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Vintage differentiated regulations and plant survival

EVIDENCE FROM COAL-FIRED PLANTS

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VINTAGE DIFFERENTIATED REGULATIONS AND PLANT SURVIVAL: EVIDENCE FROM COAL-FIRED POWER PLANTS – ENVIRONMENT WORKING PAPER No. 144

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Abstract

This paper assesses the effect of environmental regulations on plant survival and emissions using data on the extent of vintage differentiation of regulations (VDR5) regarding air pollution emission limit values for existing and new coal-fired power plants. Focussing on NOx and SOx emissions, the paper applies survival analysis techniques on a sample of generating units across 31 OECD and non-member countries between 1962 and 2012. While policy stringency speeds up the exit (decreases the survival rate) of older plants, greater vintage differentiation is associated with significantly higher age at exit of a plant. Plants in countries with the highest levels of VDR may operate up to 14 years longer than plants in countries without VDR. Simulating the environmental impact related to changes in lifetimes of old and more polluting plants, this paper provides evidence consistent with a trade-off relationship between policy stringency and vintage differentiation in achieving desired emission levels. The simulation results suggest SOx (and NOx) emissions to be around 1.3% (and 0.6%) lower if countries would not have implemented VDRs in the first place.

Keywords: vintage differentiated regulation, air pollution, emission limit values, coal powered plants, environmental policies, exit.

JEL codes: Q50, Q53, Q58, Q48.

Résumé

Cet article analyse l'effet des règlementations environnementales sur la survie des centrales électriques et sur les émissions, en utilisant des données sur l'ampleur des 'vintage differentiated regulation' (VDRs), concernant les valeurs limites d'émission de pollution de l'air pour les centrales au charbon existantes ou nouvelles. En se limitant aux émissions NOx et SOx, cet article s'appuie sur des techniques d'analyses de survie en se basant sur un échantillon d'unités génératrices se trouvant dans 31 pays membres et non-membres entre 1962 et 2012. Alors que Ia rigueur des politiques environnementales accélère Ia sortie des plus vieilles centrales (en diminuant leur taux de survie), une plus grande différentiation de l'ancien est associée avec un age d'abandon d'une centrale plus avancé. Dans les pays avec un niveau de VDR plus élevé, les centrales peuvent opérer jusqu'à 14 ans plus longtemps que dans les pays sans VDR. En simulant l'impact environnemental associé au changement au cours de la vie des vieilles centrales et celles qui sont plus polluantes, cet article fournit des éléments tangibles en conformité avec une relation de compromis entre la rigueur des politiques et la différentiation de l'ancien pour atteindre les objectifs de niveaux d'émission. Les résultats de Ia simulation suggèrent que les émissions SOx (et NOx) sont réduites de 1.3% (et 0.6%) si les pays n'ont pas mis en œuvre les VDRs en premier lieu.

Keywords: vintage differentiated regulation, pollution de l'air, valeurs limites d'émission, centrale au charbon, politiques environnementales, sortie.

JEL codes: Q50, Q53, Q58, Q48.

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All errors and inconsistencies remain the responsibility of the authors.

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1. Introduction

Entry and exit are crucial market adjustment mechanisms – promoting more efficient and more innovative solutions while punishing those who fail to adapt. General policy settings, such as bankruptcy legislation, contract enforcement or anti-trust laws can have important implications for business dynamics [see Calvino et al. (2016)]. For the specific case of regulations, Heyes (2009) notes: "regulations can advantage firms in an industry versus those outside. As with other barriers to entry they can provide shelter 'behind' which incumbent firms can make supernormal profits."

The channels are multiple – but most commonly related to raising fixed capital costs (required to meet the regulation) or increasing the burdens associated with permitting new facilities. Consequently, regulations can impact plant renewal and capital turnover, as incentives to retire old plants will be affected. Turnover may be increased due to more demanding regulations, but at the same time also decreased as a result of higher entry barriers shielding old plants from competitive pressures.

Such effects can be exacerbated in the case of vintage differentiated regulation (VDR) or 'grandfathering', whereby existing plants, technologies and products are subject to more lenient regulations than new ones. Policy domains where VDR is common include occupational licensing, building codes, product safety and quality standards, workplace health and safety, environmental regulation and zoning ordinances (see Gruenspecht [1982]; and more recently Heutel [2011]).

Kaplow (2003) and others have termed such differentiation as a reflection of "transition policy", whereby the government seeks to smooth adjustment costs in the face of changing and unexpected policy conditions. Kaplow (2003) notes that legal changes of any kind create "both gains and losses for those who under the prior regime took actions that would have lasting effects." While such policy discontinuities are likely to have significant impacts on entry, exit, competition and survival, their consequences have not been extensively studied.

The extent to which different types of vintage-differentiated policy settings impact business dynamics will depend upon the point of incidence of the policy. Grandfathered regulations which relate to product safety standards are likely to primarily affect market penetration of new goods and services, with only indirect effects on plant and firm entry and exit. Those regulations which relate to business operations (e.g. occupational health and safety) are more likely to affect plant-level dynamics. In other cases the effects are likely to be felt at the level of the firm (See Kaplow [2003] for a discussion.)

The consequences of such differentiation can take on a myriad of forms, potentially slowing market penetration of new goods and services, slowing capital turnover, and reducing rates of firm entry and exit. On the one hand, this can have adverse implications for productivity and innovation. On the other hand, it can also make the realisation of the primary policy objective (e.g. safety, environmental quality, etc.) more costly since new products, plants and firms are often the vehicles through which welfare improvements can be realised. Along the lines of Stavins (2005) the detrimental effects of differentiation can be expected to be particularly pronounced in industries with low rates of capital deterioration and technical obsolescence.

In this paper we focus on the case of environmental regulations, and in particular those related to air pollution emissions from coal-fired electricity generation plants, where VDRs are ubiquitous. The most oft-cited example is the US Environmental Protection Agency's New Source Performance Standards under the original US Clean Air Act. However, the practice is common elsewhere. For example, in the case of Canada new rules for coal plants were introduced in 2015, requiring investment in carbon capture and storage. However, these rules only apply to coal plants built after 2015.[1] Existing plants, some of which are 50 years old, can continue to operate through to 2030 without being required to undertake such investment.

