]:

$$carbintens_{i,2005} = emissions_{i,2005} \, / \, revenues_{i,2005} * 100\% \qquad (4)$$

95 Five days in between the estimation and event window is allowed for to prevent events affecting the event window.

96 The Orbis database does not provide the percentage of revenues attributable to a firm's installation(s). Firms having relatively more installations outside the EU ETS thus seem to have 'clean' output. Their lower exposure indeed enables them to switch production to the non-EU ETS installations.

97 For several firms, we relied on revenue data from Datastream in case Orbis was not able to provide it.

The effect of carbon-intensity on share prices depends whether a firm suffers from carbon leakage. We take care of this interaction via a variable $carbileak_i$, the product of $carbintens_i$ and $carbleak_i$.

Hypothesis H.1 suggests that with carbon leakage, share prices of dirtier firms increase more than those of cleaner firms. H.1 will then be accepted if $carbleak_i$ and $carbileak_i$ are positively related to CAR_i. To accept H.2, the opposite should hold.

4.3 Exposure and borrowing effects

Regarding the value effects associated with allocations and emissions two effects are important: 1) an exposure valuation: the allocations minus emissions amounts to come, and 2) a stock valuation: the value of allowances firms currently have in stock. As to the exposure valuation, it is expected that investors see annual shortfalls or surpluses in relative terms. One thus only needs to take the difference between allocations and verified emissions and divide it by either of the two. But for a part of the allowance transactions, it could not be discerned whether allocations belonged to the 2005 or 2006 tranches. The sum of the two allocations was therefore taken, resulting in the following exposure variable:

$$\exp_i = \frac{allocation_{i,2005} + allocation_{i,2006} - 2 * emissions_{i,2005}}{allocation_{i,2005} + allocation_{i,2006}} * 100\% \quad (5)$$

where $emissions_{i,2005}$ are multiplied by two given the two allocation tranches.[98] Hypothesis H.3 suggests market values increase (decrease) the more firms are short (long) on allowances. H.3 will then be accepted if exp_i is negatively related to CAR_i.

For the stock valuation effect, we devised a net holding estimate which takes into account 1) the possibility for firms to borrow, and 2) the net allowances sales – since, at higher pre-event carbon prices, it would have been profitable if firms had also sold their 2006 allocations. The reference date for the net holdings is set at the 30th of April, 2006, when allowances ought to be handed in. The net holding is then defined as:

$$borrow_i = \frac{emissions_{i,2005} + \sum_{2005}^{Apr2006} sales_i - \sum_{2005}^{Apr2006} purchases_i}{allocation_{i,2005} + allocation_{i,2006}} * 100 \quad (6)$$

[98] As the NAPs predetermined most of the allocations for Phase I it should pose less of a problem to assume that emissions for 2006 equal those of 2005.

Hypothesis H.4 suggests market values increase the more firms decreased their stock holdings. For H.4 to be accepted $borrow_i$ needs to be positively related to CAR_i.

4.4 Trade effects

Investors may value firms that are active at trading allowances, irrespective of whether they are buying or selling. The estimate we adopted is the trade-intensity (called: $tradeintens_i$)[99]:

$$tradeintens_i = \frac{\sum_{2005}^{Apr2006} purchases_i + \sum_{2005}^{Apr2006} sales_i}{\sum_{i=1}^{N}(\sum_{2005}^{Apr2006} purchases_i + \sum_{2005}^{Apr2006} sales_i)} * 100\% \quad (7)$$

In addition, a dummy variable $notrade_i$ is defined equaling 1 for firms which had nor purchases nor sales, and zero otherwise.

Hypothesis H.5 suggests market values increase the larger the firms' shares in the allowance trade. For H.5 to be accepted $tradeintens_i$ needs to be positively related to CAR_i.

5. Results and discussion

5.1 Firm and industry selection criteria

By labeling with the Bureau van Dijk's (BvD) Orbis database codes, we identified 10,419 of 10,650 installations operators from the National Allocation Plans (NAP), and 5,737 of the 5,957 European Transaction Log (EUTL) accountholders which appeared in the 2005-2006 transactions. The majority of the installations' operator names were provided through overviews on the EU ETS website. The BvD-labelling of the remaining installations or EUTL transaction accounts was possible with other provided details, such as the names of the installations or accountholders themselves. Moreover, there are 25,020 transactions between the first transaction and the last one on the 30th of April, 2006. 898 of them are conducted among the same accountholders, e.g., for moving allowances from one national registry to another, 9,664 are allocations and 4,743 are surrendered allowances. The inter-account trade data is thus based on the remaining 9,715 transactions.

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[99] This trade data, i.e., from the EUTL registry transactions, is published five years after an EU ETS calendar year. Investors thus did not have it at their disposal during or before the event. In this analysis it thus functions as a trade proxy. Investors should have obtained their allowance trading estimates via other information sources.

The only common identifier in the NAPs and the EUTL transactions were the accountholder names. For most accountholder names in the NAPs, the received and surrendered allowances could be traced in the transactions. NAP accountholders that did not appear in the transactions before end December, 2006, were not included in the analysis (776 accountholders controlling 1,073 installations). By not appearing in allowance transactions, we considered these accounts must have opted out from the EU ETS. The main allocations and emissions source we opted for were the NAPs; unlike the EUTL transactions it provides the verified emissions.[100] We complemented it with accounts which did not appear in the NAPs but according to the transactions received or surrendered allowances up until the 30th of April, 2006. We further included EUTL transaction accounts that were used for trading purposes only (and not for allowance allocations or surrenders).

The next step was to obtain the firms' International Security Identification Numbers (ISINs) or exchange-listing codes from Orbis. On the basis of the accountholder names and these listing codes, we merged the 2005-2006 allocations, emissions, and the cumulative purchases and sales until the 30th of April, 2006. Furthermore, firms were only selected if they took part in the EU ETS by having allocations and/or emissions, by having traded allowances, or both. For several firms data was unavailable in Datastream or Orbis on the share prices, revenues or total assets, decreasing the number of firms from 506 to 393. Table 1 shows the numbers of accountholders (and installations) divided over the listed and non-listed firms.

[100] As mentioned in Section 4.3, it could not be discerned whether the allowances received from or surrendered to the national registries were part of 2005 or 2006 tranches. Some installations received allowances more than twice, suggesting these were corrections rather than allocations. We thus opted for the verified emissions to be included in the analysis.

Table 1: Sample of EU ETS accountholders

Number of accountholders	NAP-related	Non-NAP with allocations and/or surrenders	Only trade	Total
EU ETS total	6132	208	435	6775
01-01-2005 to 31-12-2006	(10,650 installations)			
Identified, in transactions, and firm-specific data is available:	2,167	99	191	2,457
01-01-2005 to 30-04-2006	(4,121 installations)			
- of which: listed firms	1,128	25	139	1,292
	(2424 installations)			
- of which: non-listed firms	1,039	74	52	1,165
	(1,697 installations)			

From the 2,167 identified accountholders, 1,128 (53%) and 1,039 (48%) are assigned to the listed and non-listed firms, respectively. From Orbis we obtained the firms' NACE Rev. 2 core codes. Based on the contents of the NACE code text descriptions, the NACE industries were checked whether they were among the European Commission's lists of carbon leakage industries, and they were categorized into the following ETS sectors: 1) Power & Heat, 2) Iron, Steel & Coke, 3) Cement & Lime, 4) Refineries, 5) Pulp & Paper, 6) Glass, 7) Ceramics, Bricks & Tiles, 8) Unidentified / Others.[101,102,103]

5.2 Cumulative abnormal returns

The share prices, which determined the abnormal returns, are themselves established at the end of each trading day. These prices should thus reflect the carbon price changes on $t = 0$ for the initial decline and on $t = 1$ for the acceleration of the fall (cf. Figure 1).

[101] An overview of the NACE industries, its EU ETS sectors and carbon leakage categorization is available on request.
[102] For cases where the NACE industry text descriptions closely resembled those of the carbon leakage descriptions, we allocated them to the carbon leakage list.
[103] This ETS sector categorization is used in more studies, among others in Ellerman and Joskow (2008).

Figure 2: Full sample average abnormal returns within event window t = {-2,3}

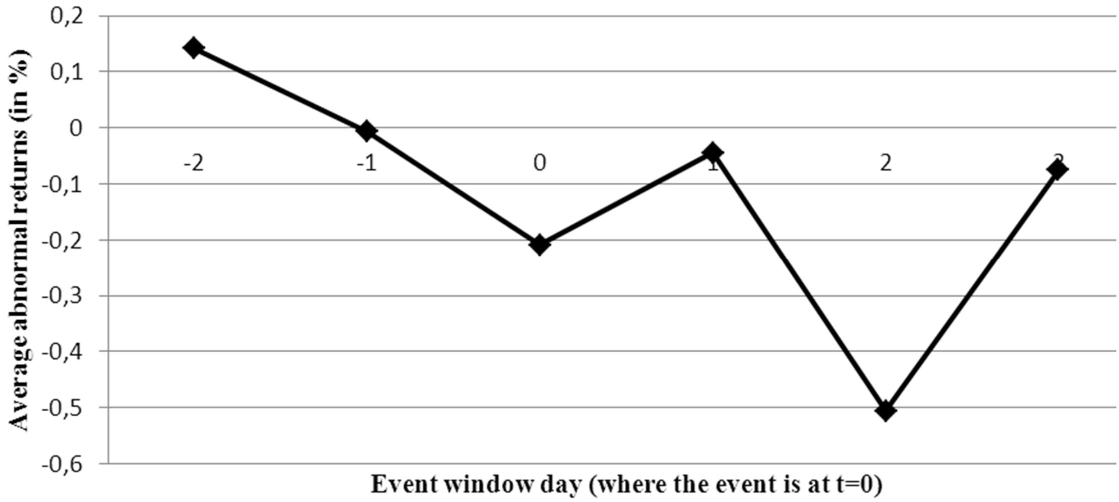

Figure 2 shows the path of the full sample average abnormal returns (*AR*s, not *CAR*s) over an event window of t = {-2,3}. This event window illustrates that before and until t = 0, the abnormal returns gravitated to the negative. The initial and positive response to the news came at t = 1, suggesting investors belatedly realized the information had an impact on the firms' valuations. The market re-evaluated this shock (downwards) at t = 2. And it took another day for the *AR*s to tend back to zero, indicating the impact was not substantial overall. We thus expect event window t_1 = {-1,1} to be informative as it includes the initial response to the news. Other event windows we consider are t_2 = {-1,2} and t_3 = {-1,3} which provide insights into the share price corrections the days after.

Table 2 shows the descriptive statistics for the *CAR*s for the three event windows t_1, t_2, and t_3.[104] From t_1 to t_2 the average firm saw a decline in the mean of its *CAR*, but there was no average change from t_2 to t_3.

[104] More than half of firms are in sector 8, the residual category. Relatively few firms within sectors 1 to 7 were publicly listed. And if we relied on primary or secondary NACE codes instead of core codes, some companies are active in more sectors.

Table 2: Descriptive statistics on the CARs and on their significance

	Full sample	sector 1	sector 2	sector 3	sector 4	sector 5	sector 6	sector 7	sector 8
CAR(-1,1)	N = 393	N = 25	N = 34	N = 13	N = 67	N = 34	N = 5	N = 4	N = 211
Mean	-0,25%	-0,90%	-0,31%	1,09%	-0,47%	-0,62%	-0,28%	1,88%	-0,16%
Std. dev.	2,91%	2,58%	3,99%	3,07%	2,98%	2,58%	2,03%	2,45%	2,78%
Median	-0,25%	-0,58%	-0,05%	0,62%	-0,45%	-0,30%	-0,72%	1,94%	-0,17%
Minimum	-13,07%	-6,99%	-13,07%	-2,14%	-8,42%	-6,98%	-2,31%	-1,14%	-11,55%
Maximum	11,91%	4,84%	8,20%	8,99%	9,92%	6,35%	2,96%	4,78%	11,91%
T-test	-1,71*	-1,74*	-0,45	1,28	-1,3	-1,41	-0,31	1,54	-0,82
SCAR test	-1,68*	-2,61***	-0,61	2,58***	-2,61***	-2,34**	0,43	2,88***	0,16
CAR(-1,2)									
Mean	-0,75%	-1,96%	-2,34%	0,39%	-1,16%	-1,22%	0,49%	1,60%	-0,29%
Std. dev.	4,11%	2,77%	4,30%	3,03%	3,72%	2,92%	3,28%	3,58%	4,48%
Median	-0,69%	-1,27%	-1,89%	-0,05%	-0,72%	-1,40%	-0,97%	2,00%	-0,34%
Minimum	-21,02%	-8,62%	-10,96%	-2,96%	-11,13%	-7,21%	-2,84%	-3,14%	-21,02%
Maximum	36,40%	2,36%	10,23%	8,71%	9,55%	7,04%	5,51%	5,54%	36,40%
T-test	-3,63***	-3,54***	-3,17***	0,46	-2,55**	-2,44**	0,33	0,9	-0,95
SCAR test	-6,97***	-6,07***	-6,04***	0,88	-5,2***	-4,37***	1,01	2,56**	-1,04
CAR(-1,3)									
Mean	-0,83%	-1,73%	-1,74%	0,32%	-1,51%	-1,10%	-0,29%	1,64%	-0,44%
Std. dev.	4,97%	3,37%	5,69%	3,53%	4,30%	4,43%	4,86%	2,76%	5,36%
Median	-0,86%	-1,18%	-2,03%	0,51%	-1,23%	-1,34%	-2,73%	1,62%	-0,47%
Minimum	-25,15%	-10,20%	-11,31%	-3,42%	-12,40%	-8,98%	-5,13%	-1,72%	-25,15%
Maximum	43,86%	3,04%	13,11%	8,84%	9,87%	12,31%	5,18%	5,05%	43,86%
T-test	-3,3***	-2,56**	-1,78*	0,32	-2,87***	-1,44	-0,13	1,19	-1,2
SCAR test	-7,85***	-5,21***	-5,07***	0,55	-7,05***	-3,89***	0,96	2,58***	-2**

For the significance of the *CAR*s two types of test statistics are provided: the t-test and the standardized *CAR* (or: *SCAR*) test (cf. Campbell et al., 1997: section 4.4). The *SCAR* test weighs the *CAR*s with the standard error of the estimation regression (cf. Section 4.1, equation 2). The corresponding p-values in Table 2 show that the *(S)CAR*s are significantly different from zero.

If we consider t_1, the *SCAR* test statistics point to significance of returns for five sectors. However, the mean *CAR* from the full sample is only significant at the 90% confidence level. As they are more significant for t_2 and t_3, this lends support to include these days in the analysis. In t_2 and t_3, four sectors had significant negative returns (sectors 1, 2, 4, and 5), and one had small negative returns (sector 8).[105] Hence, also from a sector perspective it is clear that the returns were negative in general.

Although the *CAR*s seem small, the total value effect is substantial. Multiplying all firms' *CAR*s with their average equity market values in April, 2006, yields a net value effect of € -54 billion for t_2.[106] To put this figure into perspective, we can estimate the change in the opportunity costs of holding allowances by taking the carbon price drop over t_2 (€ 13,14) and multiplying it by the sum of the firms' two remaining allocations for Phase I.[107] We find that these opportunity costs account for 1,22% of the firms' *total* April 2006 average equity market values, and 55,5% of the *change* in the April 2006 average equity market value as caused by the carbon price drop.

5.3 Carbon leakage and carbon-intensity effects

The first section of Table 3 shows the full sample statistics on carbon leakage and the carbon-intensity of production.[108] The variable *carbintens*, or the amount of emissions per unit of revenues, has an average of 0,04%. This implies that, on average, there is one tonne of CO_2 emissions for every 25 Euro in revenues. The associated positive skewness of 6,55 indicates that there are few firms emitting many emissions per unit of revenues and that there are many firms with few emissions per unit of revenues. The mean of *carbleak* (55%) shows that the majority of firms is prone to carbon leakage.

[105] We leave sectors 6 and 7 out of the discussion due to the small number of observations.
[106] The net effect consists of firms with a positive and a negative event effect. The negative effect amounts to € -109,5 billion and the positive effect to € 55.6 billion.
[107] We assume firms used (most) of their 2005 allocations to cover their 2005 emissions. The opportunity costs of holding allowances will then relate to the 2006 allocation but also the 2007 one, from which firms can borrow for their 2006 emissions.
[108] Table 3 and Table 4 below provide these statistics on different numbers of firms. Of the total amount of 393 firms, 16 firms had zero allocations so that *exp* and *borrow* could not be determined; 27 firms had zero emissions so that *carbintens* and *carbileak* could not be determined.

Table 3: Full sample descriptive statistics on the product market, exposure, borrowing, and allowance trading

Full sample	Mean	Std. dev.	Median	Min.	Max.	Skew.	N
carbintens	0,04%	0, 12%	0,003%	0%	1,23%	6,55	366
carbleak	55,22%	49,79%	100%	0%	100%	-0,21	393
carbileak	0,02%	0,06%	0%	0%	0,68%	6,65	366
exp	10,9%	54,86%	12,52%	-928%	100%	-13,44	377
borrow	-78,11%	2.285%	47,48%	-44.237%	232%	-19,3	377
tradeintens	0,25%	1,03%	0%	0%	9,53%	5,58	393
notrade	55%	0,5%	100%	0%	100%	-0,19	393

Table 4: Sector level descriptive statistics on the product market, exposure, borrowing, and allowance trading

Listed firms		Full sample	sector 1	sector 2	sector 3	sector 4	sector 5	sector 6	sector 7	sector 8
		N = 393	N = 25	N = 34	N = 13	N = 67	N = 34	N = 5	N = 4	N = 211
N *carbintens*, where		157	22	1	3	11	3	0	0	117
carbleak=0	A	0,05%	0,28%	0,13%	0,03%	0,01%	0,003%	n.a.	n.a.	0,01%
N *carbintens*, where		217	1	33	10	56	31	5	4	77
carbleak=1	A	0,03%	1E-04%	0,04%	0,19%	0,02%	0,04%	0,05%	0,05%	0,01%
N		366	23	33	12	67	32	5	4	190
carbintens	A	0,04%	0,26%	0,05%	0,15%	0,02%	0,04%	0,05%	0,05%	0,01%
	B	0,02%	0,16%	0,03%	0,09%	0,004%	0,01%	0,02%	0,004%	0,003%
carbileak	A	0,02%	5E-06	0,04%	0,14%	0,02%	0,04%	0,05%	0,05%	0,002%
N		377	23	33	13	67	33	5	4	199
exp	A	10,90%	-1%	10,08%	15,22%	14,51%	24%	11,71%	13,70%	8,68%
	B	-0,99%	-13,92%	22%	9,16%	13,31%	24%	10,53%	21,61%	9,53%
borrow	A	-78,11%	65,40%	48,74%	45,54%	49,18%	51,24%	29,65%	50,05%	-193,40%
	B	48,37%	48,74%	54,91%	46,13%	49,68%	50,35%	-2,53%	49,59%	45,04%
N		393	25	34	13	67	34	5	4	211
tradeintens	A	0,25%	1,64%	0,19%	0,26%	0,07%	0,02%	0,58%	0,00%	0,19%
	B	100%	41,08%	6,59%	3,34%	4,36%	0,80%	2,89%	0,01%	40,93%
notrade	A	54,71%	20%	55,88%	38,46%	53,73%	47,06%	20%	50%	62,09%

Table 4 provides for the variables a full sample average, sector averages (A) and a ‘sector ratio’ (B). The latter is calculated by considering each sector as being one ’firm’. The allocations, surrenders, allowance purchases and sales are summed up per sector.

Both the sector average (A) and sector ratio (B) indicate that especially sector 1 (Power & Heat) but also sector 3 (Cement & Lime) emit most CO_2 per unit of revenue. Compared to the other sectors, their production is three to twenty-six times more carbon-intensive. However, sector 1 and sector 3 differ with respect to carbon leakage. In accordance with Hypothesis H.1, sector 3 with its high carbon leakage has positive *CAR*s due to the carbon price drop. And sector 1 with no carbon leakage has negative *CAR*s, which is in accordance with H.2. The outcomes of sectors 4, 5, and 8 are not in line with H.1 or H.2 since positive *CAR*s were to be expected, given their carbon leakage.

Furthermore, Table 4 shows that the average carbon-intensity is larger for firms without carbon leakage (0,05%) than for those with carbon leakage (0,03%). This is mainly due to the relatively high carbon-intensity of Sector 1 (0,28%). Without sector 1 the statistics point out that, when subject to carbon leakage, firms produce with a relatively higher carbon-intensity.

5.4 Exposure and borrowing effects

Table 3 further reports the descriptive statistics for the variables *exp* and *borrow*. It shows most firms were long on allowances; see the positive average and median values of *exp*.

The variable *borrow* is the ratio of the stock of allowances on the 30th of April, 2006, divided by the allocations of 2005 and 2006. The mean of -78% shows that the average firm expended and sold less allowances than it purchased. However, with 47,5% the median firm expended 95% of its 2005 allocation and banked the remainder plus the 2006 allocation. This implies a few firms skew the *borrow* variable towards a large negative mean, i.e., most firms were long in allowances.

That these surpluses were not subsequently sold off is an indication that many did not foresee the carbon price drop. On the other hand, the picture from *borrow* may be distorted. Our data only contains transactions from the spot market but not the derivatives market. Firms which purchased allowances on the spot market and sold them (at higher prices) through forwards and futures thus appear as not having foreseen the carbon price drop, while they actually may have profited from it via the derivatives market. This may be the case for three firms (Barclays PLC, AB Electrolux, and Severn Trent PLC) which had highly negative borrow values.[109]

The sector perspective on *exp* and *borrow* is provided in the second section of Table 4. For most sectors the averages differ from their sector ratios, but the signs do not. The result remains that all except sector 1 (Power & Heat) are long on allowances. Interestingly, the full sample

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[109] Relative to their purchases and sales, their allocations and emissions were very small. The outlier statistics did not detect these three firms as outliers, so they were included in the analysis.

average of 11% differs from the full sample sector ratio for the EU ETS of -1%. It implies that, on average, firms are long but on the whole the EU ETS is short. This number is close to the range of the EU ETS allocation estimations from Ellerman and Buchner (2008) and Anderson and Di Maria (2011). These were in the order of +0,6% and -0,5%, respectively. Hence, although the number is small, in aggregate the listed firms faced pressure to reduce their pollution.

The sector values for *borrow* are in accordance with those of Table 3 as values were in the 45-50% range. Only sectors 1, 5, and 7 borrowed from their 2006 allocations as their *borrow* rates were in the 50-100% range. For sector 1 it is to be expected to borrow given its shortfall in allowances. Sector 5 (Pulp & Paper), however, is long in allowances but the data show that pulp and paper firms used 51% of their two allocation tranches, either via covering their emissions or via net sales.

5.5 Trade effects

The last statistics in Table 3 are on the allowance trade. As the zero median of *tradeintens* indicates, most firms did not trade in allowances. The mean of *notrade* indicates this was the case for 55% of firms. Furthermore, the average firm's share of total EU ETS purchases and sales was 0,25%. The skewness of 5,58 indicates that a few firms conducted most of the trade in allowances.

The trade differences among industry sectors are provided in the last section of Table 4. The sector ratios of *tradeintens* show that most trade originates from sector 1 (Power & Heat) and 8 (Unidentified / Others) with, respectively, 41,1% and 40,9% of total allowance trade. The sector averages, though, indicate that the average firm in sectors 2, 3, and 6 traded about as much or even more than the average firm within sector 8. Sectors 4, 5, and 7 were the least active.

5.6 Cross-sectional regression

In the OLS regressions the statistics point to a non-normal distribution of the residuals.[110] Normality of residuals, though, is not a sufficient condition for obtaining consistent estimates. In order to test whether the assumptions of the regression models are correct, Long and

[110] To detect outliers, the deviation of the residual, the leverage and influence of the observation were considered (Baum, 2006: section 5.2.10). Nature Group PLC and Providence Resources PLC were consistently detected and therefore left out of the analysis.

Trivedi (1992) suggests applying two types of specification tests: the robust LM Ramsey's RESET test and the Information Matrix (IM) test. If these tests are passed, the "interpretation of OLS estimates and application of standard statistical tests are justified" (Long and Trivedi, 1992).

There are five hypotheses to test over three event windows.[111] We group the variables in four blocks related to these hypotheses. Then we take up all significant variables in a subsequent regression. In Table 5 the OLS results with robust clustered standard errors are provided for the three windows.[112] The two specification tests do not point towards a misspecification of the estimated model.

[111] We performed several robustness checks. More information is available on request. Concerning endogeneity, we expect it to be minor. The abnormal returns (i.e., changes in the firms' expected profitability) as well as the independent variables are in relative rather than absolute terms. During the small event window, unobserved heterogeneous factors from the error term (e.g., productivity levels) are therefore unlikely to have changed and thereby impacted the abnormal returns via the covariates. Furthermore, the event was not anticipated (cf. footnote 91) and it was not induced by firms themselves, but by the EU Member States release of emissions information.

[112] We use robust clustered standard errors based on the eight industry sectors.

Table 5: OLS regressions on the CARs from event windows t_1, t_2, and t_3

	Event window t_1					Event window t_2					Event window t_3				
	H.1-H.2	H.3	H.4	H.5	H.1-H.5	H.1-H.2	H.3	H.4	H.5	H.1-H.5	H.1-H.2	H.3	H.4	H.5	H.1-H.5
carbintens	-1,649**				-1,531**	-3,782***				-4,086**	-1,339*				-3,107
	(0,043)				(0,022)	(0,0004)				(0,017)	(0,067)				(0,251)
carbleak	-0,0003					-0,003					0,001				
	(0,916)					(0,187)					(0,711)				
carbileak	0,005					-1,831					-7,767				
	(0,997)					(0,626)					(0,161)				
tradeintens		-0,002*			-0,0005		-0,003**			-0,0003		-0,003*			-0,0005
		(0,08)			(0,52)		(0,042)			(0,682)		(0,082)			(0,761)
notrade		-0,006					-0,005					-0,008			
		(0,144)					(0,377)					(0,328)			
exp			1,64E-05*		1,29E-05**			1,56E-05					1,27E-05		
			(0,099)		(0,036)			(0,128)					(0,348)		
borrow				5,56E-08*	-2,6E-08				-1,3E-07					-4,5E-07***	-5,2E-07
				(0,066)	(0,832)				(0,211)					(0,001)	(0,123)
constant	-0,002	0,001	-0,002**	-0,002*	-0,002**	-0,004	-0,004	-0,007*	-0,007*	-0,006*	-0,007**	-0,003	-0,008**	-0,008**	-0,007**
	(0,421)	(0,72)	(0,044)	(0,051)	(0,049)	(0,164)	(0,601)	(0,072)	(0,073)	(0,072)	(0,022)	(0,637)	(0,032)	(0,029)	(0,014)
R^2	0,005	0,011	0,001	0,000	0,006	0,019	0,008	0,0005	0,0001	0,016	0,014	0,007	0,0002	0,0005	0,007
Adj. R^2	-0,003	0,006	-0,002	-0,003	-0,005	0,011	0,003	-0,002	-0,003	0,011	0,006	0,002	-0,002	-0,002	-0,001
N	366	393	377	377	366	366	393	377	377	366	366	393	377	377	366
F-test	0,110	0,192	0,099	0,066	0,044	0,001	0,008	0,128	0,211	0,005	0,010	0,188	0,348	0,001	0,002
RESET	0,292	0,151	0,157	0,355	0,297	0,496	0,163	0,668	0,426	0,501	0,136	0,197	0,607	0,497	0,233
IM_total	0,071	0,144	0,109	0,102	0,781	0,806	0,430	0,714	0,720	0,955	0,803	0,610	0,693	0,717	0,998

** / ** / ***: 90% / 95% / 99% confidence level. P-values are within brackets, R^2 is the (adjusted) coefficient of determination, N the number of observations. Null of RESET p-value: correct and robust specified conditional mean of the dependent variable. Null of IM-test p-value: joint homoscedasticity and normality of the errors (Long and Trivedi, 1992). Variables are estimated with robust clustered standard errors, but not the IM-test statistics as STATA 12 does not provide these with clustered errors.*

A first inference one can make is that the fit of the model is weak, given the low (adjusted) R-squared. Yet, this is to be expected since the carbon price effect only indirectly relates to share prices. There can always be non-EU ETS related factors playing a role in determining the share price movements, e.g., changes in the macro-economic environment. And unlike the selected EU ETS variables, it may well be that the EU ETS impact on share prices manifests itself through other channels. For example, a firm's state of abatement technology and business strategy regarding climate change regulation, i.e., factors which are hardly measurable. Related to that, the carbon price shock may have changed investors' expectations on the EU ETS future stringency, and that the carbon price drop induced unanimity among policymakers for decreasing the EU ETS cap. Indeed, in October, 2006, the European Commission announced stricter NAPs for Phase II. This might explain why the abnormal returns were negative, even though lower carbon prices should be conceived as good news for cost-effectively achieving emission targets.

Over the event windows, *carbintens*, *tradeintens*, *exp,* and *borrow* had a significant impact on the *CAR*s. The variable of *carbintens* shows up in two full model regressions, *exp* in one, and *borrow* and *tradeintens* in none of them.

The coefficient on *carbintens* is negative, indicating that the carbon price drop has a more negative impact on share prices of dirtier firms. For example, for event window t_2, if a firm's *carbintens* increased by one standard deviation, this would lead to an average *CAR*-decrease of -0,41%. Relative to the *CAR*-average of -0,8% for this window, this is quite substantial. That investors value carbon-intensity negatively is a sign that the EU ETS is valued as restricting pollution. Firms are considered more profitable with lower carbon-intensity rates as these signal towards better abatement capacities. This finding is in line with Koch and Bassen (2013) and runs counter to Oestreich and Tsiakas (2012) who concluded that investors demand a higher carbon risk premium for the (expected higher) cost of capital of dirtier firms.

The insignificance of *carbleak* leads to a rejection of Hypotheses H.1 and H.2. The descriptive statistics (cf. Section 5.3) showed that only sector 1 (Power & Heat) and sector 3 (Cement & Lime) provide support for H.1 and H.2, while the support of the six other sectors was the opposite. There can be several reasons for these incompatible findings. For one thing, the variable *carbleak* may not have sufficient detail. Unknown is the actual carbon pass-through rate by firms. It is further probable that this cost pass-through threshold, for which market value impacts turn positive, does not lie at/above 100% but at lower rates. Further research is necessary to find this out.

The second variable, *exp*, is only significant in t_1. The positive estimate of *exp* indicates that the carbon price drop led to larger share price increases for firms which were more 'long' or less 'short' on allowances. Increasing *exp* by 10% translates into an average *CAR* impact of 0,013%. Since the full sample average of event window t_1 equals -0,3% its impact is small. That *exp* is positively related with the *CAR*s is in contrast with Hypothesis H.3. This positive *exp*-to-*CAR*s relationship is in line with Abrell et al. (2011) that over-allocated firms were more profitable, the latter of which should correspond to higher share prices.

The impact on *CAR*s from trade, or *tradeintens* and *notrade*, is absent in the full model regressions. It is likely that *carbintens* and/or *exp* captured the variance from the *CAR*s instead. This can also explain why *borrow* is insignificant, since the only difference in the definitions of *exp* and *borrow* is the net sales in allowances. There is thus no evidence that investors valued the firms' net sales of allowances, or that value is derived from the being a large trader, irrespective of them being buyers or sellers. Hence, both Hypothesis H.4 and H.5 need to be rejected.

In one respect it is surprising that the trade variables do not come up in the regressions. As listed firms normally manage their currency exposure, it is probable they do that for their carbon exposure as well. And as the carbon market was relatively new and carbon prices were high, market traders could have engaged in profitable trading strategies. Although they may have done so, it had no discernible effect on share prices. Nevertheless, it is also not surprising this carbon trade effect is missing. Few measures are available for investors to gauge a firm's trade activity. Data on forwards and futures positions taken is not publicly available. Besides, the EUTL data is published 5 years after an EU ETS calendar year. In some U.S. emissions trading schemes data on emissions is published daily and annually on the allowances transferred. While continuous monitoring of greenhouse gases may be expensive (at least for now), there should be no technical limits on more frequent publications of the transfer of allowances. Without a view on the trade in allowances, one cannot discern whether firms e.g., borrowed or stockpiled unused allowances. This information shortage constrains markets in realizing their valuable allocation properties.