We attempt to shed more light on the consequences of vintage differentiation to allow more educated policy decisions. We use new data on emission limit values for coal-fired power plants across 31 OECD and non-member countries, put together by Johnstone et al. (2017) as well as the UDI World Electric Power Plant Database (WEPP), which contains information on most coal-fired power generating units over time. Coal-fired plants seem a particularly interesting subject, as vintage differentiation is prevalent internationally and can have long-lasting consequences due to long plant life.

This paper is organised as follows. Section 2 reviews the debate on the economic case for vintage differentiated regulations. Section 3 presents descriptive evidence on the determinants of market dynamics, with a particular focus on evidence for plant entry, exit and lifespan. Section 4 presents the empirical approach used in this paper, and Section 5 presents the results. In Section 6 a simulation of the trade-off between policy stringency and differentiation is presented. Section 7 concludes with a discussion and conclusion. Finally, the Appendix provides supplementary results and data descriptions.

2. Background and Review

2.1. The economic arguments for (and against) vintage-differentiated regulations

Vintage differentiation can take different forms. For example, in some cases plants are exempted from the regulation entirely, while in other cases the differentiation is reflected in levels of varying stringency. VDR may be temporary, whereby existing plants are subject to more lax regulations for a limited time after which they will be expected to comply with the stricter norms; or be in place until the end of life of all existing plants.[2] Various definitions of plant "modernisation" can fall under new, stricter norms.

A debated question is whether (and the extent to which) compensation should be provided to existing operators through VDR (see Shavell [2008]). However, this paper is not concerned with the political and normative case for grandfathering *per se*, but rather with its economic consequences: especially effects on plant exit and survival. More stringent regulation for new plants may deter the exit of existing plants since the loss of rents serves as a disincentive. A VDR guarantees lower environmental compliance costs to existing plants, allowing them to generate positive profits (and hence remain operational) – but also

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[1] www.canada.ca/content/dam/themes/environment/documents/weather1/20170106-1-en.pdf.

[2] For an interesting philosophical discussion of the difference between the two cases, see Schuessler (2015).

to pollute - for longer. For the same reason, it is a deterrent to new entry, relative to a regulation that has uniform requirements for both new and existing plants. As a consequence, differentiation shifts the age distribution of the plant stock towards older plants (see for example, Maloney and Brady, [1988]; Nelson et al. [1993]) and can lead to worse environmental outcomes in the short-term. Shielding older, more pollution-intensive plants from the stricter norms can raise the overall cost of achieving an ambient standard or emission target – skewing the distribution of this burden towards new entrants. It also can have indirect adverse implications for productivity, as older plants tend to be less efficient (see Johnstone et al. [2017]).

2.2. Determinants of entry, exit, age of capital stock – evidence from the literature

Numerous empirical papers have attempted to assess the effect of different factors on firm entry and exit (see Manjón-Antolín and Arauzo-Carod (2008) for a review). However, relatively few studies focus specifically on plant (rather than firm) exit, which is subject of this paper. Plant-level studies distinguish between determinants linked to plant characteristics (age, size, capital intensity, productivity), ownership (whether the plant is part of a multi-plant firm, a multinational enterprise (MNE); has it changed ownership), market features (concentration, market dynamics), economic conditions (business cycle) and policies. They tend to focus on developments in a single country, within selected industries.

In general, older plants are more likely to exit. Examples include Mata et al. (1995) for Portuguese manufacturing facilities (both "de novo" single plant firms and those which are part of firms with multiple plants) as well as Bernard and Jensen (2007) for US manufacturing.

Larger plants have a higher chance of survival (Mata et al. [1995]; Görg and Strobl [2003]; Bernard and Jensen [2007]).[3] In a sample of UK manufacturing establishments from 1986 to 1991, Disney et al. (2003) find that for single establishment firms survival decreases with initial size, but this is offset by the effect of a contemporaneous size variable.[4] Moreover, the interaction between age and size allows drawing distinct "grow-or-out" inference, in line with Audretsch (1995): establishments that are small upon entry are more likely to exit but if they grow faster the hazard declines. In the same line, Tveterås and Eide (2000) suggest that small start-ups may be a distinct class of entrants, subject to different determinants of survival.

Somewhat unsurprisingly, more productive plants tend to have a higher chance of survival (Bernard and Jensen [2007] for US manufacturing). Capital intensity and high investment also increase survival – as found by Tveterås and Eide (2000) for manufacturing plants in Norway, Bernard and Jensen (2007) in the US and Wang (2013) in Canada. The role of R&D intensity and human capital (or skill intensity) are also sometimes evaluated and generally found to increase survival (Wang [2013]; Bernard and Jensen [2007]). Interestingly, in a study of 17000 Irish plants Görg and Strobl [2003] do not find significant differences between high and low-tech industries.

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[3] Though, Gray and Shadbegian (2003) find that the impact of environmental regulation on productivity, and thus, on plant exit does not depend on the age of plants.

[4] The reporting unit level for the Office of National Statistics (the "establishment) may cover multiple plants in some cases.

Ownership and firm structure matter. Conditional on other characteristics of the plant, plant exit is more likely for those plants which are part of multi-plant firms, are part of a MNE, and where ownership has recently changed (Bernard and Jensen [2007]). Conversely, Görg and Strobl (2003) find that in Ireland foreign multinationals are less likely to close plants. Bernard and Sjöholm (2003) look at similar issues in the Indonesian context over the period 1975-1989. They find that plants with some foreign ownership have greater survival rates, but when controlling for size and productivity they are 20% more likely to exit. This result holds when they look at the data for individual plants where there has been a change in ownership between domestic and foreign owners. They argue that multinational firms use the "extensive margin available to them to close plants more often than their domestic counterparts". For domestic owned Canadian plants born over 1973-1986, Wang (2003) finds that the presence of foreign affiliates in upstream and downstream sectors increases survival, but plants have higher exit rates due to competition from FDI affiliates in their own industry. He also finds ownership change increases the chances for survival.