Another information constraint results from the compliance timing as laid out in the EU ETS Directives (EC, 2003; EC, 2009a). While (currently) allowance auctions are spread over the calendar year and thus ensure a gradual feed-in of information, there is just one moment in the year that all firms surrender their allowances. It will be conducive to market certainty if there are more of such moments during the year (e.g., Holland and Moore, 2012) and that the European Commission subsequently reports on these compliance moments.[113] This would have prevented or at least reduced the April 2006 shock. The more that signals on scarcity are held up, the more difficult it becomes for firms to forecast whether they have planned enough emission-reduction projects. If the release of information on the scarcity in the EU ETS is stepped up, situations of over-allocation such as the EU ETS faces currently are more likely to be averted.

6. Conclusion

Did EU ETS firms' shareholders interpret the April 2006 carbon price drop as significant and, if so, how did the event's impact differ among firms' allocations and transactions? Through an event study the cumulative abnormal returns (*CAR*s), i.e., the event-induced share price returns, were derived from a sample of exchange-listed firms participating in the EU ETS. The *CAR*s statistics indicate that shareholders interpreted the April 2006 carbon price drop as having a negative effect on the future profitability of the sample of firms. In that sense, and as we conclude from our methodological framework, the EU ETS did 'bite'.

For the share price responsiveness to the EU ETS three groups of variables were checked: 1) the product's carbon-intensity and carbon leakage, 2) the short and medium-term allowance holdings, and 3) the trade in allowances. The results indicate that the product's carbon-intensity and medium-term allowance holdings were, respectively, negatively and positively related to the firms' share prices. As to the medium-term allowance holdings, we expected that the carbon price drop

[113] While Holland and Moore (2012) is on the Los Angeles NO_X market, it may be applicable to (non-point) CO_2 emissions as well.

would increase the profits for firms having allowances shortages, *et vice versa*. Since we found opposite results, the market possibly incorporates a longer time horizon than expected. With future expected stringency of the EU ETS, firms are considered more competitive with lower carbon-intensity rates and larger allowance holdings as both are signals of better abatement capacities. The EU ETS is thus valued as a restriction on pollution.

Finally, the firms' trade activity in allowances was not value-relevant. This result may well be the consequence of investors lacking sufficient data on the firms' allowance trade. A valuation will then be difficult to make when it is not known whether firms e.g., borrowed or stockpiled unused allowances. The market will therefore benefit if the European Commission increases the frequency of publications of the emissions of firms and their allowance transfers.

CHAPTER 5
EU Emissions Trading by Energy Firms[114]

1. Introduction

The European Union Emissions Trading Scheme (EU ETS) was launched in 2005 to cost-effectively reduce greenhouse gases in several industry sectors. The mechanism behind the EU ETS is a cap-and-trade system where the 'cap' is the aggregate sum of the EU Member States' emissions reduction targets and the subsequent 'trade' in allowances underlying the cap is left to the market. Allowance trades are thus an essential policy component, especially for the energy sector[115], which takes up the largest share of EU ETS emissions (approximately 70%). Energy firms are therefore more likely to leave their mark on the carbon market.

Incentives to trade are themselves a function of whether firms need to tap the carbon market. Firms can behave self-sufficiently by allocating production, emissions and, hence, allowances within firm boundaries. The more cost-effective this will be, the fewer incentives firms have to trade on the carbon market.

The aim of this chapter is to empirically analyze the actual allowance trading of energy firms and to determine the importance of allowance trade drivers when firms are either self-sufficient or not in terms of carbon allowances. The central question of this chapter is therefore as follows: do European energy firms depend less on the EU carbon market (EU ETS) when they are better able to pool their in-house pollution abatement potential?

This chapter applies an integrated analysis of market and firm-specific characteristics on EU ETS allowance trades by energy firms. It contributes to the understanding of what drives energy firms to consume,

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[114] This article version is available as Jong and Zeitlberger (2017). We are grateful for the useful comments we received from Oscar Couwenberg, Edwin O. Fischer, Henryk Gurgul, Michael Murg, Matthias Pachler, Herwig Pilaj, Stefan P. Schleicher, Edwin Woerdman, and from participants at the Netherlands Environmental Assessment Agency KLE-DO lecture (2 April, 2015), the World Congress of Environmental and Resource Economists (June, 28 - July, 2, 2014), the Energy Systems Conference (24–25 June, 2014) and the 6th EDGaR Research Day (24 April, 2014). Any remaining errors are our own.

[115] In Section 4.2.2 we define which industry categories make up the energy sector.

hold, and exchange their allowances. For policymakers and businesses, these insights will be crucial for a better understanding of the functioning of the EU ETS.

The chapter is organized as follows. Section 2 reviews the literature on allowance trading incentives for energy firms. Section 3 formulates hypotheses, upon which Section 4 discusses the methodology. The descriptive statistics are presented in Section 5. Section 6 provides the results and discussion. Section 7 concludes the chapter and discusses policy implications.

2. Energy firms and allowance trade

Theory suggests that demand for and supply of carbon allowances can realize an efficient allocation of pollution abatement (e.g., Baumol and Oates, 1988). If governments determine the allowance supply and if they have perfect information on the allowance demand of firms, for example, how demand changes as a function of the carbon contents of production, governments can allocate the first-best amounts of allowances to the carbon-regulated firms. Firms will adjust their emissions and, hence, production processes to these allowance allocations. And given this perfect allowance allocation, firms do not have allowance deficits or surpluses. Consequently, they do not need to source the carbon market.

Given imperfect information and the resultant imperfect allowance allocations, firms may need to source the carbon market. As of the start of the EU ETS, this is especially the case for energy firms. EU Member States 'under-allocated' electricity firms (i.e., they needed more allowances to cover their emissions than they received in allowance allocations), while other industrial sectors and the EU ETS as a whole were over-allocated. EU Member States considered that electricity firms were best able to cost-effectively abate pollution through fuel switching, and that their production is not susceptible to international competition (e.g., Ellerman et al., 2007, Part I).

Moreover, from an institutional point of view, energy firms source markets in matching their customers' demand with the volatile nature of production. For example, spot or derivative markets allow dispatching a firm's own plants (if available) but also tap into other firms' production capacity (if needed).[116,117] Carbon markets also provide such sourcing flexibility. For example, carbon markets enable firms with allowance deficits to 'outsource' the abatement of their pollution emissions to firms with allowance surpluses.[118]

Such firm-market interactions are not only driven by production and pollution abatement costs. If the transaction costs for contracting property within firm boundaries are lower than the transaction costs for contracting market players' property (e.g., on the carbon market), firms will consider more in- than outsourcing of their transactions. In the law and economics literature this is called the 'make-or-buy' decision.[119]

Typical emissions trading schemes, including the EU ETS, share two characteristics which reduce the need for firms to source the carbon market, in other words, to behave 'self-sufficiently' (Hanemann, 2010; Kreutzer, 2006). The first characteristic is that firms can abate pollution emissions, and exchange allowances between subsidiaries before they opt for the carbon market (i.e., when within-firm options have run out). Despite the over-allocation of the EU ETS in aggregate, Jaraitė and Di Maria (2012) show that the energy sector did abate emissions (i.e., within firm boundaries).[120] Moreover, especially larger firms in the combustion (i.e., energy) sector were likely to trade between their subsidiaries (e.g., Zaklan, 2013).[121]

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116 The latter can be optimal, for example, if prevailing market prices are low and/or capacity and operational costs are high.

117 The empirical literature on how energy firms actually optimize their capacity is scarce, primarily because these firm-level data are rarely (made) available. Typical analyses examine how bidding behavior is a function of market power (e.g., Hu et al., 2005; Perekhodtsev and Baselice, 2011).

118 Another institutional argument is that in some countries where electricity prices are regulated (e.g. Spain), electricity firms have to prove the carbon costs in order to be allowed to pass-through the carbon price on the electricity price. This may be a reason they prefer to trade via the market, as to ensure that a market price is given. Our analysis accounts for country-effects due to a panel-data framework.

119 The make-or-buy' decision is inspired by Ronald Coase's "Theory of the Firm" (Coase, 1937).

120 Bel and Joseph (2015) show that the EU ETS cut emissions, but more pollution was abated because of the 2008/09 economic crisis.

121 Moreover, the current (EC, 2009a) and previous (EC, 2003) EU ETS Directives allow (de facto) borrowing of allowances, as the next calendar year's allocation will be received (in February) before the current year's allowances need to be

The second characteristic facilitating self-sufficient behavior is that carbon allowances can be banked within and/or between compliance periods.[122] This enables firms to optimize allowance holdings over time, for example, by hedging against future carbon price increases. Already at the beginning of the EU ETS, carbon forward and futures markets were considered to be liquid, and more so than spot markets (Zeitlberger and Brauneis, 2016).

This chapter fills a gap in the firm-level empirical literature on allowance banking and trading. This literature is limited because, in addition to allocations and emissions, allowance transactions data are needed for estimates on the allowance banks. [123,124] Such transaction data are difficult to obtain from the European Union Transaction Log (EUTL), are only available after a time delay, and are not at the firm level.[125] Most carbon market analyses therefore focus only on the (empirically available) allocations and emissions but lack allowance trade-behavioral analyses. This shortcoming is significant because the energy sector had the largest share of inter-firm trade in the EU ETS (Jong et al., 2014).

This study analyzes factors that affect the extent to which firms trade allowances. By focusing on EUTL transactions, our analysis is comparable to Zaklan (2013) and Jaraitė and Kažukauskas (2014) in terms of

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surrendered (in April). In Phase I (2005-2007), the energy sector borrowed most from its subsequent allocations (Jong et al., 2014).

122 Only EU ETS Phase I (2005-2007) allowances could not be banked toward later phases.

123 The theoretical literature is more developed. Most empirical literature analyzing changes in the allowance holdings of firms focuses on US emissions trading schemes. Examples of the findings are that SO_2 allowance holdings are responsive to future changes in the cap (Ellerman and Montero, 2007); firms with higher SO_2 pollution rates maintain relatively more allowances for precautionary purposes (Rousse and Sevi, 2007); and allowance holdings respond as expected to the convenience yield and to price differences between low- and high-sulphur coal (Considine and Larson, 2006). However, plant owners did not appear to take full advantage of the available cost savings the SO_2 allowance market offered (Swinton, 2004).

124 The only carbon allowance holdings estimates that we found were in Martino and Trotignon (2013) on EU ETS totals and in Hintermann (2015) at the electricity firm level. Both analyses concern Phase I but are limited to the annual level.

125 This delay used to be five years, but a recent Commission Regulation (no. 389/2013) decreased it to three years. Although Phase I allowances become void in Phase II, an analysis of Phase I is still useful when firms were incentivized to wind up their allowance holdings.

underlying data.[126] Instead of including other EU ETS industrial sectors, this chapter concentrates on the energy sector (e.g., fossil fuels usage, fuel prices).[127] It further tests for self-sufficiency vis-à-vis the carbon market, and takes into account allowance banking, and finance-related factors affecting trades (e.g., on arbitrage opportunities). As a result, this chapter contributes to an energy market-specific understanding for EU ETS policymakers, for example, whether and how firms actually utilize the carbon market in meeting their emission constraints.

3. Theoretical framework and hypotheses

To capture the 'make' part in the abovementioned 'make-or-buy' concept, we assume that firms can behave self-sufficiently or spread their carbon costs within firm boundaries if they can flexibly adjust their carbon intensity of production. Energy firms can manage this carbon intensity through *more* and *diverse* production sources: by spreading the same production over a different number of installations and/or over different fuel-sourced installations (i.e., fuel switching). This also implies that allowance holdings will follow such within-firm optimization of production.[128] The incentives to trade for self-sufficient firms are therefore reduced (but do not necessarily disappear) because they are better able than less self-sufficient firms to absorb market shocks. The first and second hypotheses are therefore as follows:

(**H.1**) Self-sufficient firms trade less responsively than less self-sufficient firms to changes in allowance demand.

(**H.2**) Self-sufficient firms conduct more within- than between-firm trades than less self-sufficient firms.

Key among these allowance demand factors is the firms' EU ETS compliance. Firms are expected to surrender allowances corresponding to

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[126] Contrary to Jaraitė and Kažukauskas (2014), Betz and Schmidt (2015), and Fan et al. (2016) we do not distinguish between different EUTL account types but consider all transactions to be trades which occur to and from the accounts owned by the same firms, as in Balietti (2016) and Liu et al. (2016). Transactions are distinguished whether they occur within firm boundaries (i.e., *INTRAGUO*) or outside of firm boundaries (i.e., *INTERGUO*) (see Section 4.2.1).

[127] Only in cases where such firms take the opposite position in allowance transactions with an energy firm.

[128] Such within-firm holdings will be further optimized via the pooling, borrowing, and/or banking of allowances.

their emissions to avoid being penalized. Moreover, our sample runs towards the end of EU ETS Phase I, when Phase I allowances became void for Phase II. Firms are therefore expected to redeem their (Phase I) allowance surpluses. Given the incentives to both redeem allowance surpluses and surrender for allowance deficits, we hypothesize that the allowance holdings trajectory of firms is to minimize any differences between their allocations and emissions.[129] The third hypothesis is therefore as follows:

> **(H.3)** Firms minimize their allocations and emissions differences through allowances purchases and sales, and these differences converge to zero towards the end of EU ETS Phase I.

Furthermore, in managing their emissions, energy firms control two main channels. The first, production, generally needs to follow energy demand.[130] Firms will need more (fewer) allowances when demand is higher (lower) than expected. The fourth hypothesis is thus as follows:

> **(H.4)** Allowance purchases are positively related to higher energy demand levels, and allowance sales are positively related to lower energy demand levels.

The second channel affecting emissions, the emissions per unit of production, is typically controlled through fuel switching between gas and coal. Switching may not only be triggered by coal-gas price differences, but also if firms have limited alternative (non-fossil) fuels to produce energy. Given that more emissions are involved with coal than with gas, thus requiring more allowances, we hypothesize as follows:

> **(H.5.1)** Firms purchase allowances if coal prices decrease and/or gas prices increase.
>
> **(H.5.2)** The effect of H.5.1 is amplified if fossil-based fuels (i.e., coal and gas) make up a larger part of the inputs.

Moreover, meeting allowance demand from production and emissions can be costly if carbon price and volume risks are not accounted for. As energy

[129] Yet, firms may want to make sure to have sufficient reserves of allowances to cover emissions at or close to the end of Phase I, when it might be costly to cover for (unforeseen) allowance shortfalls.
[130] ‘Smart’ energy (e.g., through interruptible contracts) was not important as a source of supply in our sample period.

production, and thus emissions, is volatile and typically planned months or even years in advance, derivative markets can prevent these risks from adversely affecting production decisions.[131,132] Based on the reasoning of Smith Jr. (2008), firms are likely to hedge on the carbon market when they have few within-firm possibilities to optimize their costs – in other words, when they cannot behave self-sufficiently. Hence, less self-sufficient firms will not only trade more frequently, they will also up- and downscale their carbon allowance holdings according to the volatility of energy production. We expect here that systematic purchasing and selling, or 'bi-directional' trading, is indicative of hedging. Conversely, the transactions of self-sufficient firms are expected to be 'uni-directional', implying that they predominantly purchase (sell) when allocations-to-emissions gaps are negative (positive). The sixth hypothesis is therefore as follows:

> **(H.6.1)** Self-sufficient firms have a propensity to trade uni-directionally,
> **(H.6.2)** Less self-sufficient firms have a propensity to trade bi-directionally.

Finally, this analysis will take into account that firms purchase from or sell to the carbon market to trade given arbitrage opportunities and price expectations. In EU ETS Phase I (2005-2007) carbon forward and futures markets were considered to be liquid, which was less the case for spot markets (Zeitlberger and Brauneis, 2016). With (spot) market illiquidity the carbon price may not reflect all publicly available information, which could be due to missing market participants in this phase. Better informed, active participants therefore might have been able to use mispricing. For firms trading allowances, differences between spot and forward or futures markets can give arbitrage opportunities. For example, given negligible storage costs of allowances and differences between spot and futures prices, firms can profit by purchasing allowances via the spot market in the

[131] The possibility of banking allowances is one of the main conditions for carbon derivatives (e.g., Maeda, 2004). In addition, allowance banking has been an efficient strategy to reduce compliance costs (e.g., Ellerman and Montero, 2007).
[132] Carbon hedging structures depend on the selected timeframes and market prices in the portfolio. However, because the carbon price behaves in a volatile and discontinuous manner, hedging structures can unexpectedly lose their optimality (Daskalakis et al., 2009).

present and by selling them later via futures markets, and *vice versa*. For these two elements, we hypothesize the following:

(H.7) Firms trade allowances given carbon price expectations and arbitrage opportunities between carbon spot and futures prices.

4. Methodology

4.1 The model setup

For the response variable, the daily net allowance amounts traded, we take the within-day allowance transactions from the European Transaction Log (EUTL). We aggregate and, hence, net these transactions towards the daily level.[133,134,135] To tackle the small to extremely large

[133] Most corporate owners of the EUTL accounts were identified by the 'Ownership Links and Enhanced EUTL Dataset' through their Bureau van Dijk's (BvD) company codes. The dataset (Jaraitė et al., 2013b) as well as the technical report (Jaraitė et al., 2013a) are joint efforts by researchers from different EU-based universities.

[134] This aggregation only affects cases where similar parties conducted multiple daily transactions. In addition, because firms are aggregated at the national and 'Global Ultimate Owner' (GUO) levels (cf. Section 4.2.1), allowance trades between national GUO-subsidiaries are netted out. Furthermore, for all of the regressions in Section 6, aggregating daily data to the monthly level does not improve the model fit (results are available upon request).

[135] The transactions from the EUTL are the settlements as recorded in the EU ETS allowance registries. A limitation is that the EUTL only provides the names of the purchasing and selling parties, the amounts settled, and the time-stamp of the settlement, but not the underlying price and the nature of the contract. This framework makes it difficult to distinguish spot transactions from over-the-counter (OTC) or exchange-based derivatives that may have initiated, intermediated, or finalized the EUTL settlements. An indication regarding the delivery of futures can be obtained by identifying the trade activity in EUTL exchange clearing accounts (Martino and Trotignon, 2013), but because most of the Phase I trades took place OTC, this identification would capture only a small share of the futures trades. Forwards and futures allow firms to flexibly upgrade or downgrade the exposure that they consider to be optimal. For example, exposure can be lowered by adjusting the corresponding derivative positions (e.g., going long while maintaining an overall short position), whereby exchanges of allowance ownership can be cancelled. EUTL transactions are allowance ownership exchanges that must have been beneficial to both transacting parties. We therefore assume that these EUTL transactions are spot trades. However, without the initiated and intermediated transactions, the net benefits of the 'unobserved' observations (i.e., the latent demand) cannot be estimated. As inferences on the firms' decisions to trade are difficult to make, we are limited to estimating the volume and sign of the observed transactions only.

transaction amounts and thereby stabilize the variance, we transformed these transaction amounts by taking the natural logarithm. We next considered a 'double-hurdle' model, as applied in Jaraitė and Kažukauskas (2014). However, this model does not allow the values to be either negative, zero, or positive (i.e., for allowance purchases and sales). Jaraitė and Kažukauskas (2014) therefore separated the data into two dependent variables: one where firms conducted zero or net purchases, and one where firms conducted zero or net sales.[136] The data shows that many firms both purchased and sold allowances, not only during the day but also across days. An example of their behavior is to be net purchasers at day t but net sellers at day t+1.

To accommodate that logarithm-transformed and, hence, continuous values can be negative, zero, and positive, we therefore set up the dependent variable through the 'neglog' transformation (see e.g., Whittaker et al., 2005) in the following way:

$$TRADE_{i,t} = \text{sign}(W_{i,t}) \ln(|W_{i,t}| + 1) \quad (1)$$

where net trade $W_{i,t} = PURCH_{i,t} - SELL_{i,t}$, $PURCH_{i,t}$ and $SELL_{i,t}$ are the allowance purchases and sales of firm i at time t, respectively, and sign($W_{i,t}$) equals 1 if $W_{i,t} > 0$, 0 if $W_{i,t} = 0$ and –1 if $W_{i,t} < 0$.[137]

[136] Moreover, given the many zeroes in the response variable, if the decision to trade is separate from the decision what amounts to exchange, the estimates would be inconsistent if the decision to trade was not random. The panel data approach of Semykina and Wooldridge (2010) allowed us to test for both this selection bias as well as the presence of endogenous regressors. In all regression setups the absence of selection bias and endogeneity cannot be rejected. For the endogenous regressor, we selected the country and daily average of the temperatures from European weather stations as recorded in the European Climate Assessment & Dataset (Klein Tank et al., 2002). The reason we selected temperature is that it should only indirectly affect the emissions per unit of production and thus the demand for carbon allowances. For example, temperatures affect the ability of water to cool down power plants and, thereby, affect the fuel source of choice (e.g., Fthenakis and Kim, 2010). Temperature changes also influence electricity demand (e.g., Pardo et al., 2002).

[137] According to Castellaneta and Zollo (2014), a standard log transformation and a shift parameter making all values positive may not yield asymptotical maximum likelihood results. The 'neglog' transformation "has the same advantages of the log function and also appropriately extends monotonicity to negative values. […] This property is particularly important for financial variables where the sign of the variable corresponds to profit and loss" (Castellaneta and Zollo, 2014).

We apply a panel model framework to accommodate individual firms *i* and time *t* in our firm-level sample as follows:

$$
\begin{aligned}
TRADE_{i,t} = \quad & \beta_{CONSTANT} + \delta_0 NSSUF_i + \\
& + (\beta_1+\delta_1 NSSUF_i)INTRAGUO_{i,t} \\
& + (\beta_2+\delta_2 NSSUF_i)INTERGUO_{i,t} \\
& + (\beta_3+\delta_3 NSSUF_i)LCT_{i,t} \\
& + (\beta_4+\delta_4 NSSUF_i)(LCT)^2_{i,t} \\
& + (\beta_5+\delta_5 NSSUF_i)\,\Delta LEDEM_{i,t} \\
& + (\beta_6+\delta_6 NSSUF_i)EDEM_{i,t} \\
& + (\beta_7+\delta_7 NSSUF_i)\,\Delta FEDEM_{i,t} \\
& + (\beta_8+\delta_8 NSSUF_i)BSPREAD_{i,t} \\
& + (\beta_9+\delta_9 NSSUF_i)SPREAD_{i,t} \\
& + (\beta_{10}+\delta_{10} NSSUF_i)BDIRECT_{i,t} \\
& + (\beta_{11}+\delta_{11} NSSUF_i)UDIRECT_{i,t} \\
& + (\beta_{12}+\delta_{12} NSSUF_i)BSS_{i,t} \\
& + (\beta_{13}+\delta_{13} NSSUF_i)CCA_{i,t} \\
& + (\beta_{14}+\delta_{14} NSSUF_i)QUARTER1_{i,t} \\
& + (\beta_{15}+\delta_{15} NSSUF_i)QUARTER2_{i,t} \\
& + (\beta_{16}+\delta_{16} NSSUF_i)QUARTER4_{i,t} + \mu_i + \varepsilon_{i,\,t} \qquad (2)
\end{aligned}
$$

where subscript *i* stands for the firm (1, ..., 1549) and *t* for the trading day over EU ETS Phase I (February 7, 2005 to April 30, 2008).[138] $TRADE_{i,t}$ is the response variable capturing the daily net allowance amounts traded, and $\beta_{CONSTANT}$ is the intercept coefficient. The dummy variable $NSSUF_i$ is a

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[138] The econometric tests performed on the data point towards the use of panel data models, which account for auto-correlated, heteroskedastic, and panel-correlated structures of the error term. The Breusch-Pagan LM test rejected the pooled model, and the panel data Wooldridge test for autocorrelation rejected the null of no first-order autocorrelation, while the modified Wald statistic rejected the null of group-wise homoscedasticity. We considered it feasible to use generalized least squares models with correlated disturbances, but, unfortunately, we abandoned this effort after Stata 12 was unable to provide results. We therefore selected a fixed effects model with Driscoll-Kraay standard errors and a random effects model with panel-corrected Prais-Winsten standard errors. If the Hausman test rejected the random effects model, we selected the Driscoll-Kraay fixed effects model, and we selected the Prais-Winsten random effects model if otherwise. As the Prais-Winsten model allows for different autocorrelation structures, those with the best R^2 fits were selected. These autocorrelations are common or panel-specific and via time-series or Durbin-Watson setups. For the Driscoll-Kraay models, the default lag order of autocorrelation was selected.

self-sufficiency indicator and is applied as an interaction term (see Section 4.3.1 below). The coefficients β_1 to β_{16} capture the base effects, namely from the more self-sufficient firms (i.e., when $NSSUF_i$=0). If significant, the coefficients δ_1 to δ_{16} shift the intercept $\beta_{CONSTANT}$ and the slopes on the regressors (i.e., from $INTRAGUO_{i,t}$ to $QUARTER4_{i,t}$). Hence, these coefficients capture the differential impacts for *less* self-sufficient firms (i.e., when $NSSUF_i$=1). Both $Y_{i,t}$, $NSSUF_i$, and the regressors are discussed in the remainder of Section 4. Finally, this panel model framework allows for unobserved fixed effects μ_i (see footnote 138). The idiosyncratic shocks are captured by $\varepsilon_{i,t}$.

4.2 Defining firm and energy sector boundaries

4.2.1 Defining firm boundaries

Our data sources have not recorded the level at which allowance trades are managed within firms (e.g., centralized or decentralized). Any assumed allowance management structure is therefore correct for some firms but inadequate for others.[139] We aggregated firm-specific data over the following two 'levels': 1) per country and 2) per Global Ultimate Owner (GUO).[140,141,142] The reason for using the country level is that EU ETS compliance is a national matter, and most EU electricity markets are national. As for the GUO level, we consider it likely that subsidiaries within

[139] Future research may be needed to show the impacts of these industry-structure trade-offs.
[140] GUOs are the 'ultimate' shareholders by controlling at least 50.01% of the shares. An example resulting from this country-GUO merger is that the UK subsidiary (i.e., the country) of GDF SUEZ (i.e., the GUO) contains all of the domestic energy production and UK-registered allowance trades of International Power Ltd. (and others, such as Cofely District Energy Ltd.). In the sample, GDF SUEZ operates in 13 EU member states. It therefore controls 13 of such 'separate' country-GUO entities in the sample.
[141] In calculating *SIZE*, per GUO we sum all of the energy-related operators' assets. GUO-wide assets could be requested, but this approach would incorporate asset values from outside the EU. These assets are then averaged over the 2004-2009 period due to year gaps for several companies (e.g., only 2005 and 2007 but not 2006) and instances where the data started later (e.g., in 2006 instead of 2005).
[142] There are two main types of EU ETS accounts held by firms: Operator Holding Accounts (OHA) and Person Holding Accounts (PHA). Firms have an OHA for each of their installations. PHAs are not installation-specific, and can function as 'central' accounts from which firms conduct trade. We agree that this distinction between account types can provide a degree of (de)centralization. Yet, Bureau van Dijk's company database does not have firm details available at the installation level. We were therefore necessitated to select the national level.

the same country had a (nationally) coordinated allowance management system rather than a decentralized system.[143]

To indicate whether trades took place within a specific GUO such that a firm pools resources and thus behaves self-sufficiently, we create the following dummy variable:

$$INTRAGUO_{i,t} = \Sigma_{\text{INTRAGUO}}(PURCH_{i,t} + SALES_{i,t}) / \Sigma_{\text{INTRAGUO+INTERGUO}}(PURCH_{i,t} + SALES_{i,t}) \quad \text{if } \Sigma_{\text{INTRAGUO+INTERGUO}}(PURCH_{i,t} + SALES_{i,t}) \neq 0$$
$$= 0 \quad \text{if } \Sigma_{\text{INTRAGUO+INTERGUO}}(PURCH_{i,t} + SALES_{i,t}) = 0 \qquad (3)$$

so that $INTRAGUO_{i,t}$ equals the proportion of a firm´s daily trade among subsidiaries, and equals zero if the firm does not trade.[144] Analogous to $INTRAGUO_{i,t}$ we create the dummy variable to indicate whether trades took place between GUOs to capture whether firms do not behave self-sufficiently:

$$INTERGUO_{i,t} = \Sigma_{\text{INTERGUO}}(PURCH_{i,t} + SALES_{i,t}) / \Sigma_{\text{INTRAGUO+INTERGUO}}(PURCH_{i,t} + SALES_{i,t}) \quad \text{if } \Sigma_{\text{INTRAGUO+INTERGUO}}(PURCH_{i,t} + SALES_{i,t}) \neq 0$$
$$= 0 \quad \text{if } \Sigma_{\text{INTRAGUO+INTERGUO}}(PURCH_{i,t} + SALES_{i,t}) = 0 \qquad (4)$$

so that $INTERGUO_{i,t}$ equals the proportion of a firm´s daily trade between other firms' subsidiaries, and equals zero if the firm does not trade. For Hypothesis H.1 to be accepted, namely that self-sufficient firms have more within- than between-firm trades, the regression coefficients will need to be such that $|\beta_{INTRAGUO}| > |\beta_{INTERGUO}|$.

[143] Furthermore, of the total number of identified firms (1549), 227 firms did not trade and were left out of the sample.

[144] The model setup captures allowance holding behavior where (self-sufficient) firms first shift their allowances to one or multiple central EU ETS accounts and, right before the allowance surrender date (the 1st of May), move the required allowances back to their installation accounts. Such trades are between subsidiaries (i.e., $INTRAGUO_{i,t} > 0$), the allowance holdings are to minimize allocation-emissions differences (see Section 4.4 below), and trade is uni-directional (see Section 4.6 below). Furthermore, such firms are labelled as infrequent allowance trading firms (i.e., $FRQ_i = 1$) (see Section 4.3.2 below).

4.2.2 Defining energy sector boundaries

At the operator (not the conglomerate) level, we obtained the industry classification NACE Rev. 2 primary and secondary codes. NACE codes and, hence, firms were selected if they were active in the electricity value chain. Our selection of NACE codes includes the following:
- 'coal': 'mining of hard coal', 'mining of lignite', and 'extraction of peat';
- 'electricity': 'electric power generation, transmission and distribution', 'production of electricity', 'transmission of electricity', 'distribution of electricity', 'trade of electricity', and 'electricity, gas, steam and air conditioning supply';
- 'gas': 'electricity, gas, steam and air conditioning supply', 'extraction of natural gas', 'manufacture of gas; distribution of gaseous fuels through mains', 'manufacture of gas', 'distribution of gaseous fuels through mains', 'trade of gas through mains', and 'extraction of crude petroleum and natural gas';
- 'petroleum': 'extraction of crude petroleum', and 'extraction of crude petroleum and natural gas';
- 'uranium': 'mining of uranium and thorium ores', and 'processing of nuclear fuel'; and
- 'other': 'steam and air conditioning supply', 'wholesale of solid, liquid and gaseous fuels and related products', and 'transport via pipeline'.

Hence, the energy sector as defined here encompasses both electricity firms but also 'non-electricity' firms. For example, these firms extract fuels, trade, and transport energy. In the remainder of the text, references to 'firms' encompass both electricity and non-electricity firms.

4.3 Interaction terms and sample subsets

4.3.1 Interaction terms

As shown above in Section 4.1 and equation (2), the dummy variable $NSSUF_i$ (i.e., 'not self-sufficient') is applied as an interaction term to test for the differential impacts of self-sufficiency. Since 'self-sufficiency' cannot equivocally be measured, we looked for two different indicators for $NSSUF_i$.

The first indicator we constructed is a composite indicator (EQP_i) (i.e., 'equipped') from a set of constant and/or annual variables affecting the firms' carbon intensity. For the second indicator we use the firms' (natural logarithm) asset size ($SIZE_i$). We expect that higher valuations of assets allow firms to behave self-sufficiently. Since EQP_i yielded a lower regression fit than $SIZE_i$, we continue using only $SIZE_i$ (i.e., $NSSUF_i = \{SIZE_i\}$).[145] We turned these into dummy variables, by designating values *below* the *SIZE* or *EQP*-median to equal 1, and 0 otherwise.