Market dynamics are found to be significant: overall plant entry in the industry has a negative effect on survival (Mata et al. [1995] for Portuguese plants; Wang [2013] for Canadian plants). Bernard and Jensen (2007) further find that market diversification matters: plants that tend to export and multi-product plants tend to be more likely to survive. Finally, economic upswings generally reduce exit hazard, as found by Disney et al. (2003) in the UK and Görg and Strobl (2003) in Ireland.

2.3. Vintage differentiation as one of the determinants of business dynamics

Most studies evaluate the role of various consequences of policy settings - such as the business cycle, market structure and dynamics and foreign direct investment – on plant survival and exit, but few studies have looked at the role of policies directly. At the same time, in their review Cincera and Galgau (2005) consider that public intervention - through market reforms - is one of the most important factors influencing exit decisions. The authors argue that industry deregulation leads to an increase in both entry and exit rates.

The role of individual policy levers which might have implications for plant survival and exit has not been extensively discussed in the empirical literature. In particular the role of explicit "grandfathering" – whereby policy settings differ between established and new plants - is likely to have significant implications for plant survival and exit, the incentives for product innovations, investment in new capital equipment, etc.

The first paper to assess the effect of vintage differentiated environmental policies, (Gruenspecht 1982), examined the effect of car emission standards on scrappage rates of old vehicles. He simulated the effect of increasing "corporate average fuel economy" (CAFE) standards – on the survival of older vehicles, finding that more stringent emission standards for new cars prolonged the life of older vehicles, increasing emissions in the short run.

Early contributions at the plant level focussed on the effects of regulations on the age of capital in the electricity generating sector in the US. For example, Maloney and Brady (1998) found that electric power plants were kept in service longer during the 1970s in states with more stringent (but more discriminatory) environmental regulations. Similarly, Nelson et al. (1993) estimate a model using utility-level data, and find that tighter regulation increased the age of capital, but did not significantly impact overall emissions. In a simulation undertaken by Ackerman et al. (1999), the environmental and economic impact of removing vintage-differentiated regulation for existing coal-fired power plants in the

US. If existing utilities were to comply with the emission limits for new entrants, both SO_X and NO_X emissions from coal-fired power plants would decrease by 75%, while the electricity price would rise by only 4%. Levinson (1999) looks at the role of vintage-differentiated regulations for two competitive sectors (commercial printing and paint manufacturing), arguing that the focus on electricity supply may bias results. More specifically, with price-regulated sectors the effect of vintage-different regulations on plant dynamics will not just be a function of the environmental policy setting, but also the more general regulatory structure. Using plant age as the dependent variable he finds no evidence of the effect of vintage-differentiated regulations. However, he argues that this may be a function of the use of discrete policy variables which do not account for the degree of differentiation. He also raises the interesting point that there may be a link between vintage-differentiated and size-differentiated policy enforcement, with newer (and thus smaller) plants being less likely to be subject to regulatory enforcement.

In a more recent paper Heutel (2011) looks at the effect of vintage-differentiated SO_2 regulations on the scrapping and abatement decisions at the level of the individual boiler in US power plants. He finds that for boilers between the ages of 15 and 25 years those which have been “grandfathered” are half as likely to be scrapped as those which have not been grandfathered. They are also less likely to use low-sulphur coal or install a scrubber.

An interesting “wrinkle” on these results is addressed in a paper by Bushnell and Wolfram (2012) who look at the implications of the meaning of “new” under vintage-differentiated regulations. Under the US “New Source Review” rules a plant lost its grandfathered status if it undertook major modifications (see Nash and Revesz [2007] for a discussion of the precise meaning of these and the implications). Bushnell and Wolfram find that “vulnerable” plants were hence less likely to invest in new capital equipment.

This, of course, may have implications for productivity and other measures of performance. While somewhat dated Stanton (1993) assesses the effect of vintage-differentiated regulations on the capacity utilisation of “old” and “new” electricity plants, hypothesising that if regulations increase relative operating costs (i.e. use of more expensive low-sulphur coal or electricity-consuming scrubbers) for newer plants more than older plants, the latter will be used more intensively. His results confirm that older plants with the least degree of regulatory control have higher capacity utilisation rates.

In this paper we are strictly concerned with plant survival. The objective is to estimate the hazard rate of a plant to exit the market. In the context of our study, each firm in each period makes a decision whether or not to close a given plant in a specific year - the hazard function represents the probability that failure occurs within the year in question, conditional on having survived up to that year. This decision will be a function of plant characteristics (e.g. age, size, technology), firm characteristics (e.g. whether it is part of a multi-plant firm), market conditions (e.g. growth prospects, degree of competition) and policy settings. Some of these factors will vary over time, while others will remain constant.

Our primary concern is the role of policy settings. If the policy measure distinguishes between incumbent plants and new plants, we are interested in assessing the effect on the probability of exit. The hypothesis is that policy settings which are less onerous for incumbents will result in reduced hazard of exit. Implicitly, we treat the policy variables as exogenous. In practice, policies may be influenced by political economy - collective action of special interest groups aiming at deterring new plants from entering – by placing a higher relative burden on new plants. However, proper assessment of the potential endogeneity of policies requires data on the policy implementation process, and is beyond the scope of this paper.