To test whether self-sufficient firms trade less responsively to changes in allowance demand (i.e., Hypothesis H.2), the interaction terms δ_1 to δ_{16} in equation (2), which correspond to the effects for *less* self-sufficient firms, need to have an additional impact on the magnitude of the base terms of β_1 to β_{16}. Therefore, to accept H.2, all interaction terms δ need to be such that: $|\beta+\delta| > |\beta|$.[146]

4.3.2 Sample subsets

Furthermore, we apply the regression from equation (2) (including the interaction terms) on subsets of the total sample. To expose differences in allowance trade incentives, these subsets are demarcated based on the firms' frequency of allowance trade. We took two approaches to define this trade frequency.

The first trade frequency subset, FRQ_i, is determined through the firm's average Phase I allowance trade divided by its Phase I total amount exchanged. This variable converges to zero the more a firm trades.[147] FRQ_i approaches one for infrequent traders. FRQ_i is also turned into a dummy variable – as we did above for $SIZE_i$ and EQP_i. The second trade frequency subset is a dummy variable ($ELEC_i$) which equals 1 if a firm owns or controls at least one electricity installation and 0 otherwise. The reasoning is that electricity firms are among the most active traders in the carbon market.

4.4 Allowance demand: compliance

Hypothesis H.3 posits that firms minimize their allocations and emissions differences, and these differences converge to zero towards the

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145 All of the setups using $SIZE_i$ result in better regression fit (R_2) values than with EQP_i. For the discussion below, we therefore selected the $SIZE_i$ interaction term. Indirectly, this analysis will also contribute to the transaction costs literature, which posits that both EU ETS implementation and trading costs are declining by firm size (e.g., Jaraitė et al., 2010). The discussion of the composite indicator EQP_i is available upon request.

146 Moreover, in Section 4.2.1 we mention that, to accept Hypothesis H.1, the regression coefficients need to be such that $|\beta_{INTRAGUO}|<|\beta_{INTERGUO}|$. Given the absence of the interaction term δ, this inequality does not rule out that $INTERGUO_{i,t}$ or $INTRAGUO_{i,t}$ meet the conditions for Hypothesis H.2.

147 We calculated $(1/T \sum^{T}_{t=1} PURCH_{i,t} + SELL_{i,t}) / (\sum^{T}_{t=1} PURCH_{i,t} + SELL_{i,t})$.

end of EU ETS Phase I. We therefore constructed a compliance trajectory indicator ($LCT_{i,t}$) to capture whether allowance holdings follow a trajectory that minimizes the difference between allocations ($ALLOC_i$) and emissions ($EMISS_i$) taking into account purchases ($PURCH_{i,t}$) and sales ($SELL_{i,t}$). $LCT_{i,t}$ is defined as follows:

$$LCT_{i,t} = \text{sign}(Z_{j,t-1}) \ln(|Z_{j,t-1}| + 1) \quad (5)$$

$$Z_{j,t-1} = \sum^{J}_{i \subset j} [ALLOC_i - EMISS_i + \sum^{t}_{t=1} PURCH_{i,t-1} - \sum^{t}_{t=1} SELL_{i,t-1}] \quad (6)$$

where $\sum^{T}_{t=1} PURCH_{i,t-1}$ and $\sum^{T}_{t=1} SELL_{i,t-1}$ are the cumulative allowance purchases and sales from $t = 1$, the first day as of when trades commenced in EU ETS Phase I (Monday, February 7th, 2005), to $T = 843$ days (Wednesday, April 30th, 2008), and where sign($Z_{j,t-1}$) equals 1 if $Z_{j,t-1} > 0$, 0 if $Z_{j,t-1} = 0$ and −1 if $Z_{j,t-1} < 0$, and where subscript j stands for the conglomerate to which firm i belongs.[148,149]

$Z_{j,t-1}$ is calculated for every trading day t. It is the difference between what a firm expects to be allocated and will have emitted over the whole Phase I, taking into account its cumulative trading until day t.[150] Firms are expected to trade allowances to decrease their allowance positions: if $Z_{j,t-1}>0$, they are allocated or have purchased more allowances than they sold

148 A ratio would be less useful for $LCT_{i,t}$ because these four parameters can take up zero or positive values in all combinations. For example, also firms with zero allocations and zero emissions are expected to have sold their allowances at the end of Phase I.

149 Through the four variables which cumulatively make up the allowance holdings within $Z_{j,t}$, $LCT_{i,t}$ implicitly takes allowance banking and borrowing into account *within* Phase I (2005-2007). Firms can bank allowances if they can carry forward allowances for later compliance or trading purposes (i.e., when the allowances are not rendered invalid over time). Moreover, firms can borrow allowances by meeting their current year's obligations with the allowance allocations they received for the upcoming year. In addition, defining $LCT_{i,t}$ at the conglomerate level (j) prevents diverging values when allowances are pooled within firm boundaries.

150 For emissions ($EMISS_i$), we take the (*ex-post*) verified sum of emissions over Phase I. Firms will be (formally) certain of their emissions upon receiving their monitoring reports (i.e., after each calendar year). As energy production is typically booked ahead of time, we assume that firms are able to predict their cumulative emissions within a certain bandwidth. Based on these estimates, future allocations of allowances should be predictable as well given the terms laid out in the Phase I National Allocation Plans. We therefore take the sum of the three allocations (to be) received over Phase I ($ALLOC_i$). It is then up to firms to minimize any differences between their allocations and emissions through purchases and sales.

or needed to cover for their emissions, *et vice versa*. $LCT_{i,t}$ subsequently transforms $Z_{j,t-1}$ (as is done with $TRADE_{i,t}$) since values of $Z_{j,t-1}$ are (also) 1) continuous, 2) negative, zero, or positive, and 3) small to extremely large. Besides, while $LCT_{i,t}$ is considered at t, it is a function of $Z_{j,t-1}$ which is at t-1 (i.e., 1-day lagged). This is done so that yesterday's *deviations* from $Z_{j,t-1} \neq 0$ incentivize firms to trade today. $LCT_{i,t}$ is therefore constructed so that positive (negative) values should initiate firms to sell (purchase) allowances.[151,152]

Since $TRADE_{i,t}$ is larger (smaller) than zero with allowance purchases (sales), $LCT_{i,t}$ should be negatively related to $TRADE_{i,t}$ for Hypothesis H.3 to be accepted.

4.5 Allowance demand: energy demand and fuel-switching

Hypothesis H.4 posits that allowance purchases are positively related to higher energy demand levels, and allowance sales are positively related to lower energy demand levels. To test H.4, we relate the (country-level) current monthly MWh electricity demand ($EDEM_{i,t}$), its change with respect to the previous month ($\Delta LEDEM_{i,t}$), and its change with respect to the next month ($\Delta FEDEM_{i,t}$) to allowance trade.[153,154] Firms that are self-sufficient are expected to be less responsive with respect to their allowance purchases to electricity demand changes.

Moreover, to test whether firms purchase allowances if coal prices decrease and/or gas prices increase (i.e., Hypothesis H.5.2). we approach

151 This approach can be considered analogous to Kerr and Maré (1999), where the trade decision depends on the trade value to be gained minus the transaction costs.

152 Yet, despite the natural logarithm transformation on $Z_{j,t-1}$, values closer to zero may lower the need for firms to trade allowances (e.g., footnote 129).

153 National electricity demand is obtained via the ENTSO-E country packages. It is only available from 2006 and onward. It is not available for Latvia, Lithuania, and Sweden. The dataset comprises of monthly data. The monthly data smooth the volatile and non-linear nature of daily electricity production.

154 This is an *ex-post* constructed variable, hence, it is not based on *ex-ante* expectations on energy demand. By selecting an *ex-post* variable our approach does not account for the bias that energy firms may be behaving precautionary by ensuring more than sufficient supplies relative to demand (e.g, Tanrisever et al., 2015). Yet, the setup of these energy demand variables, namely through a moving time window, should account for both the forward-looking demand and backward-looking demand (i.e., *ex-post* corrections on previous expectations on demand). At the same time, this prevents the model from becoming overly complicated, for example, through the use of *ex-ante* stochastic approaches.

the propensity for switching via the coal–gas price difference: $SPREAD_t = \ln(COAL_t - GAS_t)$.[155] Firms have an incentive to switch to gas with a larger spread. Since gas is less carbon-intensive than coal, fewer allowances are needed to cover for the emissions. Hence, *SPREAD* should be negatively related to $TRADE_{i,t}$ in order to accept Hypothesis H.5.1.

In order to approach the effect if, additional to this negative relationship, coal and gas fuels make up a larger part of the inputs (i.e., Hypothesis H.5.2) we look at the interaction of this fuel price differential with the share of fossil fuels in electricity production ($SPREAD_t*BROWN_{i,t}$) resulting in $BSPREAD_{i,t}$ (i.e. the "brown spread").[156] In order to accept Hypothesis H.5.2, $BSPREAD_{i,t}$ should be more negatively related to $TRADE_{i,t,}$ than $SPREAD_t$.)This is because firms with higher shares of fossil fuels (i.e., higher $BROWN_{i,t}$ levels) will need to be more responsive to coal and gas price changes than firms which can make more use of non-fossil fuel inputs..[157]

4.6 Allowance demand: trade direction, arbitrage, price expectations

Hypothesis H.6.1 states that self-sufficient firms have a propensity to trade 'uni-directionally' and Hypothesis H.6.2 states that less self-sufficient firms have a propensity to trade 'bi-directionally'.[158] The 'uni-directionality' index, $UDIRECT_{i,t}$, denotes what proportion of daily trade came about through either purchases or sales, and is defined as follows:

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[155] The (EU-wide) data are obtained from Datastream: *GAS* is the London Natural Gas Index, and *COAL* is the Global Coal New Castle Index. Because we lack the exact composition of fossil fuels at the installation and (therefore) the firm level, switching prices could not be estimated, as in Bertrand (2012), for example.

[156] Data on electricity production (in MWh) were obtained from Carma.org at the installation level; the fuel input percentages were only available at the firm level. We linked up these companies with the BvD codes, as with the EUTL accounts. In addition, because Carma.org provides the 2004, 2009, and 'future' electricity production, the installations' MWh values for 2005 to 2007 were linearly extrapolated.

[157] The fuel shares are such that $BROWN_{i,t}$ + $HYDRO_{i,t}$ + $NUCLEAR_{i,t}$ + $RENEWABLE_{i,t}$ add up to 1, and refer to the shares of fossil (incl. gas and coal), hydro-electric, renewable, and nuclear fuels, respectively.

[158] For the uni-directionality and bi-directionality indices we drew inspiration from Smith and Swierzbinski (2007).

$UDIRECT_{i,t}$
$= \text{abs}(PURCH_{i,t} - SELL_{i,t}) / (PURCH_{i,t} + SELL_{i,t})$
if $PURCH_{i,t}$, $SELL_{i,t} \neq 0$
$= 0$
if $PURCH_{i,t}$, $SELL_{i,t} = 0$ (7)

The 'bi-directionality' index, $BDIRECT_{i,t}$, denotes what proportion of daily trade came about through a combination of both purchases and sales. $BDIRECT_{i,t}$ is defined as follows:
$BDIRECT_{i,t}$
$= 1 - \text{abs}(PURCH_{i,t} - SELL_{i,t}) / (PURCH_{i,t} + SELL_{i,t})$
if $PURCH_{i,t}$, $SELL_{i,t} \neq 0$
$= 0$
if $PURCH_{i,t}$, $SELL_{i,t} = 0$ (8)

As provided in equations (7) and (8), the indices are equal to zero if no trade occurred at day t (i.e. both $PURCH_{i,t}$ and $SELL_{i,t}$ are equal to zero).

For Hypothesis H.6.1 to be accepted, namely that self-sufficient firms have a propensity for uni-directional trade, it should hold that $|\beta_{UDIRECT}| > |\beta_{BDIRECT}|$. For H.6.2, namely that less self-sufficient firms have a propensity to trade bi-directionally, it should hold that $|\beta_{BDIRECT}+\delta_{BDIRECT}| > |\beta_{UDIRECT}+\delta_{UDIRECT}|$. The two conditions for H.6.1 and H.6.2 can hold both, for example, if $\delta_{BDIRECT}$ and $\delta_{UDIRECT}$ are sufficiently large and small, respectively.

For the seizing of price expectations, we assume firms are price takers. By not knowing to where the carbon price will go, these firms will trade according to their anchor price. For this anchor price we selected the 'buy-sell signal' (BSS_t). BSS_t contains the difference between the current carbon spot price and its 30-day moving average. If today's price is higher (lower) than the 30-day moving average, it indicates it is profitable to sell (buy) allowances, because they are more (less) expensive than average. As firms would sell (purchase) with positive (negative) 'buy-sell signal' spreads, the first part of Hypothesis H.7 is accepted if $TRADE_{i,t}$ is negatively related to BSS_t.

For the seizing of arbitrage opportunities, we selected the 'cash-and-carry arbitrage' (CCA_t), which is a proxy for (risk-free) arbitrage opportunities. CCA_t is the difference between the time-discounted carbon futures price minus the spot price and reflects the opportunity costs of keeping allowances.[159] Firms purchase (sell) allowances when the time-discounted carbon futures price is higher (lower) than the spot price. The second part of Hypothesis H.7 is therefore accepted if $TRADE_{i,t}$ is positively related to $CCA_{i,t}$.

5. Descriptive statistics

This section provides the descriptive statistics based on the self-sufficiency and trade frequency indicators, as discussed in Section 4.3.

159 Specifically, $CO2FUT_t$-$CO2SPOT_t$*e^{rT}, where r is the one-month EURIBOR rate, *CO2FUT* is the ICE Phase I average continuous futures CO_2 price, and *CO2SPOT* is the EEX-EU CO_2 settlement (spot) price. The (EU-wide) data are obtained from Datastream.

Table 2: $TRADE_{i,t}$, $LCT_{i,t}$, energy demand ($\Delta LEDEM_{i,t}$, $EDEM_{i,t}$, $\Delta FEDEM_{i,t}$), and fuel switching statistics ($BSPREAD_{i,t}$, $SPREAD_t$) with respect to the interaction terms on $SIZE_i$ and the subsamples on $ELEC_i$, and FRQ_i.

Variable	*SIZE*	Statistic	Full sample	Electricity (ELEC=0)	Non-electricity (ELEC=1)	*Diff:*	*Frequent traders (FRQ=0)*	*Infrequent traders (FRQ=1)*	*Diff:*
TRADE	*small*	mean	-0.021	-0.021	-0.022		-0.042	-0.012	***
	small	sd	0.639	0.673	0.632		0.917	0.460	
TRADE	*large*	mean	0.024	0.038***	0.012***	***	0.037***	-0.005***	***
	large	sd	1.733	2.063	1.354		2.054	0.476	
LCT	*small*	mean	2.769	1.685	2.989	***	1.190	3.482	***
	small	sd	9.439	10.011	9.303		10.638	8.751	
LCT	*large*	mean	2.987	2.770***	3.189***	***	2.290***	4.579***	***
	large	sd	12.148	13.009	11.283		13.006	9.727	
SPREAD	*small/large*	mean	3.776	3.776	3.776		3.776	3.776	
	small/large	sd	0.266	0.266	0.266		0.266	0.266	
BSPREAD	*small*	mean	0.441	2.614	0	***	0.413	0.454	***
	small	sd	1.139	1.417	0		1.115	1.149	
BSPREAD	*large*	mean	1.235	2.562***	0	***	1.424***	0.806***	***
	large	sd	1.591	1.360	0		1.623	1.425	
EDEM	*small*	mean	9.417	9.657	9.368	***	9.500	9.379	***
	small	sd	1.197	1.334	1.161		1.368	1.109	
EDEM	*large*	mean	9.727	9.887***	9.578***	***	9.796***	9.568***	***
	large	sd	1.226	1.230	1.203		1.222	1.220	
ΔLEDEM	*small*	mean	-0.005	-0.006	-0.005	***	-0.008	-0.004	***
	small	sd	0.104	0.115	0.101		0.127	0.092	
ΔLEDEM	*large*	mean	-0.005	-0.006	-0.004**	***	-0.006***	-0.004	***
	large	sd	0.105	0.110	0.099		0.108	0.095	
ΔFEDEM	*small*	mean	0.007	0.008	0.007	***	0.011	0.005	***
	small	sd	0.089	0.097	0.088		0.102	0.083	
ΔFEDEM	*large*	mean	0.006	0.007***	0.005***	***	0.007***	0.004***	***
	large	sd	0.090	0.093	0.088		0.092	0.087	

*The upper (lower) means and standard deviations refer to the firms with high (low) $SIZE_i$ values. The asterisks indicate the significance of the difference in means (*** / ** / * are significant at 99% / 95% / 90% confidence). To check the significance of the SIZE-differences, we follow the two-group mean-comparison approach in Cameron and Trivedi (2009, p. 78) through a regression of the respective variable on SIZE while applying heteroskedastic-consistent standard errors.*
The significance asterisks in the "Diff" column correspond to the mean difference between the subsets (e.g. ELEC and FRQ) but where SIZE of firms is fixed, for example, small electricity versus small non-electricity firms. The other asterisks (i.e. those not in the "Diff" column) correspond to the mean differences within subsets but between small and large firms, for example, between small and large electricity firms (i.e. where ELEC=0).

The variable definitions and measurement units are as follows:

- $SIZE_i$: = 1 if ln(total assets 2004-2009 average) > sample median, 0 otherwise (firm, constant level). Hence, a firm is large (small) if SIZE equals one (zero).
- FRQ_i: = 1 if > sample median, 0 otherwise, where $FRQ_i = (1/T\ \Sigma^T_{t=1} (PURCH_{i,t} + SELL_{i,t})) / \Sigma^T_{t=1} (PURCH_{i,t} + SELL_{i,t})$ (firm, constant level). Hence, a firm is a (non-)frequent trader if FRQ equals one (zero).
- $ELEC_i$: =1 if firm controls at least one electricity installation, 0 otherwise (firm, constant level)
- $TRADE_{i,t}$: Daily net allowance trade in (cf. equation (1)) (in: ln(tonnes CO_2)) (firm, daily level)
- $LCT_{i,t}$: Lagged compliance trajectory (cf. equation (5) and (6)) (in: ln(tonnes CO_2)) (firm, daily level)
- $SPREAD_t$: Price returns coal minus gas (in: ln(€)) (EU-wide, daily level)
*- $BSPREAD_{i,t}$: Weighted coal-gas price returns: $BROWN_{i,t}$ * $SPREAD_t$, where*
- $BROWN_i$: Firm's (national) MWh production by fossil fuels (in: %) (firm, daily level)
- $EDEM_{i,t}$: Monthly demand for national electricity (in: ln(MWh)) (country, monthly level)
- $\Delta FEDEM_{i,t}$: Difference next minus current electricity demand (in: ln(MWh)) (country, monthly level)
- $\Delta LEDEM_{i,t}$: Difference current minus previous month's electricity demand (in: ln(MWh)) (country, monthly level)

Table 2 shows the means and standard deviations for the daily net allowance trade ($TRADE_{i,t}$), the lagged compliance trajectory ($LCT_{i,t}$), fuel switching ($SPREAD_{i,t}$ and $BSPREAD_t$), and energy demand ($\Delta LEDEM_{i,t}$ to $\Delta FEDEM_{i,t}$). The asterisks in the "Diff" column correspond to the mean difference between subsets (e.g. *ELEC* and *FRQ*) among while holding the size of firms fixed, for example, small frequent traders versus small infrequent traders firms (i.e. *FRQ*=0 versus *FRQ*=1). The asterisks which are *not* in the "Diff" column indicate the significance of the differences in means between small and large firms, for example, within the subset of electricity firms (i.e. where *ELEC*=0).

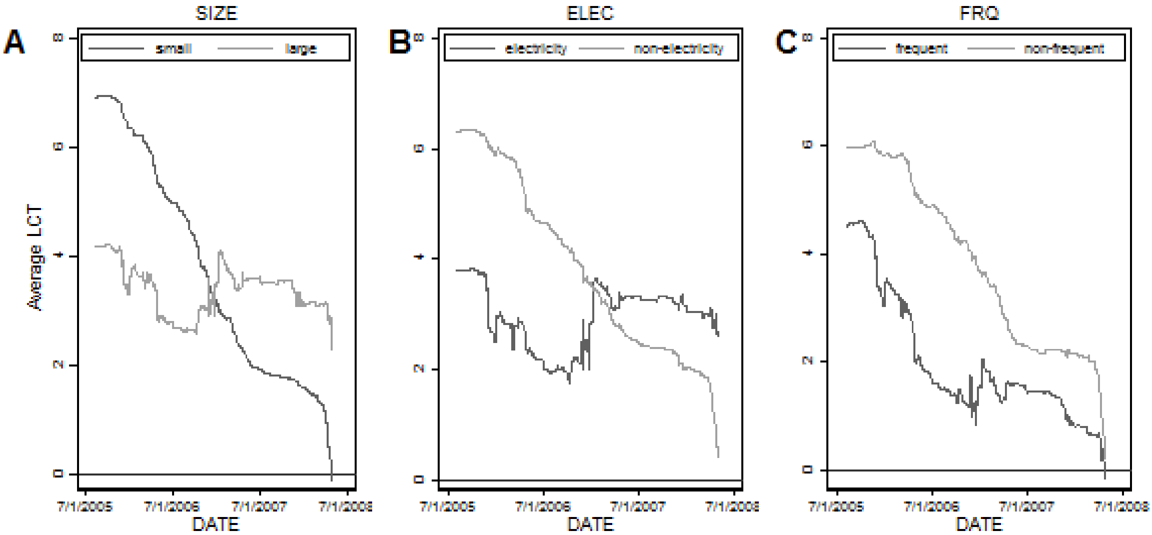
The $TRADE_{i,t}$ averages are close to zero mainly because of the many non-trades, but also because the average purchases almost equal the average sales (not shown here). In general, large firms are on average purchasers (i.e., $TRADE_{i,t} > 0$) and small firms are sellers. Only between small electricity and small non-electricity firms is the mean difference not significant.

As mentioned in Section 4.4, the lagged compliance trajectory ($LCT_{i,t}$) should converge to zero 1) to prevent penalties when having too few allowances in stock and 2) to redeem superfluous allowances. Table 2 shows the $LCT_{i,t}$ values are positive in all cases, which is likely a result of the Phase I allowance oversupply (or demand shortage). On average, all firms were running allowance surpluses (i.e. given $LCT > 0$). Large firms were running larger surpluses than small firms.

As for the fuel inputs used, we assumed that all firms follow the same EU-wide gas and coal price indices. This approach results in an equal average coal-gas price differential ($SPREAD_t$) for all of the firms (mean: 3.78, sd: 0.27). In addition, because $BSPREAD_{i,t}$ is a multiple of $SPREAD_t$ and $BROWN_{i,t}$ (i.e., the fossil share in electricity production), differences in $BSPREAD_{i,t}$ emanate from $BROWN_{i,t}$. By definition, $BROWN_{i,t}$ is zero for non-electricity producers. Table 2 shows that large electricity producers have lower average fossil shares (i.e. smaller $BROWN_{i,t}$ and thus lower $BSPREAD_{i,t}$ values) than small electricity producers.

Regarding energy demand, Table 2 shows higher electricity demand ($EDEM_{i,t}$) is associated with larger firms. This may be due to the country-specific nature of *EDEM*, and the fact that these firms operate in national markets with higher MWh demands (i.e., larger EU member states). Table 2 further suggests an upward trend of electricity demand since, on average, the next minus current month's electricity demand ($\Delta FEDEM$) is positive, whereas the current minus the previous month's electricity demand ($\Delta LEDEM$) is negative. Both type of differences are generally smaller for large firms than for small firms, although the $\Delta LEDEM$-differences are not significant among electricity firms and frequent traders.

Figure 3: Regressor over time: compliance trajectory ($LCT_{i,t}$) based on *SIZE*, *ELEC*, and *FRQ*



The firm-averaged Lagged Compliance Trajectory ($LCT_{i,t}$) for firms which are: small vs. large (SIZE: Panel A), produce electricity or not (ELEC: Panel B), and are frequent vs. non-frequent traders (FRQ: Panel C)

Figure 3 plots the firm-averaged Lagged Compliance Trajectory ($LCT_{i,t}$) based on the interaction term on self-sufficiency (i.e., *SIZE*) and the trade frequency subsets (i.e., *ELEC* and *FRQ*).[160] Despite some stagnations it shows that $LCT_{i,t}$ gradually converges to zero. What is visible from the panels is that the small (panel A), the non-electricity (panel B), and the non-frequent trader firms (panel C) adhere better to a path of gradual convergence to zero for their $LCT_{i,t}$ values than the large (panel A), the electricity (panel B) and the frequent trader firms (panel C). It is also this first group that sees a drop in *LCT* in the last weeks of Phase I, and more so than the second group.

Figure 3 further shows that, towards the end of Phase I, firms kept sizeable amounts of allowances in stock.[161] When the small firms' final

[160] The scatter plot of $LCT_{i,t}$ with the response variable, $TRADE_{i,t}$, results in a quadratic relationship (not shown here). We therefore include a squared term of $LCT_{i,t}$ in the regression analysis below.

[161] Hintermann (2015) conjectures this stocking of allowances could be a strategy 1) for precautionary purposes (i.e. to have enough in stock before the end of Phase I), and 2) to profit from a higher carbon price (i.e. if, due to conducive product demand elasticities, the product price increases more than the carbon price).

Phase I demand became certain, these firms were triggered to redeem their superfluous allowances.

Table 4: Trade direction (*UDIRECT*$_{i,t}$ *and BDIRECT*$_{i,t}$), arbitrage (*CCA*$_t$), price expectations (*BSS*$_t$), and intra- and inter-GUO trade (resp. *INTRAGUO* and *INTERGUO*) statistics with respect to the interaction terms on *SIZE*$_i$ and the subsets on *ELEC*$_i$, and *FRQ*$_i$.

Variable	*SIZE*	Stat	Full sample	Electricity production (*ELEC*=0)	Non-electricity production (*ELEC*=1)	*Diff:*	*FRQ*=0 (freq. traders)	*FRQ*=1 (infreq. traders)	*Diff:*
UDIRECT	*SIZE*=0	mean	0.005	0.005	0.005		0.009	0.003	***
	SIZE=0	sd	0.067	0.068	0.067		0.094	0.050	
UDIRECT	*SIZE*=1	mean	0.073	0.100***	0.047***	***	0.093***	0.027***	***
	SIZE=1	sd	0.249	0.286	0.205		0.277	0.157	
BDIRECT	*SIZE*=0	mean	0.0001	0.0002	0.0001		0.0003	0.00003	***
	SIZE=0	sd	0.009	0.010	0.008		0.014	0.004	
BDIRECT	*SIZE*=1	mean	0.018	0.027***	0.010***	***	0.024***	0.004***	***
	SIZE=1	sd	0.109	0.133	0.081		0.126	0.053	
CCA	*small/large*	mean	0.401	0.401	0.401		0.401	0.401	
	small/large	sd	0.530	0.530	0.530		0.530	0.530	
BSS	*small/large*	mean	-0.159	-0.159	-0.159		-0.159	-0.159	
	small/large	sd	0.336	0.336	0.336		0.336	0.336	
INTRAGUO	*SIZE*=0	mean	0.0001	0.0002	0.0001		0.0003	0.00004	***
	SIZE=0	sd	0.010	0.011	0.010		0.016	0.006	
INTRAGUO	*SIZE*=1	mean	0.002	0.003***	0.001***	***	0.003***	0.0001	***
	SIZE=1	Sd	0.038	0.048	0.025		0.045	0.007	
INTERGUO	*SIZE*=0	mean	0.005	0.005	0.005		0.009	0.002	***
	SIZE=0	Sd	0.067	0.069	0.067		0.096	0.049	
INTERGUO	*SIZE*=1	Mean	0.027	0.037***	0.018***	***	0.038***	0.002	***
	SIZE=1	Sd	0.160	0.185	0.132		0.188	0.050	

*The upper (lower) means and standard deviations refer to the firms with high (low) $SIZE_i$ values. The asterisks indicate the significance of the difference in means (*** / ** / * are significant at 99% / 95% / 90% confidence). To check the significance of the SIZE-differences, we follow the two-group mean-comparison approach in Cameron and Trivedi (2009, p. 78) through a regression of the respective variable on SIZE while applying heteroskedastic-consistent standard errors. The asterisks in the "Diff" column correspond to the mean difference* <u>*between subsets*</u> *but where SIZE of firms is fixed, for example, electricity versus non-electricity firms. The other asterisks (i.e. those not in the "Diff" column) correspond to the mean differences* <u>*within subsets*</u> *but between small and large firms, for example, between small and large electricity firms (i.e. where ELEC=0).*

The variable definitions and measurement units are as follows:
- $SIZE_i$: = 1 if ln(total assets 2004-2009 average) > sample median, 0 otherwise (firm, constant level). Hence, a firm is large (small) if SIZE equals one (zero).
- FRQ_i: = 1 if > sample median, 0 otherwise, where $FRQ_i = (1/T \Sigma^T_{t=1} (PURCH_{i,t} + SELL_{i,t})) / \Sigma^T_{t=1} (PURCH_{i,t} + SELL_{i,t})$ (firm, constant level). Hence, a firm is a (non-)frequent trader if FRQ equals one (zero).
- $ELEC_i$: =1 if firm controls at least one electricity installation, 0 otherwise (firm, constant level)
- BSS_t: Buy-and-Sell Signal: CO_2SPOT_t - 30 day CO_2SPOT_t moving avg. (EU-wide, daily level)
- CCA_t: Cost of Carry Arbitrage: $CO_2FUT_t - CO_2SPOT_t * e^{rT}$ (EU-wide, daily level)
- $UDIRECT_{i,t}$: 0 if both purchases ($PURCH_{i,t}$) and sales ($SELL_{i,t}$) are zero, and equals $abs(PURCH_{i,t} – SELL_{i,t}) / (PURCH_{i,t} + SELL_{i,t})$ if otherwise (firm, daily level)
- $BDIRECT_{i,t}$: 0 if both purchases ($PURCH_{i,t}$) and sales ($SELL_{i,t}$) are zero, and equals $1–abs(PURCH_{i,t} – SELL_{i,t}) / (PURCH_{i,t} + SELL_{i,t})$ if otherwise (firm, daily level)
- $INTRAGUO_{i,t}$: Daily average of dummy: = 0 if $PURCH_{i,t} + SALES_{i,t} = 0$, and = $\Sigma_{INTRAGUO}(PURCH_{i,t} + SALES_{i,t}) / \Sigma_{INTRAGUO+INTERGUO}(PURCH_{i,t} + SALES_{i,t})$ if otherwise.
- $INTERGUO_{i,t}$: Daily average of dummy: = 0 if $PURCH_{i,t} + SALES_{i,t} = 0$, and = $\Sigma_{INTERGUO}(PURCH_{i,t} + SALES_{i,t}) / \Sigma_{INTRAGUO+INTERGUO}(PURCH_{i,t} + SALES_{i,t})$ if otherwise.

Table 4 shows the means and standard deviations of the variables on trade direction, arbitrage, price expectations, and intra- and inter-GUO trade.

In all tabulated cases, the means of uni-directionality trade ($UDIRECT_{i,t}$) are larger than of bi-directionality trade ($BDIRECT_{i,t}$). Both self-sufficient and less self-sufficient firms have a higher propensity to trade uni-directionally rather than bi-directionally during the day. For self-sufficient firms this result is in line with Hypothesis H.6.1, but for less self-sufficient firms this result is not in line with Hypothesis H.6.2.

The cash-and-carry arbitrage (CCA_t) and buy-sell signal (BSS_t) do not differ over *SIZE*, which is why the duplicate rows are left out of Table 4. These are EU-wide. For BSS_t, we hypothesized that firms sell (purchase) allowances when BSS_t is positive (negative). With BSS_t having a negative average value, the hypothesized effect is that firms should on average be buying allowances. For firms with carbon allowances shortages a continuous buy-signal can be expected given the carbon price decline towards the end of Phase 1 (2005-April, 2008). The CCA_t averages are positive, implying an incentive to buy allowances (the hypothesized effect is that firms buy allowances when discounted carbon prices are higher than spot prices). However, the large standard deviation implies a large variation centering on zero. Such a variation might make it more difficult for firms to arbitrage profitably.

Finally, the inter-GUO means are larger than those of intra-GUO. Both self-sufficient and less self-sufficient firms therefore have more a propensity to trade outside their firm boundaries (i.e. $INTERGUO_{i,t}$) rather than within firm boundaries (i.e. $INTRAGUO_{i,t}$). For less self-sufficient firms this result is in line with Hypothesis H.2, but not for self-sufficient firms.