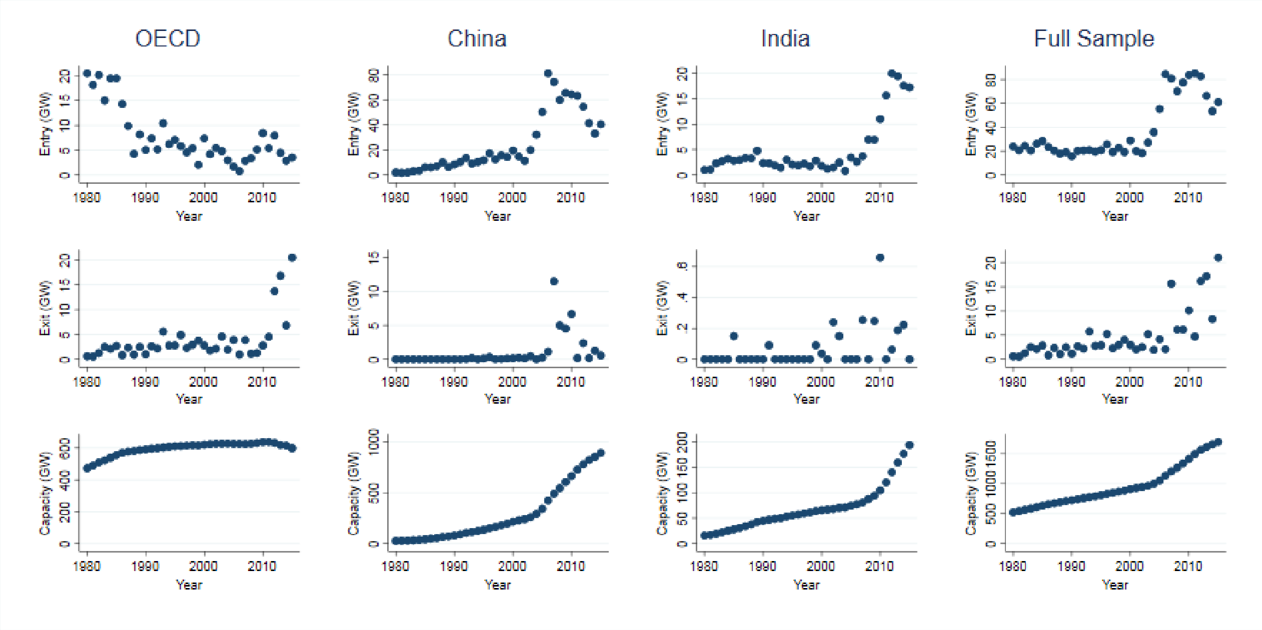
3. Data and descriptive evidence

Our unit of analysis is the sub-plant "generating unit", consisting of a boiler, a steam turbine and a generator. Data on entry and exit of units are obtained from the March 2016 release of UDI WEPP, which is also the source of unit-, company- and industry-level controls. The WEPP database includes plants in all countries, with >95% (>75%) coverage of units with capacity greater (smaller) than 50 megawatts (MW). The database includes utilities and private companies in the electricity sector, as well as "autoproducers" in other sectors, predominantly energy-intensive manufacturing companies. Our sample is limited to coal-fired generating units that came on-line between 1962 and 2012. The availability of the key explanatory variables (regulatory stringency and differentiation) limits the sample to 31 countries covering most OECD members, as well as Brazil, Bulgaria, China, Croatia and India with a total sample size of 6883, including 647 instances of exit.

Table A.1 in the Appendix shows the cross-country distribution of units within the estimation sample, as well as the breakdown of exit by decade and country. Since units that entered before 1962 are not included, there are few instances of exit prior to the 1990s. For the same reason, the number of units that are operational in a given year increases steadily over the sample period, as does their mean age. Units are concentrated in China (3131), India (1052) and the USA (930), whereas the largest number of exits are observed in China (277), the USA (99) and Germany (99).

Figure 3.1 plots global trends in coal-fired generation capacity, over the period 1980-2016. Within OECD countries, a trend of increasing exit, combined with decreasing entry, has seen total capacity growth slowing since the late-1980s, and declining since 2010. Despite this, global capacity growth has accelerated since the mid-2000s, largely thanks to rapid expansion of capacity in China and India. This expansion has coincided with increased exit worldwide.

Figure 3.1. Global trends in coal-fired electricity generation capacity (1980 – 2015)



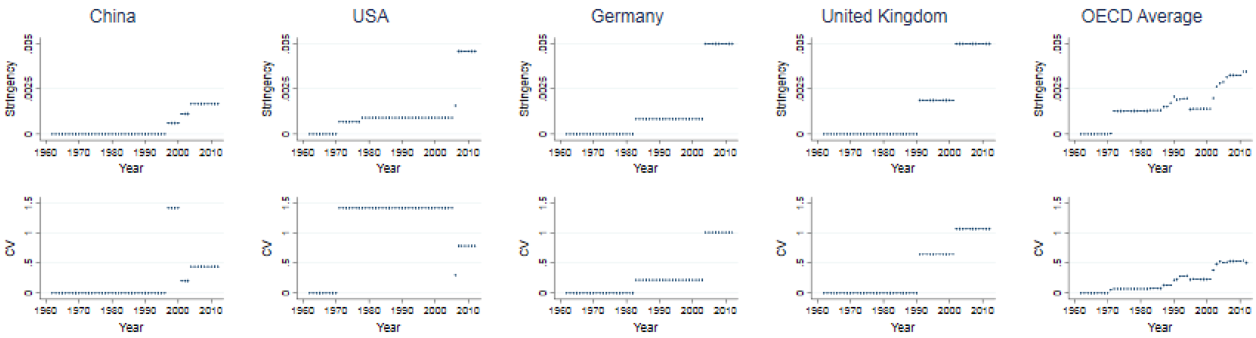
Source: UDI's World Electric Power Plant Database (WEPP), March 2016 release.

Data on emission standards faced by coal power plants are taken from the database developed in Johnstone et al. (2017), which combines information from national databases of environmental regulations and the Emission Standards Database of the International Energy Agency (IEA) Clean Coal Centre. Regulatory stringency is formulated as the inverse of the concentration limit (mg/m3) mandated by a given standard, with stringency of zero indicating no regulation. Raw data on individual regulations are used to develop 32 separate stringency variables, each relevant for a certain combination of plant characteristics (four size-classes, two coal types), plant age (new or existing) and pollutant (NO_X or SO_X).

For each pollutant, vintage-based regulatory differentiation is measured by the coefficient of variation (CV) in stringency between new and existing plants. A higher value of CV implies greater new-source bias, whilst a value of zero indicates no regulatory bias with respect to plant vintage. Our analysis uses the unweighted average for the 32 combinations of stringency and CV variables to produce a single stringency-CV pair for each country-year observation. The variables cover the full period (1962-2012) and the set of countries described above, capturing the implementation of emission standards and their evolution over time.