Figure 5: Response variable over time: the daily net allowance amounts traded

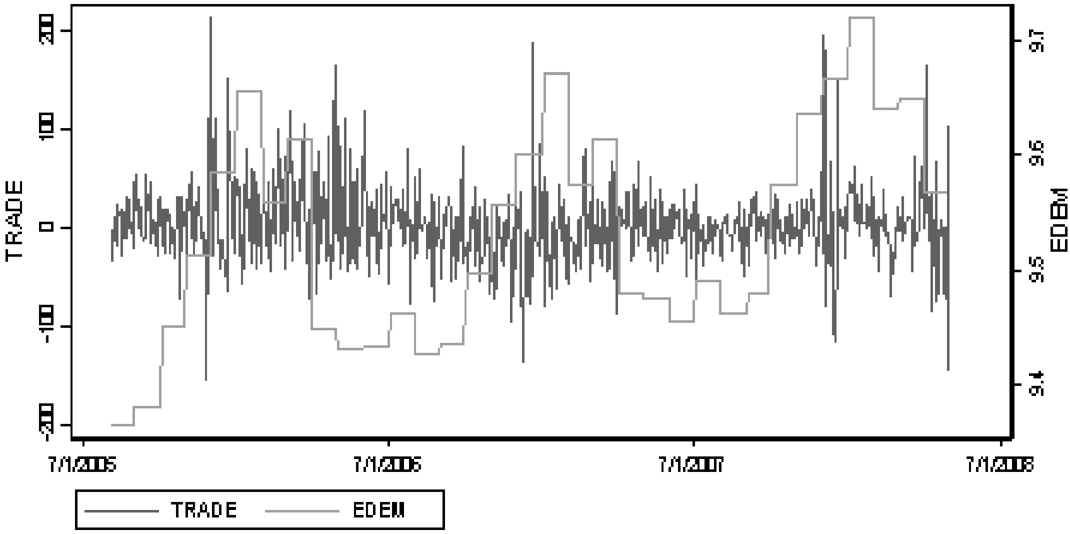


Figure 5 shows the daily net amounts traded summed over the firms in the sample (i.e. $\Sigma_i TRADE_{i,t}$) and electricity demand (EDEM).

Figure 6: Regressors over time: on energy demand and fuel switching

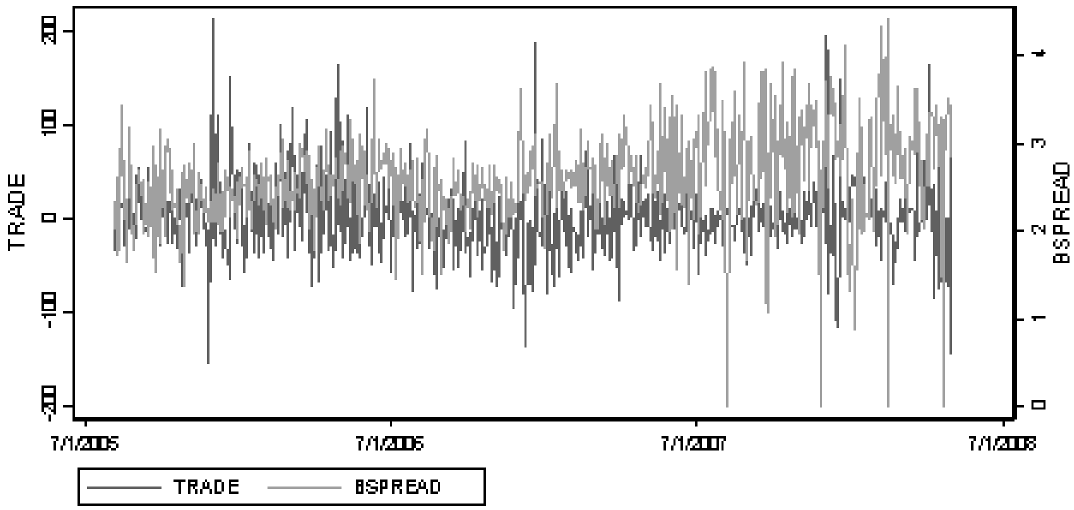


Figure 6 shows the daily net amounts traded summed over the firms in the sample (i.e. $\Sigma_i TRADE_{i,t}$) and the fossil-fuel-weighted coal-gas price spread (BSPREAD).

Figure 5 shows the daily total allowance trade and monthly electricity demand. The figure shows that trades follow three recurring patterns. First, allowance trade volumes increase gradually from January towards April, when the (previous calendar year's) allowance demand is verified, and allowances are exchanged before the annual end-of-April allowance surrender deadline. Second, volumes spike at year-end. This is probably due to the exercise of carbon derivatives and the closing of the bookkeeping year for firms. Third, the plotted allowance volumes (*TRADE*$_{i,t}$) generally move in tandem with the national electricity demand (*EDEM*$_{i,t}$). For example, allowance volumes are low during the third quartiles, when less electricity was required for the summer months.[162]

Figure 6 also shows the daily total allowance trade but with *BSPREAD*$_{i,t}$, the interaction of the coal-gas price differential with the share of fossil fuels in electricity production. The figure does not highlight a clear discernable pattern between the two variables.

Figure 7: Regressors over time: on trade direction

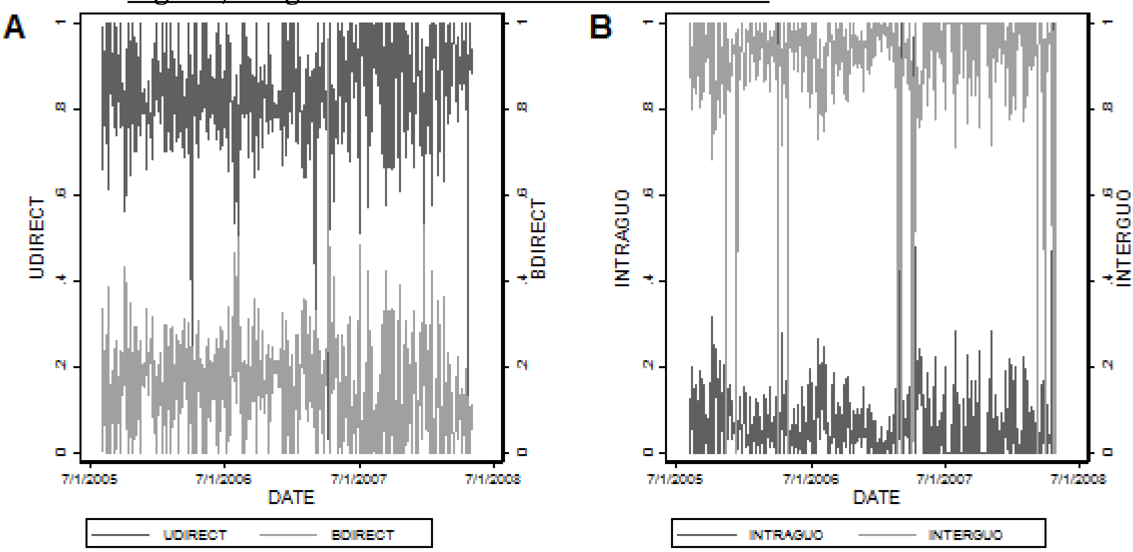


Figure 7 panel A shows the uni-directionality (UDIRECT) and bi-directionality index (BDIRECT). Panel B shows the within-conglomerate and between-conglomerate transactions (resp. INTRAGUO and INTERGUO).

Figure 7 panels A and B show that the trade direction variables tend to remain in the same ranges: *BDIRECT*$_{i,t}$ (panel A) and *INTRAGUO*$_{i,t}$

[162] During these months, trade activity is lower in general. In addition to the April and December EU ETS volume spikes, this pattern may also be driven by other factors (e.g., institutional, such as summer holidays).

(panel B) are in the lower ranges between 0 and 0.3, while $UDINDEX_{i,t}$ and $INTERGUO_{i,t}$ are in the upper ranges between 0.7 and 1. There are few moments when the lower-ranged $BDIRECT_{i,t}$ or $INTRAGUO_{i,t}$ increase at the cost of the upper-ranged $UDINDEX_{i,t}$ and $INTERGUO_{i,t}$. This figure therefore confirms the statistics in Table 4, namely that firms generally trade uni-directionally (through the upper-ranged $UDINDEX_{i,t}$ in panel A) and that firms do not trade within but between firm boundaries (through the upper-ranged $INTERGUO_{i,t}$ in panel B).

Figure 8: Regressors over time: on arbitrage and price expectations

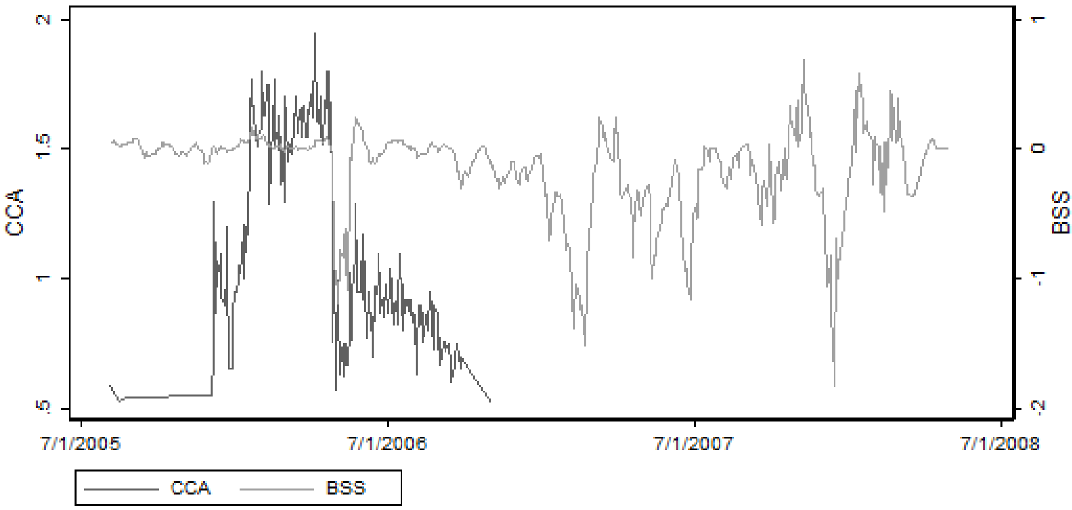


Figure 8 shows the Cash-and-Carry Arbitrage (CCA_t) for values above 0.05 and the Buy-Sell Signal (BSS).

Figure 8 shows the development of the Cash-and-Carry Arbitrage (CCA_t) and the Buy-Sell Signal (BSS_t) over time. For CCA_t we assume the transaction costs equal 0.05, which we take as the minimum required difference between the spot and futures prices. The figure shows CCA_t was above 0.05 only until mid-2006. After April 2006, it became publicly known that aggregate allowance demand was much lower than expected. This led to the downfall and subsequent decline of the carbon price towards the end of Phase I (e.g., Jong et al., 2014; Zeitlberger and Brauneis, 2016). After mid-2006, CCA_t was below 0.05, which may imply that transaction costs prevented firms from exploiting arbitrage opportunities. Furthermore, BSS_t in Figure 8 confirms the statistics in Table 4, namely that BSS_t is negative on average. Given the development of BSS_t, the market signal is for firms to buy allowances because the carbon price is less expensive than its 30-day moving average.

6. Empirical results

This section applies the methodology from Section 4 through regressions on the response variable $TRADE_{i,t}$, and subsequently interprets and discusses the regression results in light of the hypotheses from Section 3.

Table 9: Panel data regressions on $TRADE_{i,t}$

Variable	*ELEC*	*non-ELEC*	*FRQ*	*non-FRQ*
SIZE	-0.239*	-0.368*	-0.217*	-0.007
CONSTANT	0	0.334*	0.118	0
$\beta_{INTRAGUO}$	-0.700	0.240	0.031	2.406
$\delta_{INTRAGUO}$	-1.091	-2.376*	-1.989*	-1.830
$\beta_{INTERGUO}$	0.114	1.090*	0.999*	-2.555*
$\delta_{INTERGUO}$	-3.516*	-1.121*	-1.510*	-2.427*
β_{LCT}	-0.005*	-0.003*	-0.004*	-0.001*
δ_{LCT}	0.004*	0.002*	0.003*	-0.0002
β_{LCT^2}	0.001*	0.001*	0.001*	-0.0001
δ_{LCT^2}	-0.001*	-0.001*	-0.001*	0.0002
$\beta_{\Delta LEDEM}$	0.007	-0.164*	-0.160*	0.049*
$\delta_{\Delta LEDEM}$	-0.052	0.216*	0.136*	-0.074*
β_{EDEM}	0.082*	0.016*	0.017*	0.010
δ_{EDEM}	-0.067	-0.011*	-0.011*	-0.015
$\beta_{\Delta FEDEM}$	0.030	-0.256*	-0.154*	0.019
$\delta_{\Delta FEDEM}$	-0.065	0.263*	0.128	-0.028
$\beta_{BSPREAD}$	0	-0.026*	-0.016*	0.007
$\delta_{BSPREAD}$	0	0.022*	0.013*	-0.005
β_{SPREAD}	-0.050*	0.051*	0.004	0.008
δ_{SPREAD}	0.052*	-0.050	0.014	-0.009
$\beta_{BDIRECT}$	-0.183	-0.215*	-0.208*	0.120
$\delta_{BDIRECT}$	3.678*	-3.874*	-0.727	10.900*
$\beta_{UDIRECT}$	-0.165*	-0.008	-0.042	-0.030
$\delta_{UDIRECT}$	-1.263*	-4.372*	-4.054*	-0.001
β_{BSS}	-0.005	0.017	0.012	-0.008
δ_{BSS}	0.005	-0.016	-0.010	0.005
β_{CCA}	0.028*	0.013	0.023*	0.005
δ_{CCA}	-0.028*	-0.021	-0.031*	-0.004
$\beta_{QUARTER1}$	-0.010	-0.008	-0.017	0.003
$\delta_{QUARTER1}$	0.003	0.011	0.012	-0.004
$\beta_{QUARTER2}$	-0.007	0.030	0.012	-0.003
$\delta_{QUARTER2}$	0.009	-0.017	0.003	0.005
$\beta_{QUARTER4}$	-0.026*	0.049*	0.014	0.004
$\delta_{QUARTER4}$	0.027*	-0.059*	-0.019	-0.001

R^2 (within)	0.064	0.018	0.026	0.215
No. obs	456816	229636	353050	333402
No. firms	744	374	575	543

*The methodologies used are fixed effects (within) regressions with Driscoll-Kraay standard errors (for non-FRQ_i and $ELEC_i$) and panel-corrected Prais-Winsten standard errors (for FRQ_i and non-$ELEC_i$). The values are coefficients and are marked with * if significant at 95%. The δ-coefficients are the $SIZE_i$ interaction terms. If significant, the sums of the δ- and β-coefficients provide the effects for small firms, while the β-coefficients provide the effects for large firms. If the δ-coefficients are not significant, the coefficient effects are the same among both small and large firms.*

Table 10: The p-values from the joint significance (Wald) tests on the Table 9 variables

Variable	*ELEC*	*non-ELEC*	*FRQ*	*non-FRQ*
Full model (i.e., F-test)	0.000	0.000	0.000	0.000
INTRAGUO, INTERGUO	0.000	0.000	0.000	0.000
LCT, LCT²	0.000	0.000	0.000	0.000
EDEM, ΔLEDEM, ΔFEDEM	0.047	0.000	0.000	0.204
BSPREAD, SPREAD	0.001	0.000	0.000	0.756
BDIRECT, UDIRECT	0.000	0.000	0.000	0.081
QUARTER1, QUARTER2, QUARTER4	0.100	0.000	0.015	0.510

The coefficients are Wald tests including the base and interaction terms of $SIZE_i$.

Table 9 shows the regression results within the subsets of (non-)electricity producers and (in)frequent traders (i.e. $ELEC_i$, non-$ELEC_i$, FRQ_i, and non-FRQ_i). The δ-coefficients are the interaction terms. If significant, the sums of the δ- and β-coefficients provide the effects for small firms, while the β-coefficients provide the effects for large firms. If the δ-coefficients are not significant, the coefficient effects are the same among both small and large firms. This also holds for the intercept shift, $SIZE_i$. If $SIZE_i$ is significant, small firms have a different intercept (i.e. $CONSTANT_i + SIZE_i$) than large firms (i.e. $CONSTANT_i$). Otherwise, both types of firms follow $CONSTANT_i$ as the intercept. Table 10 provides the joint significance Wald test p-values for both pairs of variables (e.g. $INTRAGUO_{i,t}$ and $INTERGUO_{i,t}$) and of interaction terms (i.e., both the δ- and β-terms).

To test whether self-sufficient (i.e. large) firms trade less responsively to changes in allowance demand (i.e., Hypothesis H.1), all coefficients need to be such that: $|\beta| < |\beta+\delta|$. Applying these inequalities to the pairs of β- and δ-coefficients leads us to reject Hypothesis H.1. For example, while the inequality holds for BSS_t (i.e., since $|\beta_{BSS} = -0.005| < |\beta_{BSS} + \delta_{BSS} = -0.005 + 0.005|$, it does not hold for $UDIRECT_{i,t}$ (i.e., since $|\beta_{UDIRECT} = -0.165| \nless |\beta_{UDIRECT} + \delta_{UDIRECT} = -0.165-1.263|$). Moreover, while the inequality holds for $INTRAGUO_{i,t}$ within the subset *ELEC*, it does not hold for $LCT_{i,t}$ within this subset.

We hypothesized via H.2 that self-sufficient firms conduct more within- than between-firm trades. This implies $|\beta_{INTRAGUO}|>|\beta_{INTERGUO}|$ will need to hold. Table 9 shows this is only the case for electricity firms (i.e. *ELEC*, given $|\beta_{INTRAGUO}| = 0.700$ and $|\beta_{INTERGUO}| = 0.114$). The other large firms (i.e. the β-values in *non-ELEC*, *FRQ*, and *non-FRQ*) behaved opposite than hypothesized.[163]

H.3 hypothesizes that firms purchase and sell allowances so as to minimize differences between allocations and emissions. By construction, the $LCT_{i,t}$ coefficient would then need to be negative (see Section 4.4). Table 9 shows this is the case for all four columns, which therefore confirms Hypothesis H.3.[164,165]

Yet, since $LCT_{i,t}$ followed a quadratic relationship with the response variable ($TRADE_{i,t}$) (cf. footnote 160), we also included the squared term of $LCT_{i,t}$ in the regression. Since changes are expected to be larger when firms are further away from the expected value of $LCT_{i,t}$=0, this squared term allows for impacts to change depending on the $LCT_{i,t}$-level. The significant squared term captures the parabolic impact $LCT_{i,t}$ has on $TRADE_{i,t}$. One implication of this term is that the marginal impact will have a sign change (i.e. at $LCT_{i,t} = -\beta_{LCT}/(2^*\beta_{LCT^\wedge 2})$. Less intuitive will then be the domain where $LCT_{i,t}$ impacts are or turn positive, since a positive relationship implies that firms increase rather than diminish their

163 As discussed in Section 4.2, among the impacts of aggregating firms at the country level is that both within-firm and within-country trades were netted out. $INTERGUO_{i,t}$ and $INTRAGUO_{i,t}$ may thus change if a different allowance management structure is assumed for the sample.

164 Although $LCT_{i,t}$ and $TRADE_{i,t}$ include purchases and sales, we expect endogeneity to be negligible. First, $LCT_{i,t}$ has (t-1) lagged purchases and sales, and the selected Prais-Winsten and Driscoll-Kraay econometric models accommodate autocorrelation (i.e., a typical endogeneity source). Second, the time-invariant nature of endogeneity is tackled via the panel methodology.

165 As $TRADE_{i,t}$ and $LCT_{i,t}$ are in logarithmic terms, the coefficients are to be interpreted as elasticities.

allowance surpluses or deficits. Related to this sign change is that the marginal impacts are either diminishing or increasing (i.e. given the squared term's additional marginal effect of $2^*LCT_{i,t}{}^* \beta_{LCT^2}$). For the columns *ELEC*, non-*ELEC* and *FRQ* of Table 9 it holds that $\beta_{LCT^2} > 0$, so that the negative $LCT_{i,t}$ impacts are diminishing, whereas for the non-*FRQ* column the $LCT_{i,t}$ impacts are increasing given that $\beta_{LCT^2} < 0$. The intuitive case is when $LCT_{i,t}$ impacts are increasingly negative (i.e. where $\beta_{LCT^2} > 0$), since larger deviations from $LCT_{i,t} = 0$ provide extra incentives for firms to return their allowance holdings to $LCT_{i,t} = 0$.

Table 10 shows the three energy demand variables (i.e. *ΔLEDEM* to *ΔFEDEM*) are only jointly significant for frequent traders and non-electricity firms (i.e. *FRQ* and *non-ELEC*, respectively).[166] Adding up the three effects demand coefficients, namely the current electricity demand ($EDEM_{i,t}$), the difference of $EDEM_{i,t}$ with the previous month ($\Delta LEDEM_{i,t}$) and the next month ($\Delta FEDEM_{i,t}$), results in -0.044 (i.e. *FRQ*) and +0.064 (*non-ELEC*) for the small firms of these subsets. The sums are -0.297 and -0.404 for the large firms. Since Hypothesis H.4 states that firms are expected to purchase (sell) allowances when electricity demand increases (decreases), H.4 is accepted when values are positive. This is only the case for the small non-electricity firms (i.e. *non-ELEC*). Hypothesis H.4 needs to be rejected for the other subsets.

According to Hypothesis H.5, firms have an incentive to switch to gas with a larger spread, and more so for firms with higher shares of fossil fuels. This is, respectively, captured by a negative $SPREAD_t$ and a more negative $BSPREAD_t$-coefficient. Table 10 shows the two variables are jointly significant for all except the infrequent traders (i.e. *non-FRQ*). By adding the two coefficients, namely through $(1+BROWN_{i,t})SPREAD_t$, the overall impact of the two coefficients is negative only for the large electricity firms (i.e. $0 - 0.050 < 0$) and large frequent traders (i.e. $-0.016 + 0.004 < 0$). Among these two cases, only the large frequent traders have a more negative $BSPREAD_t$-coefficient (i.e. $-0.016 < 0.004$). Hence, only this subset is in line with Hypothesis H.5. Hypothesis H.5 needs to be rejected for the other subsets.

For the first part of Hypothesis H.6 to be accepted, namely that self-sufficient firms have a propensity for uni-directional trade, it should hold

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[166] We will not discuss the coefficients of the electricity firms subset (i.e. ELEC) since they are close to joint insignificance (0.047)

that $|\beta_{UDIRECT}| > |\beta_{BDIRECT}|$. None of the coefficients show this result, whereby the results for infrequent traders are insignificant (see Table 10). For the second part of H.6, namely that less self-sufficient firms have a propensity to trade bi-directionally, it should hold that $|\beta_{BDIRECT}+\delta_{BDIRECT}| > |\beta_{UDIRECT}+\delta_{UDIRECT}|$. This relationship holds for the electricity firms.

The first part of Hypothesis H.7 states that BSS_t (Buy-Sell Signal) should be negative when firms sell (purchase) allowances with positive (negative) BSS_t spreads. For neither of the subsets is BSS_t significant, thereby rejecting this part of Hypothesis H.7. The second part of Hypothesis H.7 suggests that CCA_t is positively related to $TRADE_{i,t}$, as higher CCA_t levels incentivize firms to trade – rather than keeping allowances in stock. CCA_t is significant for electricity firms and frequent traders. The coefficients for the large firms (β = 0.028 and 0.023) are positive and, hence, follow Hypothesis H.7. The coefficients for the small firms ($\beta + \delta$ = -0.0001 and -0.008) are negative and, hence, do not follow Hypothesis H.7.

Finally, in order to test for the time effects we introduced quarterly dummies (i.e. *QUARTER*). The *QUARTER*-dummies show the difference vis-à-vis the intercept term or base dummy, which captures the third quarter.[167] Table 10 shows the results are significant for frequent traders and non-electricity firms. Relative to the third quarter or Q3 (i.e., the base dummy) large firms and frequent trading small firms sell more in Q1, whereas small non-electricity firms purchase more in Q1. Large (small) firms purchase (sell) relatively more in Q2 and Q4.

[167] One dummy is left out to avoid the "dummy variable trap".

Table 11: Summary of the coefficients accepting or rejecting the Section 4 hypotheses for large and small firms with respect to the interaction terms on $SIZE_i$ and the subsets on $ELEC_i$, and FRQ_i.

Coefficient	*ELEC*	*non-ELEC*	*FRQ*	*non-FRQ*
$\lvert\beta_{FULL}+\delta_{FULL}\rvert>\lvert\beta_{FULL}\rvert$	H.1 Rejected	H.1 Rejected	H.1 Rejected	H.1 Rejected
$\beta_{INTRAGUO}$ $\delta_{INTRAGUO}$ $\beta_{INTERGUO}$ $\delta_{INTERGUO}$	H.2 Accepted	H.2 Rejected	H.2 Rejected	H.2 Rejected
β_{LCT} δ_{LCT} β_{LCT^2} δ_{LCT^2}	H.3 Accepted	H.3 Accepted	H.3 Accepted	H.3 Accepted
$\beta_{\Delta LEDEM}$ $\delta_{\Delta LEDEM}$ β_{EDEM} δ_{EDEM}	H.4 Not significant	H.4 Rejected (large)	H.4 Rejected (large)	H.4 Not significant
$\beta_{\Delta FEDEM}$ $\delta_{\Delta FEDEM}$		H4. Accepted (small)	H4. Rejected (small)	
$\beta_{BSPREAD}$ $\delta_{BSPREAD}$	H.5.1 Accepted (<u>only</u> large <u>not</u> small)	H.5.1 Rejected (<u>both</u> small <u>and</u> large)	H.5.1 Accepted (<u>only</u> large <u>not</u> small)	H.5.1 Not significant
β_{SPREAD} δ_{SPREAD}	H.5.2 Rejected (<u>both</u> small <u>and</u> large)	H.5.2 Rejected (<u>both</u> small <u>and</u> large)	H.5.2 Accepted (<u>only</u> large <u>not</u> small)	H.5.2 Not significant
$\beta_{BDIRECT}$ $\delta_{BDIRECT}$	H.6.1 Rejected	H.6.1 Rejected	H.6.1 Rejected	H.6.1 Not significant
$\beta_{UDIRECT}$ $\delta_{UDIRECT}$	H.6.2 Accepted	H.6.2 Rejected	H.6.2 Rejected	H.6.2 Not significant
β_{BSS} δ_{BSS}	H.7 Not significant	H.7.1 Not significant	H.7.1 Not significant	H7.1 Not significant
β_{CCA}	H.7.2 Accepted (large)	H.7.2 Not significant	H.7.2 Accepted (large)	H.7.2 Not significant
δ_{CCA}	H.7.2 Rejected (small)		H.7.2 Rejected (small)	

$\beta_{QUARTER1}$	Not significant	Large: Q1< Q3	Large: Q1<Q3	Not significant
$\delta_{QUARTER1}$		Small: Q1>Q3	Small: Q1<Q3	
$\beta_{QUARTER2}$		Large: Q1>Q3	Large: Q1>Q3	
$\delta_{QUARTER2}$		Small: Q1<Q3	Small: Q1<Q3	
$\beta_{QUARTER4}$		Large: Q1>Q3	Large: Q1>Q3	
$\delta_{QUARTER4}$		Small: Q1<Q3	Small: Q1<Q3	

Table 11 summarizes the above findings, by indicating whether the results were significant or not, and whether the results led us to accept or reject the Hypotheses from Section 4. There are three unequivocal outcomes. First, large firms do not trade less responsively to changes in allowance demand (Hypothesis H.1: all rejected). In fact, the reverse holds (i.e., $|\beta_{FULL}+\delta_{FULL}|<|\beta_{FULL}|$), implying that large firms trade more responsively. Second, firms participate in the carbon market to minimize their allocations and emissions differences (Hypothesis H.3: all accepted). This result confirms for all firms that the EU ETS, after having initially allocated allowances, decentralizes the reallocation of allowances among firms. Third, on average, firms do not follow the 'buy-sell signal' (BSS_t) as the anchor for their carbon price expectations (Hypothesis H.7.1: all rejected). This anchor may have been too basic for this purpose. We leave a more specific analysis on firms' behavior to carbon prices to future research.

The other coefficients in Table 11 provide equivocal outcomes across the firm types. The prevailing result between each of the two sets of columns (i.e. *ELEC* vs. *non-ELEC* and *FRQ* vs. *non-FRQ*) is that large firms do not conduct more within- than between-firm trades (Hypothesis H.2: most are rejected) but that the reverse holds (i.e., $|\beta_{INTRAGUO}|<|\beta_{INTERGUO}|$.). Theory suggests that allowance trades will be triggered when firms have different pollution abatement capacities (e.g., Baumol and Oates, 1988). The fact that large firms trade less within firm boundaries than on the market may imply that their within-firm abatement potential is more costly than expected. It may also imply that carbon-related transaction costs (e.g., information costs) are higher within firm boundaries and that these costs prevent them from using their within-firm abatement capacity (e.g., Stavins, 1995).

With H.4, H.5.1, and H.5.2 we hypothesized that firms sell carbon allowances when the coal-gas price spread increases, and vice versa. If the coal price increases, demand for carbon allowances is expected to fall due to the switching from coal to gas, which is less polluting. Yet, the regression results point towards an opposite and less intuitive relationship, namely that firms purchase carbon allowances when coal-gas spreads are wider, and vice versa.

This finding can be the result from hedging by the firms in our sample. Firms apply hedges to neutralize the financial impacts from one product with the counteracting financial impacts from another product. For example, when coal prices increase and firms switch to gas, neutralizing the financial impacts on the price of electricity requires a higher carbon price, given that gas is relatively less polluting than coal. Firms can put upward pressure on the carbon price by purchasing carbon allowances. At the same time, this enables them to have allowances to sell off when electricity production from coal becomes cheaper.

The trade-related Hypotheses H.6.1 and H.6.2 are predominantly rejected. This implies that (not large but) small firms have a propensity to trade uni-directionally, and that (not small but) large firms have a propensity to trade bi-directionally. As mentioned in Section 3, expected is that the large firms' systematic purchasing and selling, or 'bi-directional' trading, is indicative of hedging. For future research, a more detailed business economics view within energy firms (e.g., footnote 139) can take up the extent of hedging. For example, Graham and Rogers (2002) derive the extent of hedging from financial statements. Orbis, the company database we utilized, did not provide this specific information.

Finally, the trade-related Hypothesis H.7.2 is either not significant, or accepted for large firms, or rejected for small firms. For large firms, this finding provides a weak indication that they seize (risk-free) arbitrage opportunities.

In sum, that the allowance trade of large firms is more responsive to the selected parameters (than small firms), more between than within firm boundaries, and indicative of carbon hedging and seizing of arbitrage opportunities, leads us to infer that large firms utilize the EU ETS for more than the purpose of compliance. While both large and small firms need to cope with volatile demand for their production, large firms can better spread the costs of risk management (e.g., hedging) over their larger production volumes. They can thereby lower their effective carbon costs by accounting for their carbon price risks.

7. Conclusion and Policy Implications

This chapter examines the 'make-or-buy decision' in explaining EU Emissions Trading Scheme (EU ETS) transactions by EU energy firms. Applied to the EU ETS, the 'make-or-buy decision' posits that carbon transactions take place within firm boundaries when transaction costs are lower vis-à-vis the carbon market. The central question is as follows: do European energy firms depend less on the EU carbon market when they are better able to pool their in-house pollution abatement potential? We expected that cost-minimizing firms behave 'self-sufficiently' by first allocating production, emissions, and, hence, allowances within firm boundaries before opting for the carbon market. Self-sufficient firms' external or carbon market trades are therefore expected to be less responsive to allowance demand factors because they are better able to absorb shocks within the firm.

Since 'self-sufficiency' cannot equivocally be measured, we constructed a composite indicator based on multiple variables affecting the firms' carbon intensity. Given the regression analyses we instead selected the firms' asset size since it performed better than this indicator.