Figure 3.2 plots the development over time of stringency and CV of SO_X regulations for selected countries. The regulations presented are those applicable to a representative plant of size 240MW using hard coal. The plots show specific instances of a global trend in NO_X and SO_X regulations: increases in stringency over time have, in most cases, been accompanied by greater levels of vintage-based differentiation. Similar observations can be made for NO_X regulations and different plant sizes.

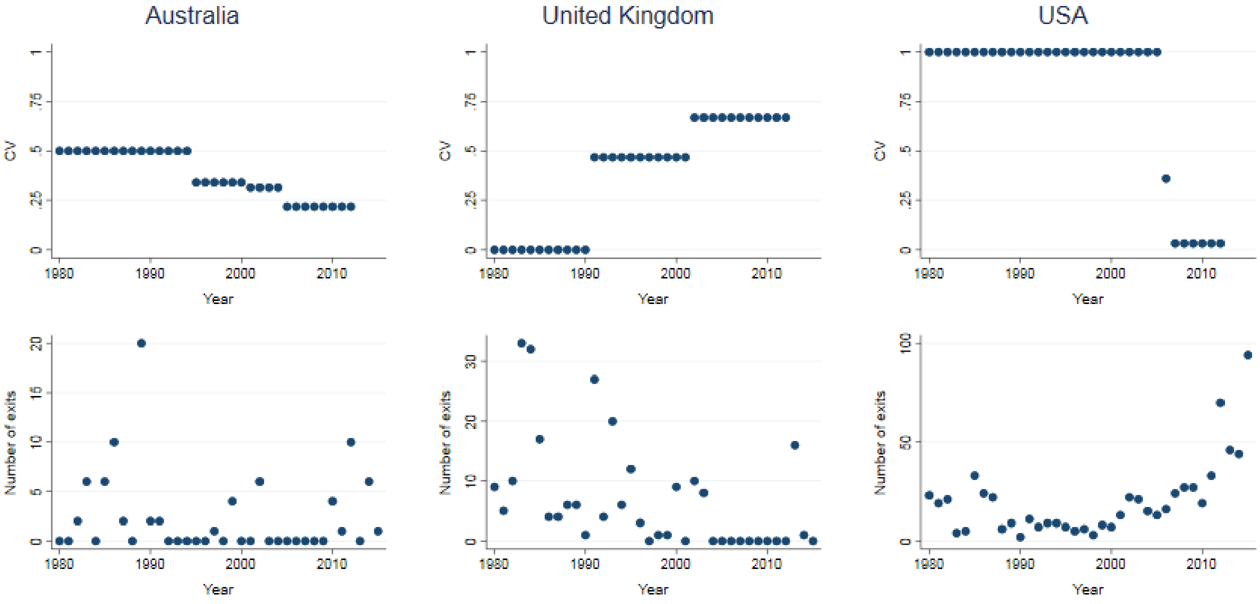
Figure 3.2. The stringency and vintage differentiation in SOX regulations over time



Note: Based on SO_X regulations applicable to plant size 240MW using hard coal. The stringency variable applies to new plants with these characteristics.
Source: Based on data from Johnstone et al. (2017).

Based on theoretical insights and empirical evidence presented above, one would expect a pattern of increased differentiation to be accompanied by reduced exit and replacement of existing plants, ceteris paribus. Figure 3.3 compares the evolution of differentiation in SO_X regulations and number of units exiting since 1980, for three OECD countries: Australia, the United Kingdom and the USA. This comparison fits the expected relationship outlined above. Australia can be viewed as a baseline case, with modest decreases in differentiation but no clear trend in exit. By comparison, a sharp decrease in differentiation in the USA in 2006 was followed by increased exit, and increases in differentiation in the UK, in 1991 and 2002, were each followed by reduced exit.

Figure 3.3. Trends in vintage differentiation and exit



Source: Johnstone et al. (2017); UDI’s World Electric Power Plant Database (WEPP), March 2016 release.

4. Empirical approach

In order to assess the influence of vintage differentiation on plant exit, we adopt the Cox (1972) proportional hazards model – a semi-parametric survival model commonly used in the industrial organisation literature (see Manjon-Antolin and Arauzo-Carod, 2008; for a review). Survival models provide a more suitable alternative to OLS, replacing the assumption of normality with a more fitting distributional assumption. In the Cox model the hazard rate $h(t)$ is defined as the event rate at time t, conditional on the event not having occurred up to time t:

$$h\left(t\middle|X_j\right) = h_0(t)\exp(X_j\beta)$$

The distributional assumptions are reflected in the baseline hazard function $h_0(t)$ with the impact of covariates reflected in the term $\exp(X_j\beta)$, the exponential form of which ensures that the hazard rate remains positive. The estimated coefficients indicate the proportional change in the hazard rate associated with a one-unit increase of a covariate.

The Cox model estimates the impact of covariates on survival without imposing a specific distribution on the baseline hazard $h_0(t)$. This avoids a major drawback of parametric models: that imposing an inappropriate distribution can produce bias in the results. Furthermore, the Cox model provides a baseline against which parametric models can be compared. On the other hand, provided that the baseline hazard is correctly parameterised, parametric models have the advantage of offering efficiency gains over semi-parametric approaches. Additionally, parametric models also allow for obtaining predicted lifetimes based on coefficient estimates, which is why we select and estimate a complementary parametric model.

In the econometric analysis, the explanatory variables of primary interest are stringency and CV. Furthermore, we interact the variable CV with an age-class dummy, which identifies units over 30 years old in order to isolate the impact of VDR on survival of older units within the plant stock. Given that the distribution of unit age at exit is concentrated around 30 years, with median 31 years and mean 29.6 years, the age-class dummy effectively identifies units that have already lived longer than average and, thus, can be considered as “existing” as opposed to “new”. Unit age is not included on its own, as a separate covariate, since the effect of age is accounted for by the baseline hazard function in our survival model. Other age-class dummies are used as a robustness check (summarised in Table A.2 in the Appendix).