The results show that large firms actually depend more on the EU ETS carbon market than small firms do. Contrary to our theoretical expectations, we find that large firms conduct more allowance trade on the carbon market than within firm boundaries. This may imply that, 1) their pollution abatement capacity is more expensive and/or 2) the carbon-related transaction costs within firm boundaries (e.g., information costs) prevent them from using their pollution abatement capacity (e.g., Stavins, 1995). Coordination of abatement through the carbon market will then be more cost-effective. This finding therefore affirms that, similar to the US Acid Rain Program (e.g., Ellerman et al., 2000), for large firms, the EU ETS leads to relative cost savings.

We further find that large firms purchase during electricity demand declines and with higher coal and/or lower gas prices and *vice versa*. This counterintuitive finding points to allowance hedging. The indications which generally affirm this conjecture are that trades were systematic repurchases and resales (instead of uni-directional trades) and that the trades were responsive to market arbitrage opportunities.

If smaller firms face higher transaction costs on the carbon market than within firm boundaries, policymakers should look into ways to improve the carbon market, for example, on the aspects of transparency and allowance property rights. Regarding allowance property rights, allowance trades were initially only lightly regulated. Although they have increasingly been treated as financial instruments, there are currently several exceptions (e.g., the Transparency Directive (EC, 2013) and the Financial Collateral Directive (EC, 2002) are not applicable to allowance spot trades. Nevertheless, some stakeholders indicate that market liquidity will deteriorate as of January, 2017, when the second Markets in Financial Instruments Directive (EC, 2014) will be applicable to energy products and emissions allowances (e.g., CEER, 2015). Future research is needed to test the willingness of small firms to participate on the carbon market after such more stringent regulations have been implemented. Furthermore, regulators can improve transparency by smoothing out the EU ETS timeline on allowance allocations and surrenders (e.g., Lucia et al., 2015) and by reporting on these events. Such smoothing can materialize, for example, if firms or sectors can decide on their own annual compliance cycles rather than following the EU-wide cycle.

CHAPTER 6
European Energy Regulators: An Empirical Analysis of Legal Competences[168]

1. Introduction

This chapter provides an empirical and comparative analysis of the legal competences of National Regulatory Authorities (NRAs) across the European Union (EU), including the extent to which those regulators have the power to intervene in contractual freedoms such as price setting, sales and investment decisions. By limiting the contractual freedom of firms, energy regulation restricts the property rights of gas and electricity companies. If contract restrictions are optimal, socially inefficient behavior by those energy firms is prevented so that competition and innovation are sustained. The aim is to test whether the differences in legal competences of NRAs are significant, and whether they are aligned to the public interest of a (1) secure, (2) competitive, and (3) carbon-neutral energy supply. By taking a descriptive and exploratory approach, this empirical analysis assesses energy governance arrangements across the EU. These insights may contribute to the European Commission's review of the regulatory framework, in particular the functioning of the energy regulators, as stipulated among the action points of the Energy Union package (EC, 2015).

The central research question is therefore as follows: what are the main differences in the legal competences of National Regulatory Authorities (NRAs) in the European gas and electricity markets, and are those differences aligned to the countries' divergent levels of secure, competitive, and carbon-neutral energy supply?

This chapter is organized as follows. Section 2 provides a review of the literature on the role of NRAs in energy regulation, and explains how the legal competences of NRAs are expected to respond to the security,

[168] This is the author pre-print version (i.e., the post-print) from the article which previously appeared in Jong and Woerdman (2016). We wish to thank Oscar Couwenberg, Francesca Pia Vantaggiato, Heinrich Winter, and the participants of the November 2014 GCEL research seminar as well as the 2014 BAEE research workshop for their comments and assistance. Any remaining errors are our own.

competitiveness, and carbon-neutrality of energy supply. Section 3 discusses the research methodology, whereas section 4 presents the results and a discussion thereof. Finally, section 5 concludes the chapter.

2. Literature review

A two-part definition of regulation is provided in Den Hertog (2012). The first part of the definition mentions "the employment of legal instruments for the implementation of social-economic policy objectives". From a law and economics point of view, gas and electricity market regulation restricts the contractual freedom that those energy firms have on their property rights. These restrictions should mainly be applied for those policy objectives related to improving the functioning of markets.[169] With regard to the energy market, the typical policy objectives or public interests at stake, according to the European Commission, are a (1) secure, (2) competitive, and (3) carbon-neutral energy supply.[170]

The second part of the regulation definition in Den Hertog (2012) considers the enforcement aspect of such legal instruments as follows: "individuals or organizations can be compelled by government to comply with prescribed behavior under penalty of sanctions." The enforcement of energy regulation has increasingly been allocated to National Regulatory Authorities (NRAs), for example, to establish "fines and penalties for non-compliance, [in acting] as arbiters in disputes between industry players, [or in protecting] end-users and [regulating] entry and exit through licences" (Battle and Ocaña, 2013).

Given this delegation of legal competences from Ministries, much of the literature on NRAs focuses on the reasoning for and the extent to which NRAs are independent from the regulated industries and from political stakeholders (e.g., Gilardi, 2008). Other NRA-related literature typically analyses either their internal organizational structure (e.g., decision-

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[169] Besides the typical market failures as natural monopolies and the continuity and availability of service, regulation should also further "distributional justice, rights protection, and citizenship – as, for example, [...] regulated utilities are obliged [...] to meet universal service obligations" (Baldwin et al., 2012).

[170] The European Commission has increasingly adopted these as the main energy supply criteria. For example, in the Energy Roadmap 2050, "the Commission explores the challenges posed by delivering the EU's decarbonisation objective while at the same time ensuring security of energy supply and competitiveness" (EC, 2011a).

making and external funding (Hanretty and Koop, 2012) or the energy sectors' market structure (e.g., Cambini and Franzi, 2013; Ugur, 2009).

Less discussed and hardly analyzed are the legal competences or 'powers' of NRAs, and the extent to which these contribute to the energy supply objectives, which are essentially the two elements which make up the definition of regulation by Den Hertog (2012). For instance, NRAs should "take all reasonable measures [...] within the framework of their duties and powers to [...] promote [...] a competitive, secure, and environmentally sustainable internal market in electricity/natural gas within the [EU]" (Johnston and Block, 2012).[171] Moreover, "in performing [the] tariff/methodology-setting function, [NRAs are to] ensure that transmission or distribution system operators are granted appropriate incentive, over both the long and short term, to increase efficiencies, foster market integration, and security of supply [...] " (ibid).

This chapter fills a gap in the literature on the relationship between NRA competences and the realization of the three abovementioned objectives of a secure, competitive, and carbon-neutral energy supply.[172] Hypothesized is that NRAs have fewer competences when those policy objectives are sufficiently met, because the realization of the objectives reduces the need for regulatory intervention.[173]

The data on legal competences are deduced from questionnaires on gas and electricity market regulation gathered in 2011 and 2012 by the

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[171] However, it may not be excluded that their objectives are shared with other authorities.

[172] In translating EU-wide goals into policies, the European Commission relied predominantly on Directives rather than Regulations. Partly, this is because energy has been among the main domains where EU Member States are reluctant to transferring their national sovereignty to the EU level. In the Energy Package Directives, the minimum list of NRA duties and competences are stipulated. In addition, if compatible with EU law, Member States can go further than this minimum set of legal duties and competences, making inter-NRA differences likely.

[173] We thank a reviewer from the journal "Competition and Regulation in Network Industries" for pointing out that higher energy scores could well result from more regulatory intervention. As indicated in footnote 190 below, the data sample limited such test. We selected the energy scores among the covariates since it lacked the competence-nesting (level c). Since the sample only covers one time period we could, hence, not test for (Granger) causality. The approach we therefore took is to hypothesize that the opposite sequence holds. Indeed, given the results below we cannot unequivocally reject that higher energy scores reduce the need for regulatory intervention.

International Confederation of Energy Regulators (ICER).[174,175] The 2011 electricity ICER survey has been analyzed before by Gianfreda and Vantaggiato (2013). From most EU Member States plus several neighboring countries, they investigate the enforcement powers of NRAs on electricity regulation and tariffs. Their main findings are that NRAs had diverse competences for transmission grids, and that the generation part of the value chain was lighter regulated than the retail part (i.e., it involved fewer competences). Moreover, Cambini and Franzi (2013) conducted surveys on competences of NRAs, but focused on Northern African and Middle Eastern countries. However, Gianfreda and Vantaggiato (2013) and Cambini and Franzi (2013) do not check whether the competences of NRAs are aligned with the countries' realization of energy supply objectives. Moreover, other researchers analyze NRA competences either concerning other impacts (e.g., the centrality of NRAs in policy-making (Maggetti, 2009) or they analyze closely related policy objectives but apply different NRA aspects (e.g., NRA regulatory independence on connection charges (Edwards and Waverman, 2006).[176]

This chapter further adds to the literature by empirically analyzing the distribution of NRA competence-types. To keep costs of both regulatory authorities and regulated firms contained (e.g., by ex-ante prescribing acceptable behavior instead of ex-post legal action) NRAs should follow the concept of 'responsive regulation' (e.g., Ayres and Braithwaite, 1992). Interventions are then differentiated according to the willingness of the regulated to comply, where the harshness of interventions is attuned with the severity of the violations at hand. In effect, and from softer to tougher interventions, regulators dispose of the following three regulatory 'tools': 1) to communicate and gather information, 2) to form subsequent judgments, and 3) possible

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[174] This data are available from: http://www.icer-regulators.net.

[175] Another EU-wide source on legal competences is a 2005 report compiled by the European Council of Energy Regulators (CEER, 2005), but CEER has not reiterated this study. More recent data on legal competences are scattered, not available in English, or not as detailed as CEER (2005) or the ICER-questionnaires as analyzed here.

[176] We could not check the source of regulator competence data from Ugur (2009), the Market Opening Milestones database, as it is not publicly available.

interventions.[177] We arrange the legal competences according to this 'responsive regulation' benchmark and, via this differentiation, we test the alignment of these competences to the various energy supply objectives.

3. Methodology

As mentioned above, the data on legal competences are deduced from 2011 and 2012 International Confederation of Energy Regulators (ICER) questionnaires on gas and electricity market regulation.[178] In these questionnaires, (non-)EU Member States are asked whether they had legal competences over several categories, among others, whether they have the power to intervene in contractual freedoms such as price setting, sales and investment decisions. Rather than a cluster analysis in Gianfreda and Vantaggiato (2013), the approach here is to label the questions according to their 'responsive regulation' competence-type (as identified from the ICER surveys on legal competences, and indexed with *c*): 1) *inform*, 2) *assess*, 3) *approve*, and 4) *penalize*.[179] Questionnaire replies with a 'no' or 'yes' were scored zero or one, respectively, upon which they were summed

[177] Indeed, these three tools can be further subdivided. For example, both financial penalties and licence withdrawals are NRA-interventions, where the former is typically less intrusive than the latter.

[178] Because the 2011 questionnaire encompasses more EU Member States (including non-EU Member States: Iceland and Norway), the two are merged where, if overlapping, the 2012 results are selected. Both the gas and electricity surveys are included, although fewer replies were provided for the gas surveys (22) than for the electricity surveys (28). The EU Member States which replied to both gas and electricity surveys are: Austria, Belgium, Bulgaria, Czech Republic, Germany, Denmark, Estonia, Spain, Finland, France, United Kingdom, Hungary, Italy, Lithuania, Luxembourg, Latvia, Malta, Poland, Romania, Sweden, Slovenia, and the Slovak Republic. The countries which only replied to the electricity surveys are: Greece, Iceland, Ireland, the Netherlands, Norway, and Portugal.

[179] Appendix 1 lists the survey questions underlying these competences-types, as well as the remaining and excluded categories of *overturn* and *n.a.*. The *n.a.*-category is excluded as it is unclear to which competences these terminologies are referring.

over the four competence-types.[180,181] Larger values thus point towards more legal competences in these categories.

Figure 1 illustrates our expectation on the four competence-types. Analogous to Ayres and Braithwaite (1992), 'softer' competences are expected to be less costly to apply than 'tougher' competences, and therefore to receive lower shares in the overall NRA competence 'toolkit'. 'Tougher' competences are more costly to apply, because they entail more extensive legal procedures than 'softer' competences do (e.g., because pleas need to be prepared). Thus, regarding the first research question (i.e., on the main differences in legal competences), the first hypothesis is as follows:

(H1). Most legal competences are allocated to the *inform*-category, and are subsequently allocated to the categories of *assess*, *approve*, and *penalize*, respectively.

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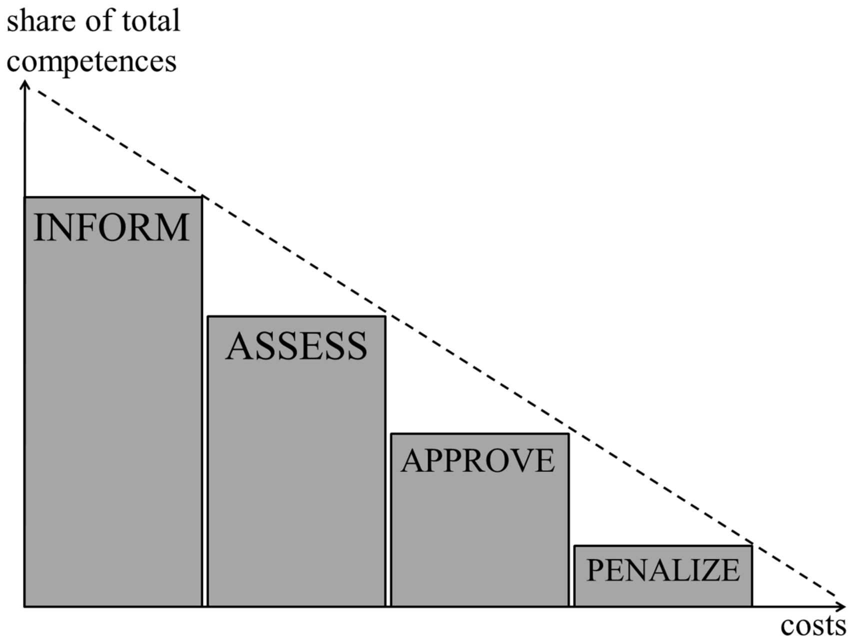
[180] For future research, weights could be applied to the scores instead of a summation.

[181] NRAs also provided some context for a few powers. We did not include this information as we could not score these varying and textual comments. Implicit in our approach is therefore that the respondents weighed up these nuances through their binary answers. In principle, a no-answer or yes-answer may in fact lie between 0 and 49% or 50 and 100%, respectively.

Figure 1: Expected distribution of legal competences



- inform: to monitor and audit compliance, rules, activities, tariffs, planning, and standards; to request and publish information
- assess: to propose rules, methodologies, tariffs, standards, and to issue opinions
- approve: to set, approve, and issue rules, tariffs, standards, and methodologies
- penalize: fines and penalties

The ICER-questionnaires have been conducted over two main sections. The first section includes subcategories analogous to the three policy objectives. The competence estimates herein will be used as response variables:
1) 'security-of-supply' (sos_{csi}) for the security-of-supply competences.
2) 'renewables and environment' and 'environmental regulation' relate to the electricity and gas sectors, respectively, where these sector-specific subcategories are merged for the carbon-neutrality competences ($carb_{csi}$).
3) The remaining competence-subcategories on 'consumer protection' ($mkst_{csi}$) and 'energy efficiency' ($enef_{csi}$) are applied for 'competitiveness'. Consumer protection is conducive to competition, for example, through

the improved bargaining position of consumers.[182] And competitiveness, in its turn, is conducive to efficiency.[183] These aspects thus capture the competitive forces confined to these competence categories.

Note that the subscript *csi* refers to the nesting of observations. The first level c = 1, ..., 4 stands for the competence-types *inform*, *assess*, *approve*, and *penalize*, respectively; the second level s = 0, 1 refers for the electricity and gas sector, respectively; and the third level i = 1,..., 28 denotes the European country.[184] Expected is that priority is given to security-of-supply, not only because (industrialized) economies depend on continuous energy consumption, but also because legal exceptions are mainly granted for security of supply purposes (e.g., Johnston and Block, 2012). It is not clear-cut which of the remaining two policies are second in line, or whether electricity or gas sectors differ regarding these priorities. Hence, the second hypothesis is as follows:

(H2). Most legal competences are allocated to security-of-supply purposes.

The second ICER-questionnaire section includes NRA competences over the four elements of the energy value chain, namely: 1) generation ($gener_{csi}$), 2) transmission ($transm_{csi}$), 3) distribution ($distr_{csi}$), and 4) retail ($retail_{csi}$). They are brought together as follows:

$$grid_{csi} = (transm_{csi} + distr_{csi}) - (gener_{csi} + retail_{csi}) \qquad (1)$$

As part of the covariates, it captures the difference in the number of competences within grids ($transm_{csi}$ and $distr_{csi}$) compared with non-grids

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182 On the other hand, 'consumer protection' can prohibit cooperative contract or ownership structures among firms, asset-specific investments can be thwarted (e.g., hold-up issues). Investments are essential to sustain medium to long-term competition.

183 There may be ‘energy efficient’ systems with only one or few firms serving the market. However, ‘competitiveness’ does not only rely on the number of firms. In addition, if efficiency competences only target the transport of energy, cost-effectiveness may still be limited. For example, also energy resource costs are a significant factor. We would like to thank attendants of our 2014 BAEE research workshop presentation for raising this last point.

184 With four competences per sector, two sectors, and 28 countries, there are four times two times 28 competences, encompassing 200 observations (as replies on six countries’ gas sectors are missing in the ICER surveys).

($gener_{csi}$ and $retail_{csi}$).[185] In liberalized energy markets, relatively more competences are allocated towards regulating transmission and distribution (i.e., $grid_{csi}$ is higher). This effect is expected to be less pronounced for the gas sector, however. Influential players outside national legal boundaries may benefit from markets which are liberalized. This especially holds for non-grid activity, as grid activity is locally bound. More non-grid competences are therefore necessary to prevent that the outcomes deviate from national public interests (i.e., $grid_{csi}$ is lower).

It is not clear-cut, however, whether market liberalization increases the total number of competences. On the one hand, market liberalization leads governments to decrease their intervention in markets, which results in fewer legal competences. On the other hand, market liberalization leads to more rules to ensure efficient and fair competition, as argued in Vogel (1996), so that more legal competences may be needed (i.e., higher values for sos_{csi} to $carb_{csi}$).[186] Based on the latter argument, the third hypothesis is therefore as follows:

(H3). The number of policy area competences increases with more grid-related competences. This relationship is weaker for the gas sector.

The remaining independent variables include the scores on the three energy supply objectives. For the security-of-supply score ($indexsos_{si}$), we applied the countries' energy security rankings as available on the World Energy Council (WEC) website. The rankings were first min-max normalized.[187] The index is then the average of these normalized

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[185] Furthermore, if taken separately, these variables correlate highly with the response variables.

[186] By including $grid_{csi}$, a causal effect may therefore be captured between the covariates and the response variables.

[187] Min-max normalization implies that: $z_i = [x_i - \min(x)] / [\max(x) - \min(x)]$) where $x = (x_1,\ldots,x_n)$, and x_i and z_i are country i's pre and post-normalization rankings, respectively.

rankings.[188] The scores thus range between 0 and 1, where higher scores point towards a better performance.[189] For consistency purposes, the same steps are also taken for the other energy scores.[190]

Because there are two 'competitiveness' competences (i.e., $mkst_{csi}$ and $enef_{csi}$), we also constructed two analogous energy scores. For the energy efficiency index ($indexenef_{si}$) a ratio is set up from Eurostat's Energy Balances items by subtracting 'consumption in energy sector' and 'distribution losses' from total energy output, and subsequently dividing it again by total energy output. Hence, the higher this ratio, the less energy

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[188] This approach follows that of Sovacool (2013), upon which one of our security-of-supply indices is based (see the next footnote). We admit that, by virtue of this methodology choice, other techniques are skipped through which countries' policy performance can be tested. One main branch concerns benchmarking, such as Data Envelopment Analysis (see e.g., Pompei (2013) specifically, or Zhou et al. (2008) generally). Nevertheless, given its own flaws, benchmarking may not lead to an improved view on a country's relative performance (see e.g., Hirschauer and Musshof (2014) and Grifell-Tatjé and Kerstens (2008)) which is needed in this analysis.

[189] For robustness purposes, we applied three security-of-supply indices. The (country-specific) index as mentioned in the text had the best model fit (AIC, BIC, log-likelihood, and the raw R^2). Information on the other two is available on request.

[190] While the security-of-supply score is country-specific, the other scores only have the subscripts *s* and *i*, as data are only available at the sector and country level, respectively. In addition, unlike the response variables sos_{csi} to $carb_{csi}$, the policy scores lack the competence nesting (*c*), so it is more natural to take the scores as covariates.

is lost at generation and/or distribution, and the more efficient the energy system is.[191,192]

For the consumer protection competences (i.e., $mkst_{csi}$) we created a market structure index ($indexmkst_{si}$) through the European Commission's internal energy market indicators on electricity and gas market structures (EC, 2012b).[193] While consumer protection mainly concerns retail markets, we also included the EC (2012b) wholesale market indicators. Market power in wholesale markets can still be maintained with competitive retail markets (e.g., Goulding et al., 1999). For the carbon-neutrality score ($indexcarb_{si}$), the energy-related carbon emissions per capita is selected for the electricity sector.[194] For the gas sector, the carbon emissions from the natural gas consumption and flaring are taken as a proportion of the total carbon emissions from the consumption of energy.[195]

Having defined the competences and the realization of energy policy objectives, the next hypothesis relates to the research question on their

[191] In the Eurostat Energy Balances, the key energy input-output equation which needs to hold is:
'Gross inland consumption' + 'transformation output' + 'exchanges and transfers, returns' = 'final energy consumption' + 'final non-energy consumption' + 'transformation input' + 'consumption in energy sector' + 'distribution losses' + 'statistical differences'. For the electricity and gas balances, separately, *indexenef* is set up through a ratio from the equation's right-hand side: (final energy consumption + final non-energy consumption + transformation input + statistical differences) / (final energy consumption + final non-energy consumption + transformation input + consumption in energy sector + distribution losses + statistical differences).

[192] The European Commission "EU Energy in Figures" statistical pocketbooks provide two useful metrics on energy efficiency: "Energy intensity" and "Primary energy efficiency". The former is a widely used indicator while, unfortunately, details on the latter are not provided. An example of energy intensity is the amount of energy consumed relative to GDP. However, we could not create electricity and gas sector counterparts because we lack data for the denominator (e.g., profits at both country and sector level).

[193] These include the national electricity and gas market values, Herfindahl-Hirschmann Indices, switching rates, numbers of generators and retailers, market shares of the largest entities, and whether prices are regulated.

[194] This is the climate change-related metric in Sovacool (2013). As it concerns only one metric, no averaging was necessary.

[195] Both statistics are available at the U.S. Energy Information Administration website. The total carbon emissions are in fact a summation of the carbon emissions from the consumption of coal, petroleum, and the consumption and flaring of natural gas.

alignment. Because NRAs should have fewer competences when policy objectives are sufficiently met, the hypothesis is therefore as follows:

(H4). The number of NRA competences decreases (i.e., sos_{csi} to $carb_{csi}$) with higher energy scores (i.e., $indexsos_{si}$ to $indexcarb_{si}$)

We selected a multilevel econometric approach which, analogous to panel data techniques, accounts for repeated measurements and thereby reduces the impacts from causal effects.[196] Specifically, it mitigates the omitted-variable bias, where effects from the covariates on the response variables depend on the (ceteris paribus) levels of one or more excluded variables. An excluded variable example can be legal origin (e.g., civil or common law). Even if two NRAs have an equal number of grid-competences (i.e., one of the covariates) the legal origin may cause one of the NRAs to have more authority over the policy in question. Standard econometric setups do not account for such fixed effects, which renders inconsistent the parameter estimation. Multilevel effects can control for multiple within-cluster effects and, thereby, account for such spurious effects as each cluster serves as its own control. Appendix 2 further discusses the econometric setup and the regression results.

4. Results and discussion

4.1 Descriptive statistics

[196] Beneficial compared with panel data techniques is that the multilevel approach enables analyzing the "cluster-level random processes that affect the response variable" (Rabe-Hesketh and Skrondal, 2012). It treats cluster effects as non-random, which is reasonable "if the clusters are, for instance, countries" (ibid). In addition, multiple levels of clustering can be analyzed, as with this three-level hierarchy (i.e., country, sector, and competence).

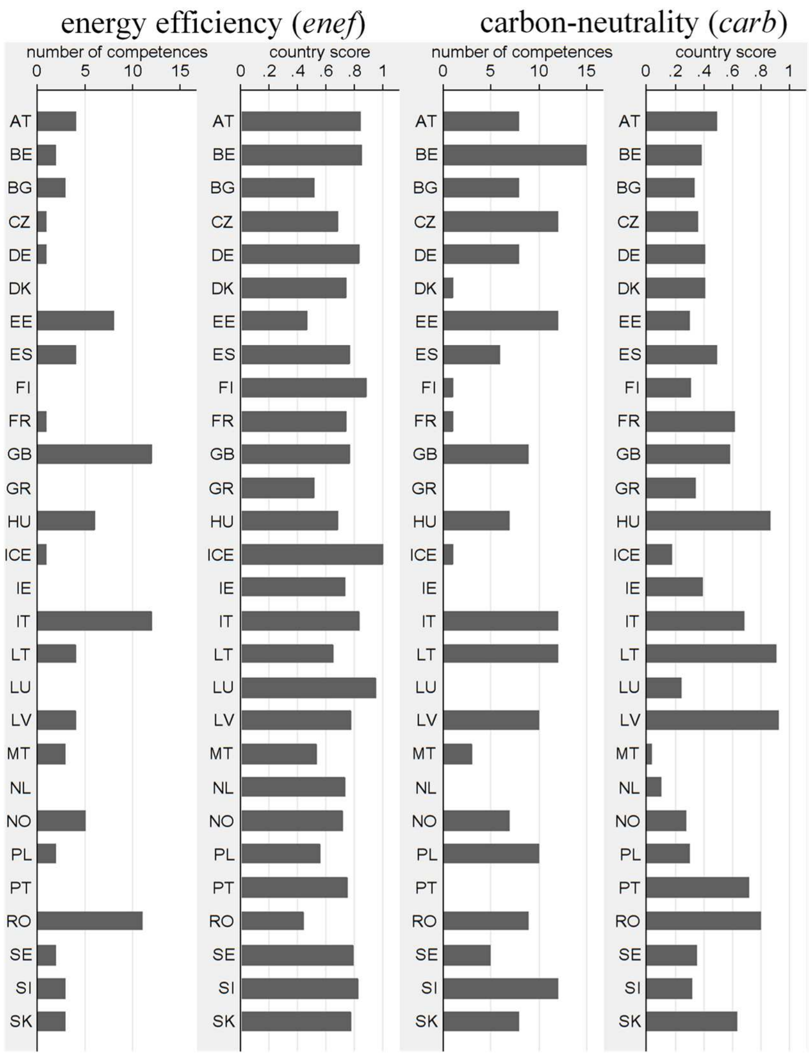
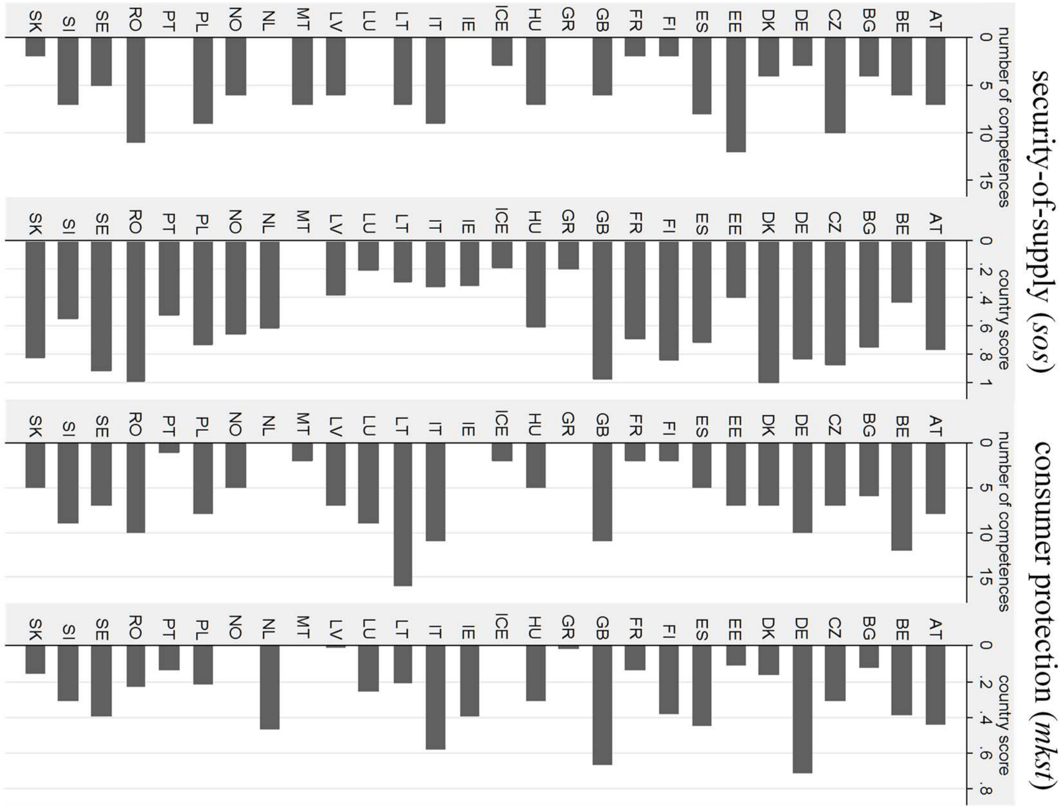
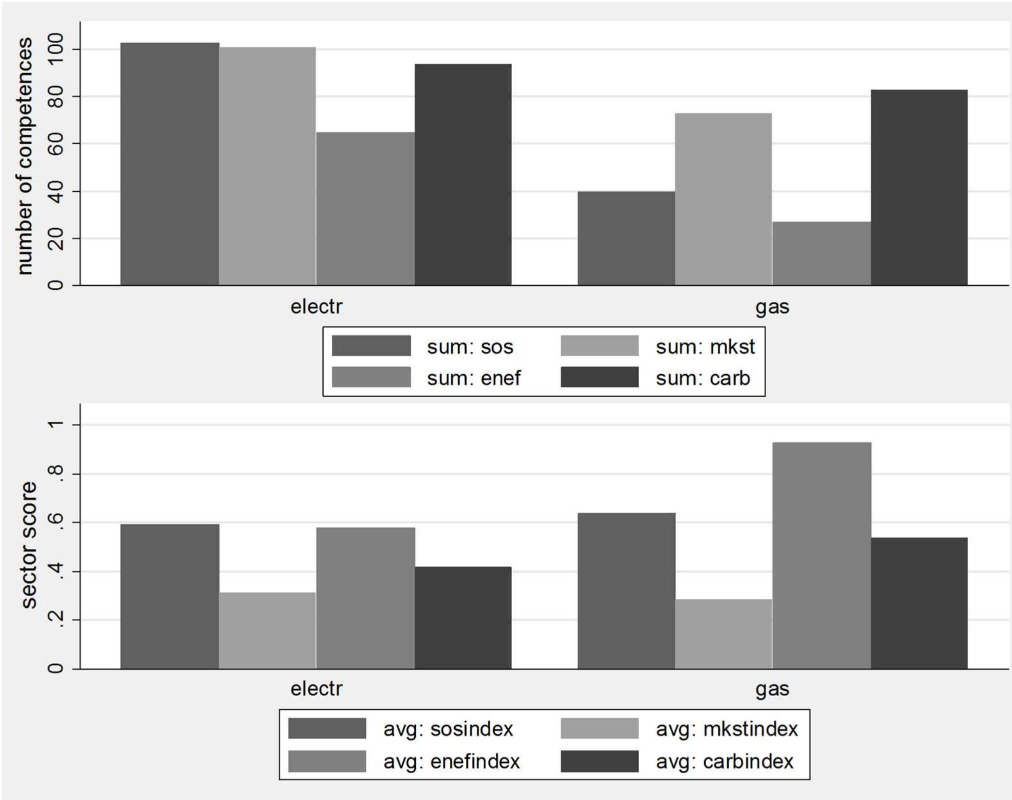


Figure 2: Per country: sum of legal competences, and average energy score



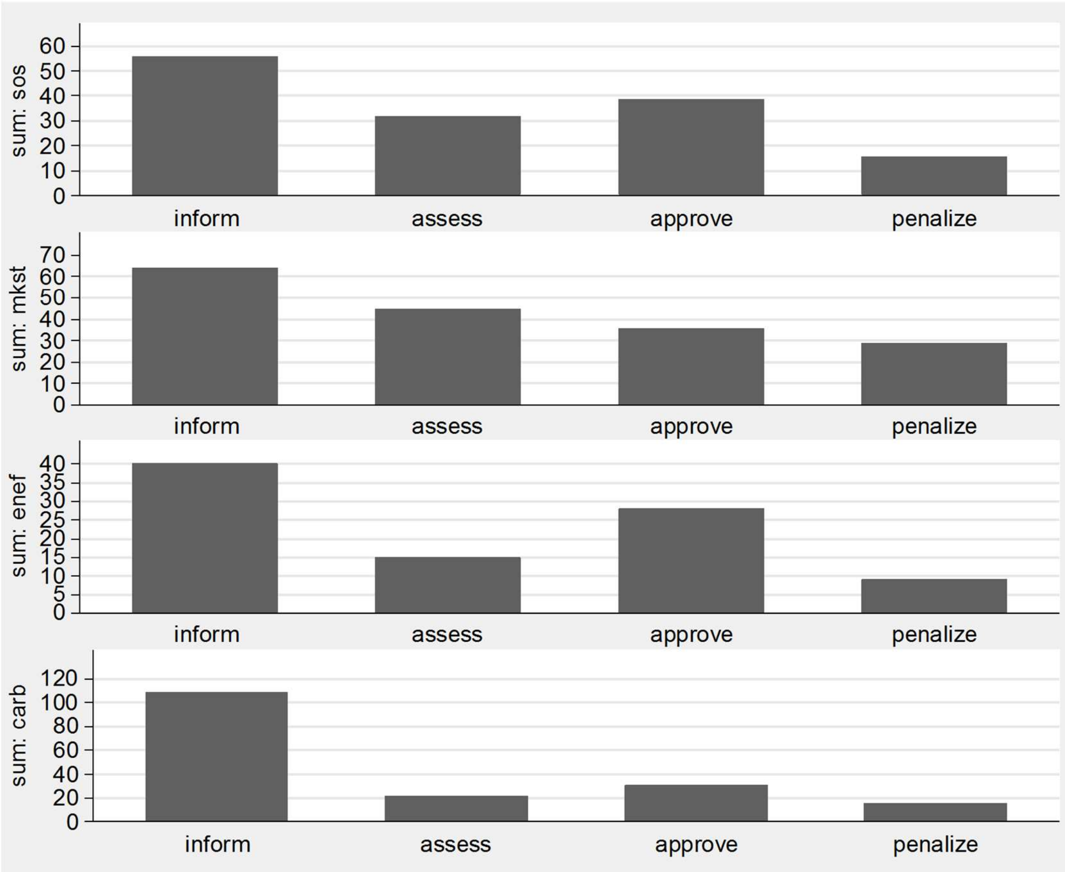
Competence-country score correlations: sos (0.17), mkst (0.31), enef (-0.27), and carb (0.33)

Figure 3: Per sector: sum of legal competences and average energy score



The upper bar graph shows the electricity and gas sector sum of competences on security-of-supply (sos), consumer protection (mkst), energy efficiency (enef), and carbon-neutrality (carb), while the lower bar graph shows the sector averages of the corresponding energy scores. The overall competence-sector score correlation is: -0.72.