We include controls at the level of the generating unit, firm and country, described in Table 4.1:

- Unit-level controls include capacity, coal type, use of cogeneration technology, and steam type.
- Capacity is in MW and is expected to reduce the hazard of exit, based on previous survival studies, which find that other measures of plant size (e.g. employment, value of shipments) are positively correlated with survival.
- Coal type lignite takes the value of one if the generator uses lignite (brown coal) and zero otherwise. Brown coal has high moisture content, low energy content, and

is considered of lower quality than the other varieties of coal commonly used in electricity generation. Since previous studies find that quality of inputs is positively correlated with survival, we expect the impact on hazard of exit to be positive.

- Cogeneration technology equals one if the unit is equipped with cogeneration technology. Cogeneration - also referred to as "combined heat and power" (CHP) - involves a turbine producing steam or hot water, as well as driving a generator. This technology allows reductions in fuel input and emissions of SO_X and NO_X, for a given level of production, thereby improving productive and environmental efficiency. Since previous studies have found that more technologically advanced plants have higher survival rates, we expect the use of cogeneration technology to reduce the hazard of exit.
- A dummy for steam type distinguishes units with supercritical (or ultra-supercritical) boilers from those with subcritical boilers, which act as the base category for comparison. As with cogeneration, the improved efficiency of supercritical boilers is expected to improve survival prospects for these units.
- Company-level controls include electric production type and a dummy for single-unit firms. Electricity production type splits companies into the following three categories: commercial or industrial autoproducers, private power companies and utilities. Units are defined as belonging to single-unit firms for a given year if the number of other units of the same company (in the same country) is zero in that year. This definition identifies cases for which unit exit implies firm exit from a given market (country), and we expect such cases to be associated with greater hazard of exit, in line with existing literature.
- At the level of the country, the share of coal in a country's total electricity capacity is included as a control, along with percentage net growth in coal capacity, and the Herfindahl–Hirschman Index (HHI) of market concentration. Growth in coal is included as a proxy for market profitability that also implicitly controls for other policies such as subsidies for fossil fuels. We expect higher growth to be associated with greater probability of survival. Likewise, in the presence of greater market concentration, units are expected to exhibit higher rates of survival – e.g. due to less competitive pressure. However, the relevance of the national-level HHI measure used may be limited since in many countries producers compete in smaller, regional markets, while on the other hand electricity is also traded across national borders (particularly within Europe).

Table 4.1. Descriptive statistics for surviving and non-surviving units

	All units (n = 6883)				Surviving units (n = 6236)				Non-surviving units (n = 647)			
	Obs	Mean	Min	Max	Obs	Mean	Min	Max	Obs	Mean	Min	Max
Stringency [a, b]	6883	0.286	0	6.722	6236	0.309	0	6.722	647	0.063	0	6.690
Coefficient of Variation (CV) [b]	6883	0.237	0	1.237	6236	0.253	0	1.237	647	0.081	0	1.061
Capacity (MW)	6883	225.8	0.2	1426	6236	237.6	0.2	1426	647	112.4	0.3	818.1
Coal type lignite	4898	0.129	0	1	4362	0.124	0	1	536	0.172	0	1
Cogeneration technology	6878	0.312	0	1	6232	0.320	0	1	646	0.232	0	1
Steam type supercritical	6866	0.094	0	1	6222	0.102	0	1	644	0.011	0	1
Electric production type [c]												
Autoproducer	6883	0.181	0	1	6236	0.192	0	1	647	0.071	0	1
Private power company	6883	0.144	0	1	6236	0.149	0	1	647	0.094	0	1
Utility	6883	0.675	0	1	6236	0.659	0	1	647	0.835	0	1
Single-unit firm [b]	6883	0.141	0	1	6236	0.139	0	1	647	0.164	0	1
Share of coal in electricity (%) [b]	6883	59.96	0	94.49	6236	60.28	0	94.49	647	56.87	4.426	93.24
Growth in coal (%) [b]	6879	11.07	-10.70	1076	6232	10.89	-10.70	1076	647	12.77	-0.111	116.7
HHI [b]	6883	0.072	0.011	1	6236	0.070	0.011	1	647	0.093	0.012	0.951

[a] Stringency is normalised with s.d. = 1, to allow more meaningful comparison.
[b] For time-varying covariates, summary statistics are for value at time of unit entry.
[c] Each row under "electric production type" describes a dummy indicating the type of producer listed.
Source: UDI's World Electric Power Plant Database (WEPP), March 2016 release.

Table 4.1 indicates that the populations of exiting and surviving units differ by individual controls. Exiting units tend to be smaller, are more likely to use lignite coal, and generally use less advanced boiler and turbine technology. They are also more likely to be owned by utilities, or single-unit firms.

Survival analysis with time-varying covariates requires the creation of a panel dataset. We therefore assume that unit-level controls, such as capacity and technology, do not change over a unit's lifetime, which is likely to provide a reasonable approximation to reality, since upgrading capacity or technology is expensive. Moreover, given the definition of our unit of analysis, expansion of capacity would likely be reflected in the creation of a new unit. It is assumed that a unit is active between the listed years of entry and retirement, and if the retirement year is missing, we assume that the unit remains operational. Construction of the single-unit firm dummy and HHI requires the assumption that a unit does not change ownership over its lifetime, which is unlikely to hold in all cases. For example, as a result of sale, privatisation or mergers and acquisitions a unit may have changed its parent company status over time, while only the last value will be reported in WEPP. At the same time, the validity of this assumption does not affect our main variables of interest or other controls. Both sector-level controls (HHI and share of coal in electricity) require the assumptions that (i) unit capacity is constant over time and (ii) the WEPP database provides complete coverage of the population of power plants.

For the empirical analysis, we include year fixed effects in order to account for temporal shocks common to all units, which may stem from factors such as business cycle dynamics (in particular the global financial crisis), global fuel price shocks or technological shocks affecting coal-fired generation. We include specifications with and without country fixed effects, since their inclusion has upsides and downsides. On the one hand, they capture all the other reasons why exit might be higher or lower in a country, across time. These may be related to e.g. electricity market liberalisation, political measures to support or discourage coal, or the extent of unionisation. Without country fixed effects, these factors could be incorrectly attributed to other country-level variables (including the variables of interest, stringency and CV). On the other hand, insofar as there are persistent differences between countries on these variables, their entire impact may not be captured in the presence of fixed effects.