Figure 4: Per competence: sum of legal competences



The bar graph shows the sum of competences on security-of-supply (sos), consumer protection (mkst), energy efficiency (enef), and carbon-neutrality (carb) over the four competence-types of inform, assess, approve, and penalize.

Figures 2, 3, and 4 show the total number of legal competences and the averaged energy scores at the country, sector, and competence level, respectively. Figure 2 shows that the differences in competences across NRAs are large. There are strongly intrusive NRAs such as Great Britain, Italy, and Romania, and there are weakly intrusive NRAs such as Greece, Portugal, and the Netherlands.[197] Figure 2 further indicates, for instance, that countries have fewer competences related to energy efficiency in comparison with their other competences.

Overall, instead of security-of-supply, most competences are allocated for carbon-neutrality purposes. This therefore rejects the second hypothesis (H2). Nevertheless, Figure 2 shows that the majority of countries have a total number of security-of-supply (average: 5.11), consumer protection (average: 6.21), and carbon-neutrality (6.32) competences around and higher than the average, respectively. Only for energy efficiency do the majority of countries have less than the average number of competences (3.29).

Figure 3 shows that overall more competences are allocated to the electricity sector, and that within the electricity sector most competences are allocated for security-of-supply and within the gas sector for carbon-neutrality purposes. Given the fewer gas competences generally and to security-of-supply specifically, Ministries may have decided not to confer these gas-sector competences to their NRAs so as to better cope with influential gas suppliers outside their national legal boundaries.

Moreover, Figure 3 shows that the inter-sector differences in scores mainly arise with regard to energy efficiency (i.e., $enefindex_{si}$).[198] The higher score for the gas sector implies that this sector is on average more efficient in the transformation of energy than the electricity sector.

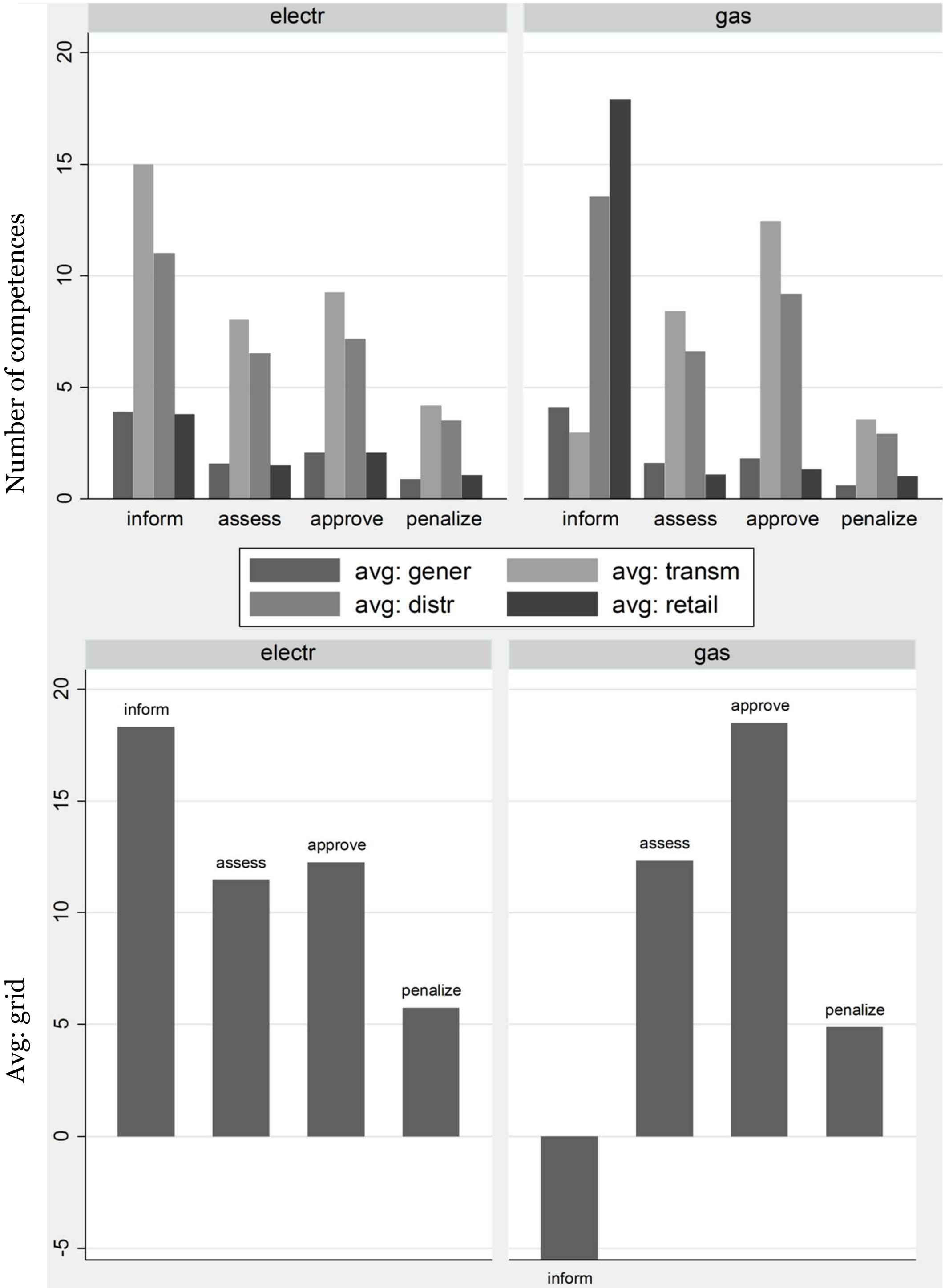
Figure 4 further shows that most competences appear in the competence-category of *inform*, fewer for either *assess* or *approve*, and least for *penalize*. Overall, the ordering is hierarchic from *inform* to *penalize*, as expected from Hypothesis H1. Strictly speaking, though, only for consumer protection (*mkst*) this ordering is fully hierarchic. For energy efficiency, security-of-supply, and carbon-neutrality, NRAs need to be allocated more *assess* and/or fewer *approve* competences, according to

[197] For some countries, the (country level) competence sums are low. Partly, this is because they have not answered the gas surveys (these were: Greece, Iceland, Ireland, the Netherlands, Norway, and Portugal). Even so, the graphs show they have few electricity-competences as well (except Norway). Rather than the no = 0-49% and yes = 50-100% range as in footnote 181, these low numbers may be caused by countries which only answered with "yes" for unequivocal cases.

[198] The scores do not vary between the competence-types, but only across sectors and countries. The covariate *secindex* is not dependent on the sectors, but it differs slightly because the electricity sector subsample comprises more countries.

our theoretical benchmark. Additional research is necessary to draw more robust conclusions on whether these cases could serve as indications regarding either under- or overregulation by NRAs.

Figure 5: Graphs of *gener*, *transm*, *distr*, *retail*, and *grid*.



The upper bar graph shows the electricity and gas sector average of competences on generation (gener), transmission (transm), distribution (distr), and retail (retail), while the lower bar graph shows the transformation into grid = gener + retail – transm - distr.

The upper part of Figure 5 shows the competences over the four elements of the energy value chain, namely: 1) generation ($gener_{csi}$), 2) transmission ($transm_{csi}$), 3) distribution ($distr_{csi}$), and 4) retail ($retail_{csi}$). The lower part of Figure 5 shows the transformation into $grid_{csi}$. The fact that the $grid_{csi}$-bars are generally positive implies that most NRAs are allocated more competences for the grids. This result is in line with EU developments of grid unbundling whereby NRAs need to monitor and enforce the structural and behavioral rules for transmission (TSOs) and distribution system operators (DSOs). For example, operators which control (transmission) grids in the gas and electricity value chains are prohibited from controlling generation and retail facilities, and vice versa.[199]

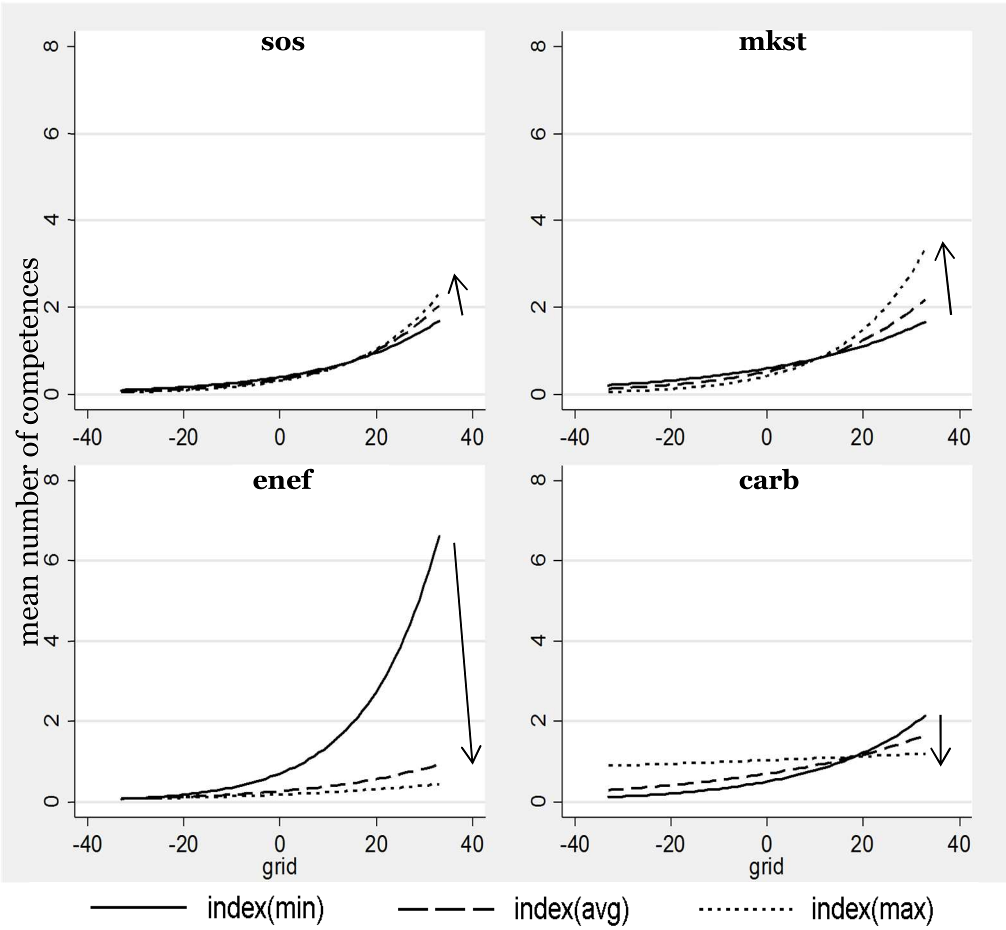
4.2 Multilevel results

Figures 2, 3, and 4 indicate that the sample follows a Poisson distribution, mainly because the number of competences is non-negative, they comprise multiple-valued integers (i.e., whole numbers) and, without a natural upper bound, they comprise multiple zeroes – in the policy areas for which NRAs were not conferred legal competences.[200]

[199] More on the unbundling regulations can be found in chapter 3 of Johnston and Block (2012).

[200] Moreover, the overall mean and variance of the observations are almost equal (i.e., the 'equidispersion' property). Detailed descriptive statistics are available on request.

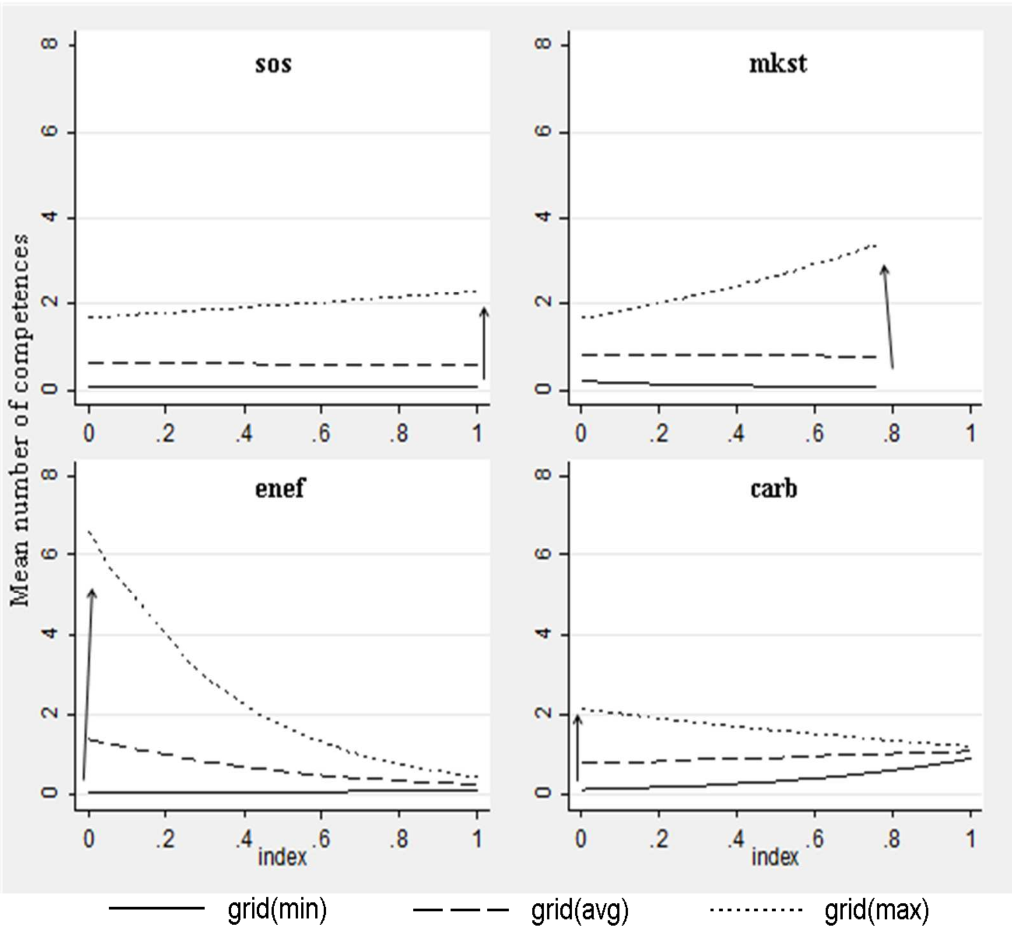
Figure 6: Effects on the predicted mean number of legal competences (including multilevel fixed and random effects of sos to carb) from changing the grid-related competences (grid) with energy score (i.e., indexsos to indexcarb) held fixed



The variables are: 1) the number of competences in security-of-supply (sos), consumer protection (mkst), energy efficiency (enef), carbon-neutrality (carb), and grid-related competences (grid), and 2) the energy scores on security-of-supply (indexsos), market structure (indexmkst), energy efficiency (indexenef), and carbon-neutrality (indexcarb), and where:

indexsos(min) = 0 *indexsos(avg) = 0.61* *indexsos(max) = 1*	*indexmkst(min) = 0* *indexmkst(avg)= 0.30* *indexmkst(max) = 1*
indexenef(min) = 0 *indexenef(avg) = 0.73* *indexenef(max) = 0.76*	*indexcarb(min) = 0* *indexcarb(avg) = 0.47* *indexcarb(max) = 1*

Figure 7: Effects on the predicted mean number of legal competences (including multilevel fixed and random effects of *sos* to *carb*) from changing the corresponding energy score (*indexsos to indexcarb)* with grid-related competences (*grid*) held fixed.



The variables are: 1) the number of competences in security-of-supply (sos), consumer protection (mkst), energy efficiency (enef), carbon-neutrality (carb), and grid-related competences (grid), and 2) the energy scores on security-of-supply (indexsos), market structure (indexmkst), energy efficiency (indexenef), and carbon-neutrality (indexcarb), and where: grid(min) = -13 ; grid(avg) = 10.01 ; grid(max) = 33

Figures 6 and 7 show, based on the Appendix 2 multilevel regression outcomes, how the average numbers of competences (i.e., the y-axis) are aligned with the energy scores and the grid-related competences. Figure 6 shows these averages as a function of the energy scores (*index*) while the number of grid-related competences (*grid*) is held fixed at the minimum, average, and maximum levels. Figure 7 does the opposite for the energy scores and *grid*. Important to note is that the results on carbon-neutrality ($carb_{csi}$), as shown in this section (i.e. Figures 6 and 7), are not significant (see Appendix 2). We nevertheless provide and consider the results in order to discuss all three policy areas, including the important pillar of carbon-neutrality.

Figure 6 indicates that Hypothesis H3 holds, which conjectures a positive relationship between the number of NRA competences (i.e., sos_{csi} to $carb_{csi}$) and grid-related competences (i.e., $grid_{csi}$). This finding thus endorses the 'freer markets, more rules' conjecture of Vogel (1996), if the 'freer market' aspect can be captured by the number of grid-related competences (i.e., market liberalization), and the 'more rules' can be captured by the number of policy area competences (i.e., sos_{csi} to $carb_{csi}$). This effect especially holds for security-of-supply (*sos*) and consumer protection (*mkst*), because these lines become increasingly positive from *index*(min) to *index*(max) – while the energy efficiency (*enef*) and carbon-neutrality (*carb*) lines level off.

Furthermore, Figure 7 indicates that Hypothesis H4 does not always hold; not for all policy areas are fewer competences conferred to NRAs (i.e., sos_{csi} to $carb_{csi}$) when energy scores are higher (i.e., *index*). Because the impacts from carbon-neutrality change sign (i.e., from *grid*(min) to *grid*(max)), as with Figure 6, we infer that carbon-neutrality ($carb_{csi}$) is a mixed bag. Its mixed (and insignificant) results may relate to the overall separation of EU climate and energy policy. Although generally the largest, the energy sector is not the only contributor to carbon emissions. This may have led governments to delegate some competences to other climate policy-specific NRAs or Ministries. However, such shared responsibilities need to be accurately delineated so that, for example, NRAs can still sufficiently monitor "corporations that operate or have interests in different sectors and industries" (Jordana and Levi-Faur, 2010). Effectiveness may therefore improve if the sampled countries reconsider the regulatory scope of their NRAs.[201]

[201] It may also originate from the ICER survey categorization of "renewables and environment" and "environmental regulation" for the electricity and gas sectors, respectively. There is a possibility that these competences relate to more than the carbon-attributes of electricity and gas.

Next of interest is why impacts on energy efficiency (*enef*) competences are opposite to those of security-of-supply (*sos*) and consumer protection (*mkst*). One distinguishing factor is that energy efficiency, despite its large potential in the management of energy systems, has received relatively less attention in national and EU policies.[202] Indeed, as shown in Section 4.1 above, fewest competences are allocated for energy efficiency purposes. A comparison with security-of-supply and consumer protection would therefore be on unequal terms. It is therefore the question whether the same outcomes would hold if NRAs were to be equipped with more energy efficiency competences ($enef_{csi}$).

In the development of EU energy law, especially security-of-supply (sos_{csi}) and consumer protection ($mkst_{csi}$) (i.e., competition policy) have interchangeably occupied center stage on the policy agenda (Johnston and Block, 2012). It is reasonable to assume that firms will not voluntarily incur expenses to improve these two energy aspects. Energy efficiency improvements, conversely, reduce costs and may even result in energy demand increases (the so-called 'rebound effect'). The positive relationships between legal competences and scores of security-of-supply (sos_{csi}) and consumer protection ($mkst_{csi}$) may therefore be driven by a regulatory 'lock-in' effect. Higher scores are then matched with stricter rules and enforcement.[203]

4.3 Recommendations for future research

Rather than following the path of ever stricter regulations, policymakers should rearrange energy property rights such that it is in the firms' own interest to arrive at the (socially) optimal levels of security-of-supply and consumer protection.

With demand for energy set to rise, the incentives increase to optimize the contractual freedom of energy stakeholders and therefore the boundaries of energy property rights (see also Section 2). At the wholesale

[202] For example, among the European Commission's 20-20-20 targets (i.e., 20% reductions on carbon emissions, renewables, and energy efficiency), the targets on energy efficiency are not binding at Member State level.

[203] Finally, the second part of Hypothesis H3 has not yet been discussed, namely whether impacts on the number of competences are weaker for the gas sector. While Figure 3 shows that gas versus electricity sector differences are substantial, effects at the sector level were either not significant or had a poorer model fit. Competences at the sector level are therefore not sufficiently pronounced for the hypothesis to be accepted or rejected regarding the gas sector.

level, for example, derivative markets have taken up an important role in this contractual optimization by allocating risks. However, risk allocation at the retail (e.g. consumer protection) and system level (e.g. security-of-supply) is primarily provided through regulation. One possible research venue, hence, is the extent to which market parties can assist in allocating risks (e.g., via insurance) and can be a complement to or substitute for regulation.

Another research venue is in the measurement of the influence of NRAs. For example, having legal competences does not necessarily imply that NRAs have exercised them (e.g., Voigt, 2012). Moreover, an extension of this analysis may include the legal competences of Ministries and the judiciary (i.e., in case of legal action).

5. Conclusion

This chapter presented an EU-wide empirical study of energy market regulators and their legal powers. The following questions were posed: what are the main differences in the legal competences of National Regulatory Authorities (NRAs) in European gas and electricity markets, and are those differences aligned to the countries' divergent levels of (1) secure, (2) competitive, and (3) carbon-neutral energy supply?

From a variety of sources, we derived energy scores on the extent to which European countries have realized a (1) secure, (2) energy efficient, competitive and consumer-protective, as well as (3) carbon-neutral energy supply for their electricity and gas sectors. Based on surveys by the International Confederation of Energy Regulators (ICER), we developed estimates on NRA competences analogous to these energy supply properties, which range from less intrusive ('soft') to more intrusive ('tough') competences.

Across NRAs, it appears that the differences in the number of legal competences are large. Ministries have mainly conferred competences to NRAs for the electricity sector, primarily for carbon-neutrality purposes, but also for security-of-supply, consumer protection, and energy efficiency. NRAs are allocated more grid-related (i.e., transmission and distribution) than non-grid-related competences (i.e., generation and retail), which is in line with EU grid 'unbundling' developments. Moreover, the legal competences of NRAs do not follow the 'optimal' competence arrangement of regulatory authorities: compared with a theoretical benchmark there are relatively more 'tough' than 'soft' competences, while the latter are less costly to exercise. These potential regulatory 'mismatches' could be corrected by adjusting the number and intrusiveness of the NRAs' legal powers.

Through a multilevel analysis we find that NRA competences are not fully aligned with their corresponding energy scores. First of all, although higher energy scores should reduce the need for regulatory intervention and thus legal competences, this inverse relationship does not hold for most of the policy objectives. For energy efficiency, energy scores and competences move oppositely as hypothesized, but definitive conclusions cannot be drawn because only few NRAs have competences in this policy area. For carbon-neutrality, energy scores and competences move both in similar and opposite directions. These mixed findings likely result from governments which have delegated these competences to other policy-specific NRAs or Ministries. Effectiveness of regulations may therefore improve if the sampled countries reconsider the scope of their NRAs. The research recommendations we provide, for instance in improving the measurement of the influence of NRAs, may further sharpen the competence-policy perspective on energy efficiency and carbon-neutrality.

Finally, for security-of-supply and consumer protection, energy policy scores and competences move in similar directions. These interactions may be driven by a regulatory 'lock-in' effect. Higher scores are then matched with stricter rules and enforcement.

In addition, we find evidence that NRAs with more grid-related competences, which operate in more 'unbundled' and liberalized sectors, also have more of the above policy area competences. This finding supports the 'freer markets, more rules' proposition by Vogel (1996). However, instead of creating more rules, future research is needed to find out to what extent delegating the insurance of energy and climate objectives to private parties is recommendable in assisting the regulation of energy markets.

Appendix 1 – Competence categories

Competence: (1) *inform*

Complaint management
Do you monitor and/or audit access rules to the distribution networks?
Do you monitor and/or audit compliance with access rules for distribution networks?
Do you monitor and/or audit compliance with access rules for transmission networks?
Do you monitor and/or audit compliance with consumer protection measures?
Do you monitor and/or audit compliance with consumer protection measures?
Do you monitor and/or audit compliance with energy efficiency obligations?
Do you monitor and/or audit compliance with rules concerning environmental obligations?
Do you monitor and/or audit compliance with rules concerning renewables and environmental obligations?
Do you monitor and/or audit congestion and balancing rules?
Do you monitor and/or audit congestion and balancing rules?
Do you monitor and/or audit cross-border activities?
Do you monitor and/or audit distribution activities?
Do you monitor and/or audit distribution tariffs?
Do you monitor and/or audit distribution tariffs?
Do you monitor and/or audit generation activities?
Do you monitor and/or audit generation and/or wholesale tariffs/prices?
Do you monitor and/or audit investment planning in distribution?
Do you monitor and/or audit investment planning in distribution?
Do you monitor and/or audit investment planning in transmission?
Do you monitor and/or audit investment planning in transmission?
Do you monitor and/or audit production/import activities?
Do you monitor and/or audit quality standards and/or KPI in distribution
Do you monitor and/or audit quality standards and/or KPI in distribution?

Do you monitor and/or audit quality standards and/or KPI in transmission?
Do you monitor and/or audit quality standards and/or KPI in transmission?
Do you monitor and/or audit retail activities?
Do you monitor and/or audit retail activities?
Do you monitor and/or audit retail tariffs and/or prices?
Do you monitor and/or audit retail tariffs and/or prices?
Do you monitor and/or audit security of supply standards and/or KPI?
Do you monitor and/or audit security of supply standards and/or KPI?
Do you monitor and/or audit the way compliance with access rules to transmission networks is managed?
Do you monitor and/or audit transmission activities?
Do you monitor and/or audit transmission tariffs?
Do you monitor and/or audit transmission tariffs?
Do you monitor and/or audit unbundling of distribution activities?
Do you monitor and/or audit unbundling of distribution activities?
Do you monitor and/or audit unbundling of transmission activities?
Do you monitor and/or audit unbundling of transmission activities?
Do you monitor and/or audit wholesale gas prices/tariffs?
Publication of letters and reports
Request of information and data from regulated entities

Competence: (2) *assess*
Arbitration
Hearing
Issue of opinions
Proposal of access rules
Proposal of distribution tariffs
Proposal of energy efficiency rules
Proposal of investment planning rules
Proposal of nomination rules
Proposal of prices/tariffs
Proposal of quality standards and/or KPI
Proposal of retail tariffs and/or prices
Proposal of rules/methodology
Proposal of standards and/or KPI

Proposal of tariffs/prices
Proposal of transmission tariffs
Proposal of unbundling rules

Competence: (3) *approve*
Actual settlement
Any other authorization procedure
Approval of access rules
Approval of distribution tariffs
Approval of energy efficiency rules
Approval of investment planning rules
Approval of nomination rules
Approval of prices/tariffs
Approval of quality standards and/or KPI
Approval of retail tariffs and/or prices
Approval of rules/methodology
Approval of standards and/or KPI
Approval of tariffs/prices
Approval of transmission tariffs
Approval of unbundling rules
Imposition of your decision
Issue of nomination rules
Rule-making power
Setting investment planning rules
Setting of access rules
Setting of distribution tariffs
Setting of energy efficiency rules
Setting of investment planning rules
Setting of prices/tariffs
Setting of quality standards and/or KPI
Setting of rules
Setting of rules/methodology
Setting of standards and/or KPI
Setting of tariffs/prices
Setting of transmission tariffs
Setting of unbundling rules
Setting retail tariffs and/or prices

Competence: (4) *penalize*
Issue of penalties

n.a.
Interconnectors
Licences
LNG Terminal
Other
Production terminal
Storage Terminal
Switching
Tendering
Vulnerable customers

Appendix 2 – Multilevel regressions

The interactions of the variables are tested through the following econometric setups:

$$\begin{aligned}
sos_{csi} &= \beta_{1_SOS} + \beta_{2_SOS}{*}grid_{csi} + \beta_{3_SOS}{*}indexsos_{si} \\
&\quad + \beta_{4_SOS}{*}grid_{csi}{*}indexsos_{si} + \varepsilon_{csi_SOS} \\
\varepsilon_{csi_SOS} &= (\zeta_{1c_SOS}+\zeta_{1s_SOS}+\zeta_{1i_SOS}) + (\zeta_{2c_SOS}+\zeta_{2s_SOS}+\zeta_{2i_SOS})grid_{csi} \\
&\quad + (\zeta_{3s_SOS}+\zeta_{3i_SOS})indexsos_{si} \\
&\quad + (\zeta_{4c_SOS}+\zeta_{4s_SOS}+\zeta_{4i_SOS})grid_{csi}{*}indexsos_{si} + \nu_{csi_SOS} \qquad (2)
\end{aligned}$$

$$\begin{aligned}
mkst_{csi} &= \beta_{1_MKST} + \beta_{2_MKST}{*}grid_{csi} + \beta_{3_MKST}{*}indexmkst_{si} \\
&\quad + \beta_{4_MKST}{*}grid_{csi} * indexmkst_{si} + \varepsilon_{csi_MKST} \\
\varepsilon_{csi_MKST} &= (\zeta_{1c_MKST}+\zeta_{1s_MKST}+\zeta_{1i_MKST}) + (\zeta_{2c_MKST}+\zeta_{2s_MKST}+\zeta_{2i_MKST})grid_{csi} \\
&\quad + (\zeta_{3s_MKST}+\zeta_{3i_MKST})indexmkst_{si} \\
&\quad + (\zeta_{4c_MKST}+\zeta_{4s_MKST}+\zeta_{4i_MKST})grid_{csi}{*}indexmkst_{si} + \nu_{csi_MKST} \qquad (3)
\end{aligned}$$

$$\begin{aligned}
enef_{csi} &= \beta_{1_ENEF} + \beta_{2\,ENEF}{*}grid_{csi} + \beta_{3\,ENEF}{*}indexenef_{si} \\
&\quad + \beta_{4\,ENEF}{*}grid_{csi} * indexenef_{si} + \varepsilon_{csi\,ENEF} \\
\varepsilon_{csi_ENEF} &= (\zeta_{1c_ENEF}+\zeta_{1s_ENEF}+\zeta_{1i_ENEF}) + (\zeta_{2c_ENEF}+\zeta_{2s_ENEF}+\zeta_{2i_ENEF})grid_{csi} \\
&\quad + (\zeta_{3s_ENEF}+\zeta_{3i_ENEF})indexenef_{si} \\
&\quad + (\zeta_{4c_ENEF}+\zeta_{4s_ENEF}+\zeta_{4i_ENEF})grid_{csi}{*}indexenef_{si} + \nu_{csi_ENEF} \qquad (4)
\end{aligned}$$

$$\begin{aligned}
carb_{csi_CARB} &= \beta_{1_CARB} + \beta_{2_CARB}{*}grid_{csi} + \beta_{3_CARB}{*}indexcarb_{si} \\
&\quad + \beta_{4_CARB}{*}grid_{csi} * indexcarb_{si} + \varepsilon_{csi_CARB} \\
\varepsilon_{csi_CARB} &= (\zeta_{1c_CARB}+\zeta_{1s_CARB}+\zeta_{1i_CARB}) + (\zeta_{2c_CARB}+\zeta_{2s_CARB}+\zeta_{2i_CARB})grid_{csi} \\
&\quad + (\zeta_{3s_CARB}+\zeta_{3i_CARB})indexcarb_{si} \\
&\quad + (\zeta_{4c_CARB}+\zeta_{4s_CARB}+\zeta_{4i_CARB})grid_{csi}{*}indexcarb_{si} + \nu_{csi_CARB} \qquad (5)
\end{aligned}$$

where, through a multilevel approach, the elements of the error terms (i.e., ε_{csi}) are tested for their significance: the random intercepts at the competence (ζ_{1c}), sector (ζ_{1s}), and country levels (ζ_{1i}), and the covariates at the competence ($\zeta_{2c},\ldots,\zeta_{5c}$), sector ($\zeta_{2s},\ldots,\zeta_{5s}$), and country levels ($\zeta_{2i},\ldots,\zeta_{5i}$).[204] Covariates at such nested levels are also called random coefficients.

Moreover, through the interaction terms in equations (2) to (5) we can determine whether impacts from the energy scores (i.e., *indexsos*$_{si}$ to

[204] The random coefficients depend on the random intercepts being significant.

indexcarb$_{si}$) change with different numbers of grid-related competences (i.e., *grid*$_{csi}$), and vice versa. Via these interactions we test these combinations for their possible impacts on the number of NRA competences (i.e., *sos*$_{csi}$ to *carb*$_{csi}$).

Table A.1: Standard Poisson with robust standard errors, multilevel Poisson regression (QR-decomposition) without robust standard errors, and fixed effects two-stage least squares (2SLS)

`p' = respective variable	Single level (standard) Poisson				Multilevel Poisson			
	sos	mkst	enef	carb	sos	mkst	enef	carb
(i) index`p'	-0.001	-0.410	-0.145	1.367**	0.770	0.638	0.260*	2.058**
	(0.672)	(0.735)	(0.486)	(0.578)	(0.518)	(0.44)	(0.195)	(0.715)
(ii) grid	0.034	0.030*	0.089***	0.034	1.045*	1.032***	1.070*	1.045**
	(0.026)	(0.016)	(0.020)	(0.026)	(0.028)	(0.015)	(0.039)	(0.022)
(iii) index`p'*grid	0.007	0.040	-0.087***	-0.109***	1.017	1.043	0.960	0.961*
	(0.040)	(0.037)	(0.028)	(0.041)	(0.039)	(0.038)	(0.039)	(0.023)
constant	-0.785*	-0.520*	-1.062***	-0.649*	0.358*	0.57*	0.554	0.326*
	(0.420)	(0.277)	(0.383)	(0.374)	(0.165)	(0.152)	(0.385)	(0.18)
(iv) var(competence-type)						0.069***	0.728***	0.001***
						(0.064)	(0.648)	0.001
(v) var(sector)								
(vi) var(country)					0.214**			
					(0.140)			
(vii) var(grid)							0.001	0.001
							(0.001)	(0.001)
(viii) cov(grid, constant)							-0.029	-0.026
							(0.028)	(0.022)
N	200	188	196	200	197	188	192	198
no. groups	1	1	1	1	28	4	4	4
Joint significance:								
(i), (ii), (iii)	0.002	0.000	0.000	0.006	0.000	0.000	0.000	0.085
(i), (iii)	0.940	0.323	0.000	0.027	0.898	0.461	0.0004	0.093
(ii), (iii)	0.001	0.000	0.000	0.003	0.0001	0.001	0.140	0.099
log-likelihood	-221.245	-212.996	-164.136	-274.007	-201.049	-209.593	-142.811	-225.143
AIC	450.491	433.992	336.272	556.014	412.098	429.186	299.622	464.286
BIC	463.684	446.937	349.385	569.207	428.514	445.368	322.425	487.304
'raw' R2	0.086	0.190	0.213	0.071	0.230	0.315	0.225	0.320
RESET p-value	0.000	0.000	0.000	0.000	0.376	0.996	0.908	0.157

*The coefficients are marked with ***/**/* if they are significant at 99%/95%/90%. The standard errors are between brackets. AIC and BIC are the Akaike and Bayesian Information Criterion, respectively, and 'raw' R2 is {corr(y,yhat)}2. The response variables are the number of competences on: the security-of-supply (sos), consumer protection (mkst), energy efficiency (enef), carbon-neutrality (carb). The covariates are: the number of grid-related competences (grid), and the energy scores (abbreviated to index`p') on security-of-supply (indexsos), market structure (indexmkst), energy efficiency (indexenef), and carbon-neutrality (indexcarb).*

The first four columns of Table A.1 show the benchmark case of simple Poisson regressions, although statistical tests point out that clustered model specifications are required.[205,206] To conserve table space, we named the energy scores index`p'$_{si}$ where `p' represents the policy competence to which it corresponds (i.e., of sos_{csi}, $mkst_{csi}$, $enef_{csi}$, and $carb_{csi}$).

With multilevel regressions, the correlated nature of the hierarchical data can be taken into account. With multiple nests, the typical approach is to nest observations top-down: from the country (level-3), to sector (level-2), and competence level (level-1). Because the aim of this research is to determine the relationship between competences and energy scores, we did not follow such hierarchy but selected all possible combinations of random intercepts (i.e., the nests) and random coefficients.[207] As in Hamilton (2013), we therefore applied likelihood-ratio tests on full versus restricted models. For example, for random intercepts we tested the likelihood of a setup with (i.e., full) versus without level-2 nests (i.e., restricted). In addition, for the random coefficients we applied setups

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[205] Breusch-Pagan and likelihood-ratio tests point towards significant random effects (available on request). Furthermore, there is more within than between-subject variation, so that a panel data approach would be appropriate, such as a multilevel analysis as applied here. Moreover, "between individual associations are often more susceptible of confounding" (Vittinghoff et al., 2012).

[206] In the remaining regressions, standard errors are not made robust because these block analyses of the random intercepts and coefficients, and they may perform poorly in small samples (Rabe-Hesketh and Skrondal, 2012).

[207] With the multilevel Poisson regressions, unstructured co-variances are selected to allow for correlation between random effects. For aiding convergence, we apply the QR-decomposition multilevel version. In addition, with issues in the regressions, we enable Stata's 'difficult' option, and/or integration points fewer than the Stata default (i.e., seven).

without random coefficients (i.e., restricted) versus setups with one or several included (i.e., full). We further checked for the Poisson model's dispersion assumption (i.e., whether the expectation equals its variance). For this purpose, we selected 'negative binomial' models as Stata only supports these among multilevel models.[208,209] Finally, we constructed a Durbin-Wu-Hausman (endogeneity) test by transforming the covariates into within and between effects, and testing whether their joint and separate differences were significantly different from zero.[210] This approach led exogeneity to be violated for $carb_{csi}$. The subsequent

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[208] We test for both the mean and constant conditional over-dispersion parameters. Moreover, although zero-inflatedness is supported for pooled models, it is not for multilevel Poisson models. However, in a blog post on statisticalhorizons.com, Prof. Paul Allison argues that the "zero-inflated Poisson model is one way to allow for over-dispersion". In selecting zero-inflated as against negative binomial models, he proposes to check the model fit through AIC or BIC statistics. Prof. William Greene comments on this post by questioning the AIC and BIC measures in this regard. We therefore checked for the squared correlation of the response variable with the 'y-hat' (i.e., the response variable minus the raw residual). In all our multilevel setups, the multilevel squared correlations were higher.

[209] The initial result is that nest *c* (competence) is significant for all of the response variables, *s* (sector) is only so for *sos*, and *i* (country) only for *sos*, *enef*, and *carb*. Each setup had its own possible random coefficient(s). Several of these setups were disregarded, because multilevel models require a "correct specification of the mean structure, and lack of correlation between the random intercept [, the random coefficients,] and the covariates" (Rabe-Hesketh and Skrondal, 2012).

For the correlation checks, we applied (standard) random effects panel regressions to test for the significance of these univariate combinations. For the mean specification checks, we obtained the Anscombe residuals, the standardized Pearson and squared deviance residuals and, via the 'mltcooksd'-package, the 'dfbeta' and Cook's D values. The mltcooksd-package "estimates Cook's D and dfbeta's for the second level units in two-level mixed models". This Stata ado-package is written by Dr. Katja Möhring and Dr. Alexander Schmidt, and is available via SSC. Standardization is performed via the hat matrix (see Hilbe, 2009, p. 275).

Observations were detected as outliers if they exceed all of these critical values. From the regressions without these outliers we saved the (new) hat matrices, and included their higher order polynomials (2nd to 4th). Regressions were excluded where Ramsey RESET specification tests are rejected (i.e., the joint significance of these polynomials). Where we had multiple setups per response variable, we selected the one with the best model fit (i.e., via AIC, BIC, log-likelihood, and the 'raw R^2').

[210] If significant, these tests point towards endogenous time-varying covariates (Rabe-Hesketh and Skrondal, 2012, pp. 251—252). The Hausman-Taylor approach cannot be applied since none of the covariates are time-invariant.

instrumental variable (2SLS) approach we applied rendered the $carb_{csi}$-coefficients to be insignificant.[211]

The last four columns of Table A.1 show the final multilevel regression setups of the response variables. Several coefficients are not significant separately, but their interaction terms (e.g., $grid_{csi}$ with $grid_{csi}$*index`p'$_{si}$) are jointly significant for most of the setups. The reported values of Table A.1 are 'incidence rates', whereby coefficients below (above) 1.0 imply that the average rate impact is negative (positive) on the response variables.[212] With all intercepts and index`p'$_{si}$ coefficients below 1.0, a first inference is therefore that Hypothesis H4 holds, namely that the number of competences decreases (i.e., sos_{csi} to $carb_{csi}$) with higher energy scores (i.e., index`p'$_{si}$). However, this relationship varies due to the

[211] For the instrumental variables, we selected two categories of competences which were not included in the analysis before, namely *overturn* and *n.a.* (see footnote 179 and Appendix 1). Both only vary at country and gas levels, not at the four levels of competences (i.e. *inform* to *penalize*). NRAs with high *overturn*-rates are more likely to be overturned by their Ministry. The *n.a.*-scores capture the number of competences which did not fit into the categorization of the three policy areas (i.e. sec_{csi} to $carb_{csi}$). With higher *n.a.* and *overturn*-scores, NRA competences are more and less likely to impact energy market performance, respectively.

[212] To provide a numerical example, the effect of increasing *index`p'* by 10 basis points (e.g., from 0.4 to 0.5) is to reduce the expected number of energy efficiency competences by $0.554*0.260^{0.10} = 0.4842$, corresponding to a 1 - 0.4842 = -51.58% decrease.

interaction of index`p'$_{si}$ with grid-related competences (i.e., grid$_{csi}$).[213,214] Next to coefficients (i) to (iii), the 'fixed' effects, also the random effects (iv) to (viii) affect this relationship. Table A.1 shows that the random intercepts (i.e., (iv) to (vi)) are significant at the competence level (ζ_{1c}) for consumer protection, energy efficiency, and carbon-neutrality, and at the country level (ζ_{1i}) for security-of-supply.[215] The random coefficient of grid$_{csi}$ (i.e., (vii) and (viii)) is significant for energy efficiency (enef$_{csi}$).[216] Determined as variances, these random intercepts and random coefficients indicate the (competence or country-specific) range around the total average intercepts and grid$_{csi}$-coefficients, respectively.

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213 Because the coefficients have a multiplicative interpretation, the impact at the average *grid* level (10.01) would amount to: $0.554 * 0.260^{0.10} * (0.960^{0.10})^{10.01} = 0.4648$, or a *larger* decrease of -53.52%.

214 Regarding the previous footnote: we applied page 690 of Rabe-Hesketh and Skrondal (2012), so that the incidence rate ratio for two NRAs with covariate values x_i and x_i' along with an interaction term $\beta_3 x_i y_i$ will be:

$$\exp(\beta_1)\exp(\beta_2 x_i)\exp(\beta_3 x_i y_i)\exp(\beta_4 y_i) \, / $$
$$\exp(\beta_1)\exp(\beta_2 x_i')\exp(\beta_3 x_i' y_i)\exp(\beta_4 y_i) = \exp(\beta_2(x_i-x_i'))\exp(\beta_3(x_i-x_i')y_i).$$

Here the covariate increase (xi-xi') equals 0.1, and y_i equals 10.01. For this calculus, we applied page 701 of Rabe-Hesketh and Skrondal (2012), so that the incidence rate ratio with covariate values x_i and x_i' will now be:

$$\exp(\beta_1)\exp(\psi_{11}/2)\exp(\beta_2 x_i)\exp\{(\beta_3+\psi_{31}+y_i\psi_{33}/2)x_i y_i\}\exp\{(\beta_4+\psi_{31}+y_i\psi_{33}/2)y_i\} \, /$$
$$\exp(\beta_1)\exp(\psi_{11}/2)\exp(\beta_2 x_i')\exp\{(\beta_3+\psi_{31}+y_i\psi_{33}/2)x_i' y_i\}\exp\{(\beta_4+\psi_{31}+y_i\psi_{33}/2)y_i\} =$$
$$\exp(\beta_2(x_i-x_i'))\exp\{(\beta_3+\psi_{31}+y_i\psi_{33}/2)(x_i-x_i')y_i\}$$

where ψ_{11} and ψ_{33} is the variance of the random intercept and coefficient, respectively, and ψ_{31} is the covariance of the random intercept with the random coefficient.

215 Random intercepts are not affected by covariate changes, so that the previous numerical example cannot be applied. If the competence-specific intercept of consumer protection (*mkst*) changes from zero to one standard deviation ($0.2626 = 0.069^{0.5}$) by shifting to another competence, the ceteris paribus effect will be $0.570^{0.2626}$ (where 0.570 is the fixed intercept).

216 Building on the previous numerical examples, the expected *index`p'* effect can be obtained by further raising the interaction coefficient $(0.960^{0.10})^{10.01}$ to the power of [cov(*grid*,cons) + ½ *grid**var(*grid*)] = -0.029 + ½(10.01)0.001 = -0,024, resulting in a total decrease of -51.53%.

Figure A.2: The random intercepts are at the country level of security-of-supply (sos), and at the competence level for consumer protection (mkst), energy efficiency (enef), and carbon-neutrality (carb)

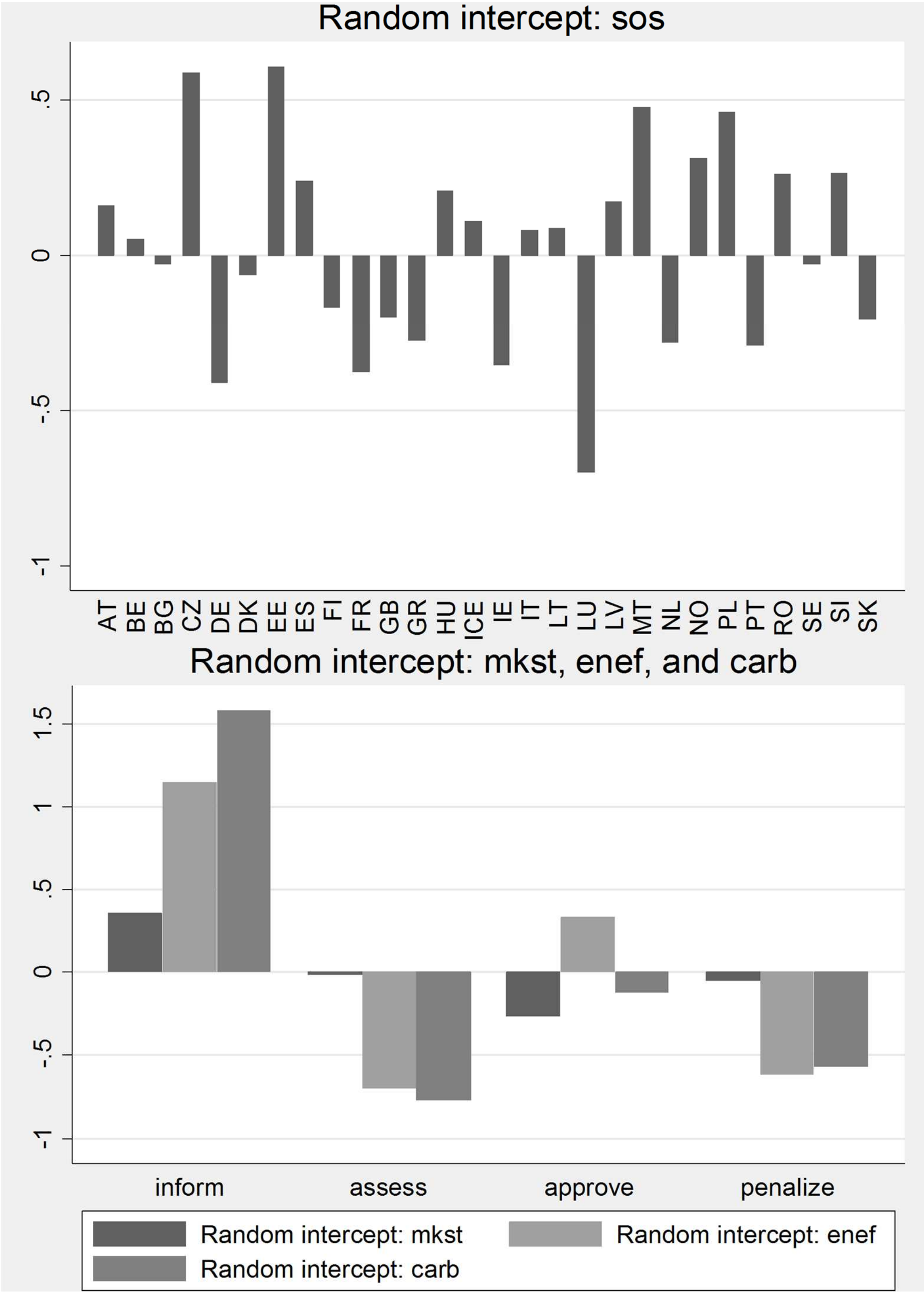
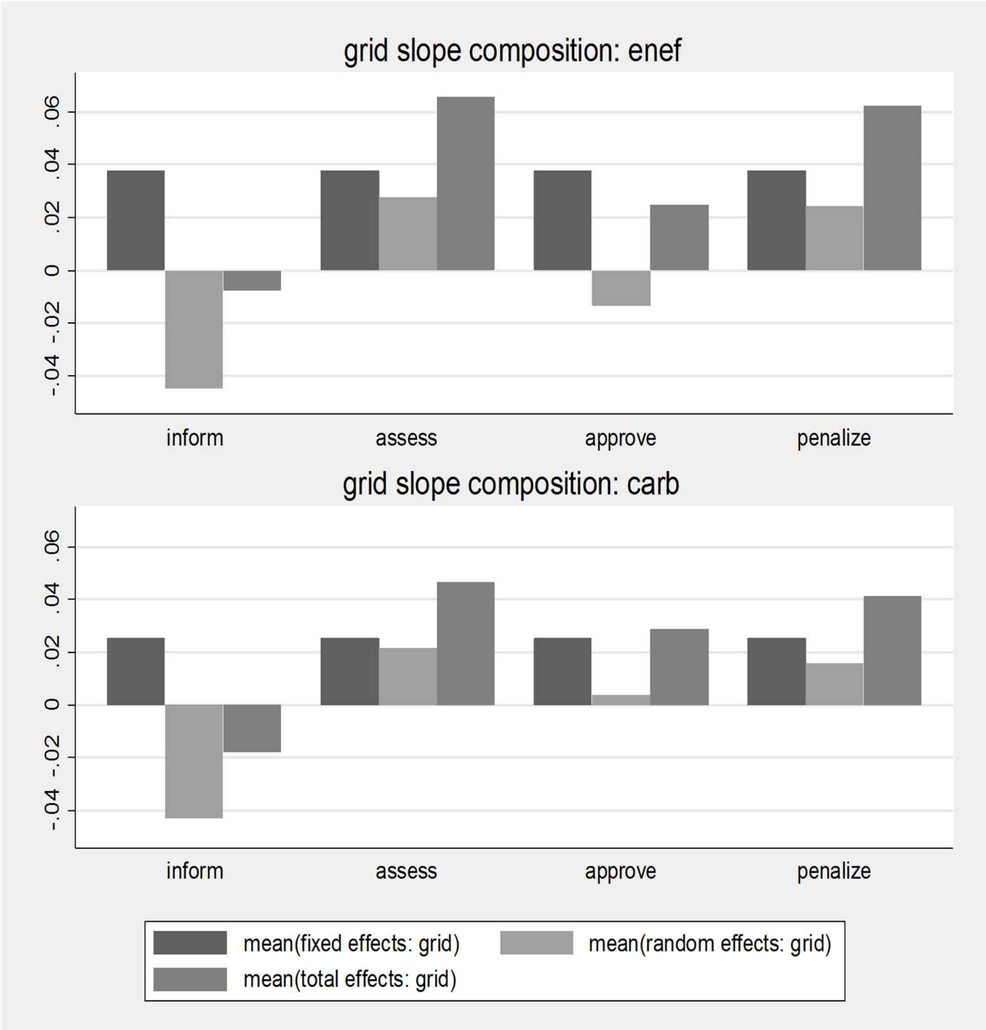


Figure A.3: The random grid-related competences (grid) coefficients are at the competence level of energy efficiency (enef) and carbon-neutrality (carb)



As mentioned above, the econometric methodology enables us to scrutinize the impacts as channeled via the multiple levels (i.e., countries, sectors, and competence-types). The upper part of Figure A.2 shows the (random) intercepts at the country level for security-of-supply (i.e., ζ_{1i} from Appendix 2 equation (2)). No obvious pattern can be discerned, as a bit more countries have positive security-of-supply random intercepts (15) rather than negative ones (13). The lower part of Figure A.2 shows the random intercepts at the *competence* level (i.e., ζ_{1c}) (i.e., from *inform* to *penalize*) for consumer protection, energy efficiency, and carbon-neutrality. These follow the pattern as in Figure 4 and 5, namely that the intrusiveness of the intermediate *assess* and *approve* do not follow the 'optimal' hierarchic ordering. If *assess* and *approve* had more positive and negative impacts, respectively, NRA competences would have been hierarchic and, as a result, in accordance with Hypothesis H1.

Random coefficients are the other source which channels multilevel effects. Appendix 2 Table A.1 shows that these are only significant with the grid-related competences ($grid_{csi}$) for energy efficiency ($enef_{csi}$). Figure A.3 shows that, due to these random coefficients, the total effects from the grid-related competences ($grid_{csi}$) vary per competence-type (i.e., the random intercept). The strongest negative effects are found with *inform* (i.e., smallest relative to the 1.0 incidence rate), and the weakest with *assess*. These results thus indicate that with more liberalization (i.e., more grid-related competences) there are fewer soft competences (i.e., *inform*).

CHAPTER 7
Conclusions and recommendations

This section interprets the empirical findings through the theoretical framework of Chapter 2, namely the economics of property rights and transaction costs. These inferences will then serve to answer the central research question: Are property rights regarding EU carbon and energy markets valued, used and traded, and restricted in an economically efficient way? The recommendation section describes suggestions for policy changes and future research.

1. Data: Emissions trading registries and data problems

The EU ETS registry, the EU Transaction Log (EUTL), is the key data source for the first two empirical studies. Chapter 3 discusses data problems that arise when monitoring transactions and checking compliance with the EUTL. Particular attention is paid to the difficulty of linking data from this registry to other relevant data, such as firm ownership information. Recommendations for improvement of the EU registry are also provided.

1.1 Policy recommendations

One of the data issues Chapter 3 reveals is that it cannot consistently be found out via the EUTL whether and how transactions with national EU allowance registries add up to the (annually provided) statistics on allowance allocations and surrenders. Another is that transactions downloads do not reveal historical transactions from registry accounts which have been closed. Moreover, this chapter focuses particularly on firm ownership. Firms are the actual owners and users of EUTL accounts and, therefore, influence how the EU ETS is run. However, company information from the EUTL is both inconsistent and ambiguous.

The issues have their roots in one main aspect: the EUTL lacks crucial variables or identifiers, such as the previous names of the installation operators and of the accountholders, the (country-specific) identifier of the installations accounts, or the date when accounts have been closed. Moreover, for some identifiers the value is either too generic or not available, making it equivocal by whom or for what purpose the transaction was conducted.

Not only can this extra information mitigate the above mentioned issues. It can also make the EUTL robust against recurring updates, which have resulted in retroactive data changes. However, the EUTL cannot provide these identifiers because they are limited by the EU ETS registry regulation. Moreover, the information the EUTL provides is exactly what has been received from EU Member States. The recommendations of this chapter are therefore primarily relevant for the European Commission and the EU Member States. They are in the position to change the regulations that determine which information the EUTL can provide.

As of end-December 2011, the EU energy market has a counterpart to the EUTL, namely the Regulation on Wholesale Energy Market Integrity and Transparency (REMIT). Although its basic purpose is to monitor "energy markets to detect and deter market manipulation and insider trading" (ACER, 2015), its functioning is primarily based on transactions as is the case for the EUTL.[217] Even more so, upon enforcement of the second Markets in Financial Instruments Directive (EC, 2014), or MiFID II, authorities will need to estimate market shares, for which they (also) need to start linking firm ownership to the accounts. This EUTL chapter can therefore be informative for the possible data issues involved.

1.2 Research recommendations

The EU ETS part of this research focuses on Phase I (2005-2007). It is considered to be the EU ETS pilot or learning phase for participants, attested by the fact that allowances could not be banked to the subsequent Phase. Phase I was not subject to the Kyoto Protocol, unlike Phase II (2008-2012). In addition, the EU ETS is almost 10 years further, has gained in market liquidity, and improved its financial market regulations, while at the start of this research only transactions data from the earlier years were available. The EU ETS functioning is fundamentally the same and, once more, faces a surplus of banked or accumulated allowances. Moreover, the Phase I perspective enables us to see how firms closed their allowance books. Research on later periods will need to accurately account

[217] Yet, ACER will also obtain information on outstanding orders, the (only yet crucial) virtual data element.

for the fact that firms do not have uniform but differing or overlapping time horizons (i.e., across EU ETS Phases).[218]

Working with the actual and (non-anonymous) transactions data allows the examination of several issues. For example, do the transactions attest the VAT fraud, the allowance theft, or the renewable policy differences among EU Member States? And given the latest EU ETS policy change: do firms transact more for idiosyncratic or systematic risks, do they effectively cope with the volatility of the carbon market, and will the EU ETS Market Stability Reserve support or hinder firms in coping with this volatility?

2. Case I: Property valuation

The first study, Jong et al. (2014), analyses the value-relevance of the property rights restriction as imposed by the EU ETS. From the theoretical framework in Chapter 2, we can derive the hypothesis that if some shareholders have a higher valuation on the property restriction as imposed by the EU ETS than other shareholders, they will base their higher valuations on *more* attributes of this property (e.g., Barzel, 1997).

Carbon allowances can be used as inputs for emissions, for trading and/or backup purposes. A drastically lower carbon price is thus expected to be more valuable for firms which need them more (i.e., with higher carbon-intensities of production) and which hold few of them (i.e., given the assets' worth). Based on the April 2006 carbon price drop, we instead found that shareholders consider firms with such characteristics to be less valuable. Such firms are indeed less profitable given the decreasing emissions cap. We therefore concluded that the EU ETS is valued by investors as restricting pollution.

This conclusion supports the first research question element, namely that property rights from EU carbon markets are valued in an economically efficient way. However, we also tested for another property attribute, namely the information advantage in the market of firms which actively trade allowances. Its insignificance may be the result from investors limitedly valuing the profit impact of the EU ETS on firms, so that the first two attributes already capture most of the impact. Its insignificance may

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[218] However, we show that in Phase I (2005-2007) we cannot exactly pinpoint which allowances refer to which Phase I or II or to which calendar year within Phase I. Chapter 3 provides recommendations how this issue can be solved.

also emanate from investors lacking insufficient information on the firms' allowance trade activity.

Indeed, share prices reflect how market participants discount all *publicly* available information into their expectations on the profitability of firms. If information is lacking, shareholder profitability estimates are less precise. This constrains markets in realizing their valuable allocation properties (i.e., to channel capital where return relative to risk is highest). For example, valuations will be impeded when it is not known whether firms, for example, stockpiled unused allowances or borrowed them.

2.1 Policy recommendations

The European Commission can improve the functioning of the EU ETS market by administering a more detailed and gradual feed-in of information. A key information constraint originates from the compliance timing as laid out in the EU ETS Directives (EC, 2003; EC, 2009a). While (currently) allowance auctions are spread over the calendar year and thus ensure a gradual feed-in of information, there is just one moment in the year that all firms surrender their allowances. It will be conducive to market certainty if there are more of such moments during the year (e.g., Holland and Moore, 2012; Lucia et al., 2015) and that the European Commission subsequently reports on these compliance moments. For example, instead of the default annual EU-wide compliance cycle, firms or sectors may then opt for their own preferred cycle (which may be quarterly or even more frequent). This could have prevented or at least reduced the severity of the April 2006 shock. The more that signals on scarcity are held up, the more difficult it becomes for firms to forecast whether they have planned enough emission-reduction projects. Uncertainty around the carbon price will therefore be limited if the release of information on the scarcity in the EU ETS is stepped up.

2.2 Research recommendations

In answering the research question, not all sources of property rights valuation have been considered. For example, this study applied public-based information. The literature includes several private-based sources, such as survey-based estimates from expert respondents, companies, or industry associations (e.g., Borghesi et al., 2015). Future research can therefore consider how inferences from private sources exactly differ from public ones. A deeper understanding of the size and distribution of externalities among stakeholders can be attained through a systematic identification of the value impact of contractual (i.e., typically private) and property right (i.e., typically public) restrictions. Such an analysis of externalities can be a fruitful research contribution to the current European Commission's aim for Better Regulation, the law-making framework which designs and evaluates EU policies and laws.[219]

3. Case II: Property use and trade

According to the 'make-or-buy decision', transactions take place within firm boundaries when transaction costs are lower vis-à-vis the market. For example, energy firms, when meeting contracted demand, can dispatch their own plants but also tap into other firms' production capacity by purchasing energy on the market (i.e., via spot or derivative markets). This sourcing flexibility also holds for the carbon market. Instead of trading on the carbon market and mobilizing other firms' pollution abatement capacity, allowances can be transacted within firm boundaries with existing or newly integrated entities.[220]

Analyzing EU ETS transactions, Jong and Zeitlberger (2017) examine whether firms behave 'self-sufficiently' by first allocating production, emissions, and, hence, allowances within firm boundaries before opting for the carbon market. Self-sufficient firms' external or carbon market trades are therefore expected to be less responsive to allowance demand factors because they are better able to absorb shocks within the firm.