5. Results

The results of the Cox regression provide strong evidence that vintage-based regulatory differentiation extends the lifetime of existing coal-fired plants. Our main specification is model (i) in Table 5.1, which includes country and year fixed effects. The negative coefficient on the interaction between vintage differentiation (CV) and the age-class dummy, which is significant at the 1% level, tells us that differentiation reduces hazard of exit for (older) existing plants more than for new plants. Multiplying the hazard ratios of CV and its interaction with the age-class dummy gives the overall impact of vintage differentiation on hazard of exit for existing plants: a one standard deviation increase in CV reduces hazard rate by 51%. Whilst the sign and significance of the coefficient on CV varies between specifications – for example comparing model (i) with model (ii) which excludes country fixed effects – increases in CV consistently reduce hazard of exit for existing plants. The results also prove to be robust across specifications using different age-class dummy variables (Table A.2 in the Appendix). Whether existing plants are defined as those over 20 years old, 40 years old, or any 5-year increment in between, differentiation is associated with greater survival rates for existing plants.

Table 5.1. Results for the Cox proportional hazard model

	(i) Country and year fixed effects			(ii) Year fixed effects only		
	exp (β)	β	z	exp (β)	β	z
Stringency	1.37	0.31**	2.00	1.09	0.08**	2.22
CV	0.86	-0.16	-1.43	1.13	0.12**	2.11
CV * Units older than 30	0.57	-0.56***	-3.88	0.73	-0.31***	-3.80
Capacity (MW) $^{\Psi}$	0.37	-0.99***	-10.23	0.42	-0.87***	-9.98
Coal type lignite	1.23	0.21	1.48	1.25	0.23*	1.66
Cogeneration technology	0.65	-0.43***	-3.23	0.52	-0.65*	-4.79
Steam type supercritical	1.69	0.53	1.48	1.30	0.26	0.63
Electric production type						
Autoproducer	0.39	-0.94***	-4.18	0.46	-0.78***	-3.68
Private power company	0.70	-0.35**	-2.00	0.75	-0.28*	-1.70
Single-unit firm	3.39	1.22***	6.36	3.03	1.11***	6.72
Share of coal in electricity (%)	1.21	0.19***	9.30	1.01	0.01***	4.64
Growth in coal (%)	0.92	-0.08***	-5.25	1.00	0.00	0.02
HHI	0.98	-0.02	-0.70	1.00	0.00	-0.18
Year fixed effects	yes			yes		
Country fixed effects	yes			no		
# of failures	532			532		
# of observations	4785			4785		

*p<0.10, **p<0.05, ***p<0.01 based on robust standard errors

Notes: The dependent variable is years of operation. A hazard ratio exp(β) above one implies a higher probability of failure (increase in the hazard rate), as does a positive β-coefficient.

$^{\Psi}$ Capacity is normalised with s.d. = 1, to assist interpretation of results.

Greater regulatory stringency increases hazard of exit, with significance at the 5% level in our main specification, according to which a one standard deviation increase in stringency increases hazard rate by 37%. This result is robust across all of the models tested. Control variables generally prove to be significant and of expected signs: Greater capacity and use of cogeneration technology both increase survival rates. Survival rates are also higher for units run by private power companies (compared to utilities), and higher still for units of autoproducers. Being the sole remaining unit of a company is associated with a threefold increase in hazard rate, a result that is robust across models (i) and (ii) and significant at the 1% level. At the country level, a greater share of coal in electricity production is associated with lower rates of survival, and growth in the coal-fired power sector is associated with improved survival, though this final relationship is not significant for model (ii).

Since the inclusion of a dummy for lignite coal reduces the number of observations from 6 644 to 4 785, we include results without the lignite dummy, as a robustness check

(Table A.3).[5] Comparing Table A.3 and Table 5.1 reveals that dropping the lignite dummy and thus increasing the sample size has little impact on the estimates obtained; the sign and significance of estimated coefficients are unchanged, though magnitudes change slightly. The same holds true when focussing on a limited sample that only consists of units belonging to utilities, and omits those belonging to autoproducers and private power companies (Table A.4). This entails a reduction of the sample size from 4 785 to 3 773 units. Coefficient estimates differ little from the main specification, with the exception of the dummy for lignite coal, which is associated with greater hazard of exit in the "utilities only" sample and significant at the 5% level. The extent of similarity with the main specification suggests that the observed relationships are driven by generating units of utilities.

To understand the economic implications of our results, we propose a simple quantification exercise to calculate the impact of vintage differentiation on plant lifetime. We adopt a Weibull model with two specifications: (i) including country and year fixed effects and (ii) including country fixed effects only.[6] Considering specification (i), coefficient estimates and significance levels are similar to the Cox model (Table A.5), which suggests that a Weibull-distributed baseline hazard provides a good fit for our data. A model without year fixed effects is included for the purpose of predicting lifetime of generating units, given different levels of differentiation. Unit lifetime is predicted based on the assumption that covariates are constant over time, so it does not make sense to include year fixed effects, which are designed to capture changes over time and are unpredictable themselves. The only major difference when excluding year fixed effects is a greater estimated effect of stringency on survival, though this inconsistency is not problematic because the aim of the exercise is to quantify the impact of differentiation, not stringency.

Figure 5.1 plots predicted lifetime against CV by percentile, based on the distribution of CV across countries in 2012. The example is based on a hypothetical representative generating unit, located in the USA with continuous covariates taking the mean value across units in the sample, and discrete covariates taking the modal value, at time of entry. The exercise looks at the effect of increasing differentiation on the predicted lifetime of this unit. Amongst the two-thirds of countries with some level of regulatory differentiation, the majority have a level such that unit lifetime is extended by 5-8 years; however, in the extreme case of the top 10% of countries, we see differentiation being associated with a lifetime extension by 8 to even 14 years. Another way to look at the predicted lifetime is with respect to hypothetical values of CV for the same representative unit. Translating the estimated coefficients for CV from the parametric hazard model into predicted lifetime reveals that a one standard deviation increase in differentiation leads, ceteris paribus, to an increase in lifetime of around 6 years.