Contrary to our expectations, we find that firms with highest potential to be self-sufficient conducted fewer allowance trades across their subsidiaries than on the carbon market – as opposed to less self-sufficient firms. Inferring from the 'make-or-buy' theoretical framework, this result may suggest, within firm boundaries, that 1) their pollution abatement capacity is more expensive and/or 2) their carbon-related transaction costs (e.g., information costs) are higher than on the carbon market. This finding therefore affirms that, similar to the US Acid Rain

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[219] For example, see the European Commission's Better Regulation website: https://ec.europa.eu/commission/priorities/democratic-change/better-regulation_en

[220] Indeed, in the literature 'transactions' do not only regard the exchange of property. It encompasses a wider range of interactions, many of which revolve around contracts. For example, contract agreements and monitoring (cf. footnote 5).

Program (e.g., Ellerman et al., 2000), for self-sufficient firms, the EU ETS leads to relative cost savings. Indeed, because their allowance trades point to carbon risk hedging, self-sufficient firms can reap further cost savings through the carbon market.

3.1 Policy recommendations

For the policy recommendations we focus on the less self-sufficient firms, since their market-based (within-firm) transaction costs were higher (lower) (i.e., they traded more among subsidiaries). We mention two ways through which the market-based transaction costs can be lowered. The first is taken up in the information provision recommendation already discussed above in Section 7.1.

The second is that allowance property rights have not been clearly excluded. Although regulations have increasingly treated carbon allowances as financial instruments, there are still several exceptions through which firms are able to externalize their risks or costs. For example, the Transparency Directive (EC, 2013) and the Financial Collateral Directive (EC, 2002) are still not applicable to allowance spot trades. Moreover, the future version of the Markets in Financial Instruments Directive (EC, 2014), or MiFID II, is contested by market stakeholders for its impacts on market liquidity. Policymakers should therefore take into consideration how property right restrictions or exemptions through such policies affect allowance trade across time (i.e., carbon hedging) or place (i.e., within-firm versus the market).

3.2 Research recommendations

Through our choice of the 'make-or-buy' theory we selected one perspective on the research question, namely whether the usage and trade of EU carbon property rights is economically efficient. A wider scope could have included more varieties of the main property rights aspects, such as the right to transfer some or all of the rights to others (*transferability*), the right to use the assets (*usus*), the right to its returns (*usus fructus*), the right to change their form and substance (*usus abusus*), the right to exclude others (*excludability*), and the right to sell or lease some or all of these rights to others (*alienation*) (e.g., Müller and Tietzel, 2005).

The choice to 'make-or-buy' is a function of transaction costs. From these transaction costs, inferences can be made on the allocation of property rights, of which carbon allowances are an example. The outcome of our 'make-or-buy' analysis therefore 'only' indirectly relates to the pollution abatement.

Our research did not delve into the reasons for the higher (lower) transaction costs within self-sufficient firms (on the market). For example, as put in Kasper et al. (2012):

> *Where market institutions are poor and create high transaction costs, for example because of poor regulation, legislation and law enforcement, one can observe a tendency to integrate many activities within organizations. A high degree of vertical integration is, for example, typical of dysfunctional markets for inputs where genuine prices are not formed, so that much valuable information is never communicated.*" (Kasper et al. , 2012, page 294)

Given that our analysis shows that self-sufficient firms favour the carbon market to within-firm trade, this may support the claim that the EU ETS as a market institution is functioning well. For example, instead of a within-firm central coordination of carbon demand, lower transaction costs enable firm-owned business units to act separately on market parameters (e.g., the carbon price) rather than within-firm ones.

Moreover, several refinements to our analysis can be mentioned. First, we approached the 'make-or-buy' principle only through a binary selection, namely the potential of being 'less' and 'more' self-sufficient. Although 'make-or-buy' is phrased as a binary principle, it actually encompasses a spectre; firms operate as hybrids (e.g., Ménard, 2010). Long-term contracts, for instance, are considered a hybrid form in between the 'make' and 'buy' dichotomy.[221] In addition, high within-firm transaction costs can "give rise to numerous specialized sub-contractors to whom producers can delegate specific tasks, not least in information gathering" (Kasper et al., 2012). Future research can therefore explicitly account for EU ETS intermediaries in the 'make-or-buy' topic, for example, by including banks and brokers.[222] Second, the make-or-buy literature

[221] Our data sample does not tell through which contract types transactions have occurred.

[222] The approach taken in Jaraitė and Kažukauskas (2014) is to consider trades to be 'third-party' if these are from Operator Holdings Accounts (OHAs) to Person Holding Accounts (PHAs) and the OHAs and PHAs are not company-affiliated (more on OHAs and PHAs in Chapter 3).

typically analyses the (Williamsonian) transaction characteristics of 'asset-specificity', 'uncertainty', and 'frequency'. Our data did not allow us to account for 'asset-specificity' and 'uncertainty' – although we accounted for 'frequency'. Future research may be able to fill this gap.

4. Case III: Property restrictions

To approach the third part of the research question, namely whether property rights regarding EU carbon and energy markets are restricted in an economically efficient way, we check for the alignment of policy objectives and their enforcement. The main EU energy policy objectives or public interests at stake are a (1) secure, (2) competitive, and (3) carbon-neutral energy supply. Because the enforcement of European gas and electricity regulation has increasingly been allocated to National Regulatory Authorities (NRAs), Chapter 6 analyzes whether EU Member States have aligned the legal competences of their gas and electricity NRAs with the divergent realizations of their energy policy objectives.

4.1 Policy recommendations

In the study, we hypothesized that NRAs have fewer competences when energy policy objectives are sufficiently met, because the realization of the objectives reduces the need for regulatory intervention. From the results it appears that this does not hold for most of the policy objectives.

For energy efficiency, the indicators on policy objectives and competences move oppositely as hypothesized, but definitive conclusions cannot be drawn because only few NRAs have competences in this policy area. One explanation can be that energy efficiency has not received as much attention as the other policy areas, or that these competences are exercised by Ministries.

For carbon-neutrality, we obtained mixed (and insignificant) results on the relationship between policy objectives and NRA competences. Although generally the largest, the energy sector is not the only contributor to carbon emissions. This may have led governments to delegate some competences to other policy-specific NRAs or Ministries. However, such shared responsibilities need to be accurately delineated so that NRAs can still sufficiently monitor "corporations that operate or have interests in different sectors and industries" (Jordana and Levi-Faur, 2010). Effectiveness may therefore improve if the sampled countries reconsider the regulatory scope of their NRAs, for example, by enabling NRAs to jointly exercise their competences when obtaining information from the regulated firms.

Moreover, the policy objectives and competence indicators on security-of-supply and consumer protection move similarly, contrary to what we hypothesized. These policy-competence interactions may be driven by a regulatory 'lock-in' effect. Higher policy scores are then matched with stricter rules and enforcement. Rather than via the path of ever stricter regulations, policymakers should implement regulation such that it is in the firms' own interest to arrive at the (socially) optimal levels of security-of-supply and consumer protection.

Finally, we recommend correcting the intrusiveness of the NRAs' legal powers. The legal competences do not follow the 'optimal' competence arrangement for regulatory authorities; compared with a theoretical benchmark there are relatively more 'tough' than 'soft' competences, while the latter are less costly to exercise.

4.2 Research recommendations

Transactions within the energy industry are generally characterized by high levels of uncertainty, frequency, and asset-specificity (e.g., Spanjer, 2009).[223] The higher these levels, the more the energy market governance should move away from being market-based to one involving vertical integration, long-term contracts, and government involvement (e.g., Williamson, 1979; Mulder, 2011). The primary rationale hereof is to mitigate contractual hazards (e.g., the hold-up problem) which prevent socially inefficient behavior and sustain competition and innovation.

This research focuses on government involvement via the legal competences of NRAs. These competences can be considered as contractual restrictions on property rights. However, the above indicates that such restrictions appear in varieties, for example, vertical integration and public ownership. Analyzing these along with the legal competences

[223] Kasper et al. (2012) provides the following clear description of asset-specificity: "*Asset-specificity is a condition of a productive asset – such as an item of capital equipment or a body of specialized knowledge – which does not allow it to be switched to alternative uses.* [...] *The costs of converting out of specific capital investments are often high, so that capital owners become vulnerable to the exercise of power by the owners of complementary and supposedly more fungible production factors.* [...] *This explains why owners of specific assets have a keen interest in binding complementary inputs providers in organizations (or in obtaining strong institutional controls).*"

will be a useful improvement for future research. Moreover, from private via common to public ownership, these varieties imply a decreased exclusiveness or sharing of property. Extra coordination costs are then incurred to mitigate the value-capturing incentives of the shared property, and to accommodate (semi-)public interests besides the (private) profit maximization objective. The ‘tough’-to-‘soft’ competences method of this chapter can then be of use when measuring the effectiveness of coordination.

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Summary

The “trilemma” facing energy markets is that it is challenging if not impossible to simultaneously 1) guarantee the supply of energy, while 2) production, trade, and consumption occurs efficiently (e.g., at the lowest possible transaction costs), and 3) scarce resources are used optimally (e.g., that emissions of greenhouse gases are equal to its absorption).

This Ph.D. research applies Law and Economics, a sub-discipline of both law and economics. It analyzes the economic causes and effects of laws and regulations on EU energy and carbon markets – which, as the “trilemma” shows, are increasingly complex and intertwined. After hypotheses are derived from property rights theory, they are tested using econometric techniques. The overall research question is: Are property rights regarding EU carbon and energy markets valued, used and traded, and restricted in an economically efficient way? To that end, three EU-wide empirical studies have been conducted:

1) How shareholders value the EU ETS impact on firms;
2) How energy firms used and traded carbon allowances; and
3) Whether the legal competences of National Regulatory Agencies (NRAs) are aligned to the public interests of the energy markets they supervise.

Data: Emissions trading registries and data problems

Any emissions trading scheme needs an emissions registry. The EU Transaction Log (EUTL) is the registry for the EU Emissions Trading Scheme (EU ETS), and at the same time the key data source for two empirical studies in this Ph.D. research.

Chapter 3 discusses data problems that arise when monitoring transactions and checking compliance with the EUTL. Particular attention is paid to the difficulty of linking registry data to other relevant data, such as firm ownership information. Firms are the actual owners and users of EUTL accounts and, therefore, influence how the EU ETS is run. However, company information from the EUTL is both inconsistent and ambiguous.

These issues have their roots in one main aspect: the EUTL lacks crucial variables or identifiers. However, the EUTL cannot provide these because they are limited by the EU ETS registry regulation. Moreover, the information the EUTL provides is exactly what has been received from EU

Member States. The recommendations of this chapter are therefore primarily relevant for the European Commission and the EU Member States. They are in the position to change the data to the EUTL and the regulations that determine which information the EUTL can provide.

Case 1. Property valuation

According to property rights theory, valuations and restrictions mutually affect property rights. Higher valuations lead to more comprehensive restrictions on property, and more aspects of property being priced.

The first study, Jong et al. (2014), analyses the value relevance of the property rights restriction as imposed by the EU ETS. Carbon allowances can be used as inputs for emissions, for trading and/or backup purposes. A drastically lower carbon price is thus expected to be more valuable for firms which need them more (i.e., with higher carbon-intensities of production) and which hold few of them (i.e., given the assets' worth).

Based on the April 2006 carbon price drop, we instead found that shareholders consider firms with such characteristics to be less valuable. Such firms are indeed less profitable given the decreasing emissions cap. We therefore concluded that the EU ETS is valued by investors as restricting pollution.

However, we also tested for the information advantage of firms which actively trade allowances in the carbon market. We find an insignificant impact from this aspect, which may emanate from investors lacking insufficient information on the firms' allowance trade activity.

Indeed, share prices reflect how market participants discount all publicly available information into their expectations on the profitability of firms. If information is lacking, shareholder profitability estimates are less precise. This constrains markets in realizing their valuable allocation properties (i.e., to channel capital where return relative to risk is highest).

Our main policy recommendation is therefore for the European Commission to administer a more detailed and gradual feed-in of information. For example, there is just one moment in the year that all firms surrender their allowances. It will be conducive to the functioning of the carbon market if there are more of such moments during the year, in order to step up the release of information on the scarcity in the EU ETS.

Case II: Property use and trade

According to the 'make-or-buy decision' principle within property rights theory, transactions take place within firm boundaries when transaction costs are lower vis-à-vis the market. For example, energy firms, when meeting contracted demand, can dispatch their own plants but also tap into other firms' production capacity by purchasing energy on the market (i.e., via spot or derivative markets). This sourcing flexibility also holds for the carbon market. Instead of trading on the carbon market and mobilizing other firms' pollution abatement capacity, allowances can be transacted within firm boundaries in order to spread the reduction of carbon emissions over multiple subsidiaries.

The second study, Jong and Zeitlberger (2017), examines whether firms behave 'self-sufficiently' by first allocating production, emissions, and, hence, allowances within firm boundaries before opting for the carbon market. Contrary to our expectations, we find that firms with the highest potential to be self-sufficient conducted fewer allowance trades across their subsidiaries than on the carbon market – as opposed to less self-sufficient firms. Inferring from the 'make-or-buy' theoretical framework this result may suggest, within firm boundaries, that 1) their pollution abatement capacity is more expensive and/or 2) their carbon-related transaction costs (e.g., information costs) are higher than on the carbon market. This finding therefore affirms that, for self-sufficient firms, the EU ETS leads to relative cost savings.

Case III: Property restrictions

According to property rights theory, socially inefficient behavior by firms can be prevented by contractual restrictions on property (e.g., regulation) to sustain policy objectives such as competition and innovation.

For this purpose, the third study, Jong and Woerdman (2016), checks for the alignment of policy objectives and their enforcement in European gas and electricity markets. For the objectives, we consider the corresponding countries' divergent levels of 1) security, 2) competitiveness, and 3) carbon-neutrality of energy supply. Since European gas and electricity regulation has increasingly been allocated to European National Regulatory Authorities, for the enforcement we consider the legal competences of NRAs. We then derived scores (a) on the extent to which these energy supply characteristics are realized and (b) on the weight and number of competences NRAs have regarding these policy objectives.

Although higher energy scores should reduce the need for regulatory intervention and thus legal competences, it appears that this does not hold for most policy objectives. With security-of-supply and consumer protection, higher policy scores are matched with stricter rules and enforcement. Rather than via the path of ever stricter regulations, these regulations may improve if designed such that it is in the firms' own interest to arrive at the (socially) optimal levels of security-of-supply and consumer protection.

No definite conclusions can be drawn for the objectives on carbon-neutrality and energy efficiency. One explanation can be that these competences are delegated to other policy-specific NRAs or Ministries. Effectiveness may then improve if the sampled countries reconsider the regulatory scope of their NRAs, for example, by enabling NRAs to jointly exercise their competences when obtaining information from the regulated firms.

Finally, the legal competences do not completely follow the 'optimal' competence arrangement for regulatory authorities; compared with a theoretical benchmark there are relatively more 'tough' than 'soft' competences, while the latter are less costly to exercise. These potential regulatory 'mismatches' could be corrected by adjusting the intrusiveness of the NRAs' legal powers.

Samenvatting

Het "trilemma" van energiemarkten gaat over de uitdaging dan niet de onmogelijkheid om voor energie 1) de voorziening te garanderen, 2) efficiënte productie, handel, en consumptie te hebben (bijv. tegen de laagste transactiekosten) en 3) een optimaal gebruik van schaarse bronnen te hebben (bijv. een toename die gelijk is aan de afname van CO_2).

Dit promotieonderzoek past rechtseconomie toe, een sub-discipline van zowel rechten als economie. Het onderzoek analyseert de economische oorzaken en gevolgen van wet- en regelgeving van EU energie en CO_2 markten – die, gegeven het "trilemma" steeds complexer en vervlochten worden. Na opstellen van hypotheses uit de eigendomsrechten theorie hebben we deze met econometrische methodieken getest. De algemene onderzoeksvraag luidt: Worden eigendomsrechten in de EU markten van CO_2 en energie op een economisch efficiënte wijze gewaardeerd, gebruikt, verhandeld, en beperkt? Drie empirische studies zijn hiertoe uitgevoerd:
1) Hoe aandeelhouders het EU ETS waarderen;
2) Hoe energiebedrijven emissierechten gebruiken en verhandelen; en
3) In hoeverre de wettelijke bevoegdheden van Nationale Regulerende Instanties op één lijn liggen met de beleidsdoelstellingen op de energiemarkten waar ze toezicht op houden.

Data: Data kwesties binnen het EU emissierechten handelsregister

Ieder systeem van emissierechten handel heeft een emissierechten register nodig. Het 'EU Transaction Log' (EUTL) is het register voor het Europese emissierechten systeem, het 'EU ETS', en een voorname databron voor twee studies in dit promotieonderzoek.

Hoofdstuk 3 behandelt data kwesties bij het nagaan van de EUTL geregistreerde transacties en de naleving van de gereguleerde entiteiten. Bijzondere aandacht krijgt het koppelen van de registerdata met andere relevante data, zoals wie eigenaar is van deze rechten. Voornamelijk bedrijven zijn gebruikers van emissierechten, en bepalen hiermee de werking van het EU ETS, maar het EUTL stelt de informatie van het eigendom van deze rechten niet consistent of eenduidig beschikbaar.

Deze kwesties hebben hun oorsprong in één hoofdaspect: dat het EUTL ontbreekt aan cruciale variabelen. Het EUTL kan hier niet in voorzien door beperkingen vanuit de EUTL regelgeving. Daarnaast fungeert het EUTL grofweg als een data-doorgeefluik vanuit EU lidstaten. De aanbevelingen van dit hoofdstuk zijn daardoor vooral relevant voor de Europese Commissie en EU lidstaten. Zij zijn in de positie om de data aan het EUTL en de regelgeving van het EUTL te wijzigen.

Case I: Waardering van eigendom

Volgens de eigendomsrechten theorie vindt er een wederzijdse beïnvloeding plaats tussen waarderingen en beperkingen op eigendom. Hogere waarderingen leiden tot uitgebreidere beperkingen op eigendom, en tot meer aspecten van het eigendom die beprijsd worden.

Het eerste onderzoek, Jong et al. (2014), analyseert de waarde van de eigendomsrechten beperking door toedoen van het EU ETS. Emissierechten kan men gebruiken ter compensatie van de uitstoot, om mee te handelen, en om als reserve aan te houden. Een drastisch lagere CO_2 prijs zal dus naar verwachting goed nieuws zijn voor bedrijven die meer emissierechten nodig hebben (bijv. met een hogere uitstoot) en die weinig emissierechten op voorraad hebben.

Op basis van de CO_2-prijsval van april 2006, zien we dat aandeelhouders bedrijven met deze eigenschappen juist lager waarderen. Deze bedrijven zijn geacht minder winstgevend te zijn gezien het dalend emissierechten plafond. We concluderen dat het EU ETS door investeerders gewaardeerd wordt als een beperking op vervuiling.

We hebben daarnaast getest of bedrijven die actief handelen in emissierechten ook informatievoordelen behalen in de CO_2-markt. Dat we een insignificante impact vinden kan het gevolg zijn dat investeerders niet beschikken over voldoende informatie op deze handelsactiviteiten.

Door dit tekort aan informatie kunnen aandeelhouders minder accurate inschattingen maken van de winstgevendheid van bedrijven, die ze vervolgens vertalen naar aandelenprijzen. Informatietekorten kunnen dan markten beperken in hun waardevolle allocatie rol (bijv. in het alloceren van kapitaal naar investeringen met een hoog rendement t.o.v. de risico's).

Onze voorname aanbeveling is dat de Europese Commissie aanstuurt dat de emissierechten administratie voorziet in een meer gedetailleerde en gelijkmatige informatie voorziening. Er is nu bijvoorbeeld slechts één moment per jaar dat bedrijven hun emissierechten in dienen te leveren. Het is bevorderlijk voor de marktwerking als er meer van zulke momenten zijn per jaar, zodat de markt vaker signalen ontvangt over de schaarste in het EU ETS.

Case II: Gebruik van en handel in eigendom

Volgens het 'make-or-buy decision' principe binnen de theorie van eigendomsrechten vinden transacties plaats wanneer de transactiekosten binnen bedrijfsgrenzen lager zijn t.o.v. de markt. Om de gecontracteerde vraag te voorzien kunnen energiebedrijven bijvoorbeeld hun eigen installaties draaien, maar ook gebruik maken van de productiecapaciteit van andere bedrijven door energie op de markt in te kopen (bijv. via spot of derivaten markten). Deze flexibiliteit in bronnen is ook van toepassing op de CO_2 markt. Naast handel op de CO_2 markt en het gebruik van andermans capaciteit in het verminderen van CO_2 vervuiling, kan men emissierechten binnen bedrijfsgrenzen verhandelen om de CO_2 vermindering uit te smeren over meerdere dochterondernemingen.

Het tweede onderzoek, Jong en Zeitlberger (2017), bekijkt of bedrijven 'autarkisch' gedragen door eerst productie, emissies en dus emissierechten binnen bedrijfsgrenzen uit te wisselen voordat ze de CO_2 markt op gaan. In tegenstelling tot onze verwachtingen vinden we dat bedrijven met het hoogst potentieel om autarkisch te zijn minder emissierechten uitwisselen binnen bedrijfsgrenzen dan op de CO_2 markt – dan bedrijven met een lager autarkie potentieel. Gegeven het 'make-or-buy' principe maken we uit deze bevinding op dat, binnen bedrijfsgrenzen, 1) hun capaciteit om CO_2 te verminderen duurder is en/of 2) hun CO2-gerelateerde transactiekosten (bijv. informationkosten) hoger zijn dan op de CO_2 markt. Deze bevinding bekrachtigt dat, voor autarkische bedrijven, het EU ETS kostenbesparingen heeft gerealiseerd.

Case III: Restricties op eigendom

Volgens de eigendomsrechten theorie kunnen beperkingen op de contractuele vrijheid op eigendom (bijv. via wet- en regelgeving) maatschappelijk inefficiënt gedrag van bedrijven voorkomen, om daarmee beleidsdoelstellingen te ondersteunen zoals competitie en innovatie.

Het derde onderzoek, Jong en Woerdman (2016), bekijkt of beleidsdoelstellingen op één lijn liggen met de uitvoering in Europese gas- en elektriciteitsmarkten. Voor de doelstellingen nemen we van Europese lidstaten de verschillende niveaus m.b.t. 1) de zekerheid van hun energievoorziening, 2) het concurrentievermogen en 3) de CO_2-neutraliteit. Aangezien de uitvoering van Europese regelgeving op gas- en elektriciteitsmarkten veelal overgedragen is aan Europese Nationale Regulerende Instanties (NRI's), analyseren we de wettelijke bevoegdheden van NRI's. We leiden vervolgens scores af (a) in hoeverre deze energie doelstellingen gerealiseerd zijn en (b) wat de hoeveelheid en zwaarte is van de bevoegdheden van NRI's omtrent deze doelstellingen.

Hoewel de noodzaak tot regulatoire interventie lager is bij hogere scores op de doelstellingen, vinden we dit niet terug in het merendeel van de gevallen. De regulatoire interventie is bijvoorbeeld hoger in het geval van de zekerheid van de energievoorziening en van de consumentenbescherming. In plaats van steeds strengere regelgeving, is onze aanbeveling dat het ontwerp van deze regelgeving er meer voor dient te zorgen dat bedrijven, bij het behartigen van hun eigen belangen, tegelijk het (maatschappelijk) optimaal niveau van deze doelstellingen bereiken.

We kunnen geen duidelijke conclusies trekken voor de doelstellingen op het gebied van CO_2-neutraliteit en energie efficiëntie. Een mogelijke verklaring is dat deze bevoegdheden bij andere beleids-specifieke NRI's of ministeries liggen. Het zou de effectiviteit ten goede kunnen komen als de lidstaten uit de steekproef de regulatoire reikwijdte van hun NRI's herzien. Dit kan bijvoorbeeld door toe te staan dat NRI's gezamenlijk hun bevoegdheden gebruiken bij het ontvangen van informatie van de onder toezicht gestelden.

Ten slotte bevinden we dat NRI's niet volledig de 'optimale' rangschikking van bevoegdheden hebben. In vergelijking met een theoretisch criterium zijn er relatief meer 'harde' dan 'zachte' bevoegdheden, hoewel laatstgenoemden goedkoper zijn om uit te voeren. Deze mogelijk verkeerde regulatoire combinaties kan men corrigeren door het gewicht van de bevoegdheden van NRI's aan te passen.

Acknowledgments

I still remember the day I got in the train for a three hours ride to Groningen. This was the first time for me I went to “the North”, in my thoughts one large no-man’s-land “above Amersfoort”, where the few people, who are able to live there, are stiff and never heard of carnival. It was a crazy rainy day and, to make it more challenging, I had a job interview for the Ph.D. position for which I applied.

Yet, the warmth and cheeriness from this job interview completely undid this blue and stressful mental state. This moment symbolized for me how “Groningen” would stand as an entity against the tons of focus and perseverance that is necessary when “doing a Ph.D.”. My supervisors, Oscar and Edwin, really were a team, each with complementary roles to keep me going. Oscar is no-nonsense and sharp, both in fun and business terms. Edwin is an excellent wordsmith, and goes to considerable lengths to get me involved with and connected to “the outside world”. I am very grateful for their endless patience, their multifaceted support, and their guidance into the academic world.

Fortunately, for me Groningen was really littered with cornerstones. Fitsum is one of the brightest and warmest persons I have ever known. During lunch or coffee breaks, we were able to find solutions to all world problems. Ela, always present at the notorious Ph.D. council drinks or other social events, precisely knows when and how to make fun of the things I am saying (and in case you did not know, I can be outspoken occasionally). Surya often shared us with his fascinating law and non-law perspectives, which resulted in some vortex which boggled our minds.

Many of the Groningen cornerstones could be found during lunchtime. On the way to abduct Teo for lunch, chances were high to be caught by the cheerfulness from the Graduate Office: Ela, Marjolijn, and Barbara. When standing (but also when not standing) in front of the Graduate Office door, Anneke could also take part in her warm determination to relieve me from all “purple crocodiles” the University brought forth. The lunch procession thereafter passed by Charis, Stefan, Zeeshan, Adam, Björn, and Enrique, where we were testing our powers of

persuasion that both God and the universe required them to join. During lunch, it was always a joy with Teo to switch on the (rude) Dutch-mode, and to tell our foreign-born colleagues this rudeness helped them to integrate into Dutch society. At first, Yingying thought we were serious, but she is a quick learner and now can win this game hands down. After lunch it was time for coffee to immediately suppress the tiredness from digesting lunch, where we often encountered more fellow Ph.D. students. This daily lunch ceremony enabled me to get reborn, in order to continue battling away on Excel and STATA for the remainder of the working day.

After taking on Excel and STATA alone, I was joined by brother-in-arms from the European University Institute who were like-minded in cracking the EU ETS data vault: Jūratė Jaraitė-Kažukauskė, Andrius Kažukauskas, Aleksandar Zaklan, and Alexander Zeitlberger. I was happily surprised and grateful that Alexander was willing to join me in the endless search for a bunch of needles in the EU ETS haystack, even with other more pressing things on his mind. I am further indebted to the EUI in providing me with the opportunity to work together with Stefano Verde, Claudio Marcantonini, and Christoph Graf, and to get to know many others in the EU ETS domain.

Not only am I indebted to the Energy Delta Gas Research (EDGaR) consortium in its contribution to realize this Ph.D. research project, I have learned much from the interesting meetings and conferences with my EDGaR project partners from: DNV GL (Karen van Bloemendaal, Bert Kiewiet, Maurice Vos), ECN (Marit van Hout, Jeroen de Joode (currently: ACM), and Özge Özdemir), and TU Delft (Christopher Davis (currently: RuG), Gerard Dijkema (R.I.P.), Bas Gerben (currently: Widget Brain), Zofia Lukszo, and Ahmad Mir Mohammadi Kooshknow (currently: RuG)).

Since I considered myself an expat in this country within my first months in Groningen, I wanted to explore the "real Groningen" and so I joined the soccer club "Groen Geel". With the team, including the Thomas-duo, Jos, and Joseph, all 'three halves' of the match were a delight. We had no real "Grunnegers"; luckily I had the chance to encounter them as opponents in our soccer matches. It was the splendid "Groen Geel" team spirit and ambiance which made me got out of bed on time, for those early Sunday mornings when our matches started.

The Groningen time in its purest went by rapidly. I sent my Ph.D. manuscript the day before I started working at the Energy Directorate of the Authority for Consumers and Markets (‘ACM’). And so after a while I had to run two lives: one on the rewarding work at the ACM on electricity markets, and one on processing the Ph.D. reviews. I could not have finished these Ph.D. reviews without the many pats on my back from my warm ACM-colleagues: Hannah, Jacco, Johan, Jorieke, Lisanne, Max, Paul, Pauline, Robert, Roy (the list is longer, I had to stop at ten). I also could not have completed it without being able to kick some balls at my soccer team, SVC ‘08 (including the moment of glory at Lisse), and without the regular reminders that I must have “lived in a cave” during the pub quizzes with Lydwine, Hannah, Lena, Rieks and Ingrid.

I consider myself lucky that, during my adventure to and from Groningen, at many people’s places the coffee was still hot and the beer was still cold: my family (my mother; Lydwine; Willeke, Roelant and Paul; Ada, Oscar, Lauren and Louise; Klaas and Annelies; Thom and Annelies; Frans and Truus, Camiel and Kim), Serge, Stefan, Verbs 26 (David, Arjan, Fred, Evert-Jan, Benedikt), The BitterBall Boys (Jochem, Justin, Louis, Rob), the VITE-rans and Finals (Rob, Thomas, Shiao Li, Meike, Eline, Lotte, Ilse, Sanja, Koen), and the München Münsters (Bart, Eelco, Jasper, Krijn, Pim, Willem, Winand). You guys know how to get me out of my daily grind. Thanks for always being around, and for your sincere interest in what I am doing and what is up my mind.

Very special thanks go to Lydwine. It was painful to wave each other goodbye at the end of every weekend, in The Hague or Groningen. And when finally living together in The Hague, my evenings and weekends were often spent on the Ph.D. reviews. I am thankful she looked further than the horizon; we both knew the Ph.D. research was temporary, but not exactly “how temporary” it was going to be.

Finally, I would like to dedicate this dissertation to my parents. When I started this Ph.D. research, my father was already about a year in hospital after a heavy brain hemorrhage. From that incident until he passed away, he fought a battle he could not win, only to have more time with his wife and children. My mother, in return, almost set herself

completely aside in shining her bright light in the latest and darkest chapters of his book.

My mother and my father, when he was still alive, often made the joke that LDP was the secret ingredient in their meals. In the same breath, they immediately told the secret what LDP stands for: Love, Dedication, and Patience. This dissertation could never have been made without their LDP.

Thijs Jong
The Hague, the Netherlands
21 December, 2017

Curriculum Vitae

After obtaining a Bachelor's degree in International Economics and Finance and a Research Master's degree in Economics at Tilburg University, Thijs Jong started a Ph.D. in Law and Economics at the University of Groningen in March, 2011, in the Netherlands. His Ph.D. research was part of and sponsored by the Energy Delta Gas Research (EDGaR) program.

Jong compiled the 'Ownership Links and Enhanced EUTL Dataset' during a 2012 research visitorship at the European University Institute (EUI) Climate Policy Research Unit in Italy, and in subsequent collaboration with the EUI and international researchers. This database makes the EU allowance transactions registry useable for firm-level empirical analyses, and aims to facilitate new, in-depth research on the EU allowance transactions by companies.

The EUTL and this database are at the basis of five of his six (joint) research papers dealing with: (1) share prices, (2) the use and trade of carbon allowances, (3) CO_2 spot market manipulation, (4) installation entry and exit factors regarding the EU ETS, (5) two technical CO_2 data manuals, and (6) legal competences of energy market authorities. Jong published in *Energy Policy* and *Competition and Regulation in Network Industries*, among others.

Following his strong interest in the economics and regulation of energy markets, Jong started working for the Directorate Energy at the Dutch Authority for Consumers & Markets (ACM) in November, 2015.