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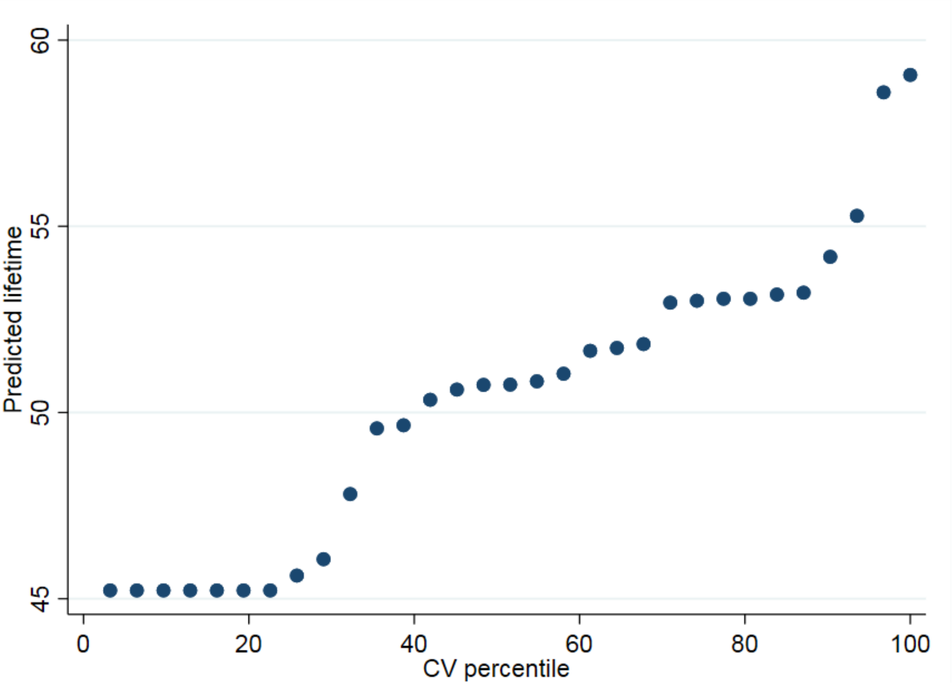
[5] The loss of observations is due to missing values on coal type for these units.

[6] To quantify changes in survival time associated with changes in covariates, we need to assume that the baseline hazard takes a particular parametric form. A baseline hazard that is increasing monotonically over time seems most plausible, since units will deteriorate – and their technology will become increasingly outdated – as time passes. Unlike in the case of firms, it does not make sense to think of generating units gaining experience with time, which might reduce the hazard of exit over some interval. The decision is in line with plots obtained for the hazard function from our main-specification Cox model and a series of Wald tests on the parameters of a generalised gamma model which rule out two nested models – lognormal and exponential. In addition, we apply the Akaike (1974) information criterion (AIC) to compare a wider selection of non-nested models, namely exponential, Weibull, Gompertz, lognormal, loglogistic and generalised gamma. The AIC points to the Weibull model.

Figure 5.1. Vintage differentiation and predicted lifetime of existing plants



Note: CV percentile is based on the distribution of CV across countries within the sample in 2012.
Source: Authors' calculation.

6. Simulation of environmental implications of vintage differentiation

How does the slow-down in capital turnover translate into environmental terms? Simulations based on the VDR-induced increase in lifetime of old, more polluting plants can provide an idea of the additional emissions generated and the trade-off between VDR and the stringency of norms. The basic formula for calculating the annual emissions for each plant is:

$$Emissions = Capacity \cdot Operating\ time \cdot Emissions\ factor$$

While the capacity of each unit is given, we assume the operating time to be 75% of full load (0.75 · 8 760 = 6 570) hours per year. For the emission factor of new plants, we take the value of the emissions limit for new power plants that was in place in that country in the year in which the plant became operational and apply the methodology proposed by EEA (2016).[7]

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[7] For obtaining the emissions factor, the emission limit needs to be multiplied by the dry flue gas concentration as well as by adjustment factors accounting for temperature, caloric value and oxygen level. While the dry flue gas concentration is given by $2.65 \cdot 10^{-7} m^3/J$, we follow EEA (2016) by assuming a temperature adjustment of 273/293, a caloric value adjustment of 1.05 and an oxygen level of 6%. For plants that entered when no regulation was in place, we take two times the average emission factor given by EPA Tier 1 methodology from 1998. These emission limits (expressed in g/GJ) are 418 (hard coal) and 494 (brown coal) for NO_x; and 1640 (hard coal) and 3360 (brown coal) for SO_x.

We predict the expected lifetime under the current policy scenario and under a scenario in which vintage differentiation is removed from 1988[8] – i.e. CV = 0 for 1988 and all subsequent years. In order to control for the scale effect we apply an adjustment factor that guarantees both capacity and electricity generation to be equal in both scenarios. This is equivalent to an assumption that the remaining plants under the "no vintage-differentiation" scenario are run more than normal hours in order to compensate for the earlier exit of the other plants relative to the other scenario. Using the results in the central scenario (CV interacted with a dummy for plants greater than 30 years), we find that the difference in stylised SO_X emissions that can be attributed to vintage differentiation is greater than 1.3% of the annual emissions in 2012 (0.6 % for NO_X). This is the average across countries, and in countries where VDR is higher the effects will also be larger. Notably, this result may appear in stark contrast to the findings of Ackerman et al. (1999), who find emissions to decrease by 75% after removing vintage differentiation. However, the prime difference and novelty of our paper is the use of empirical evidence on actual retirement decisions, and particularly the effects associated with both the pure stringency of regulations and those associated with vintage differentiation. In Ackerman et al. (1999) the simulation behind the removal of grandfathering is represented as an increase in the stringency for all existing plants to norms for new plants. In our approach this would manifest itself via an increase in the value of the stringency variable (to fully reflect that all plants have to comply with the most stringent norms) and setting VDR equal to zero. Doing so yields back-of-the-envelope estimates consistent with Ackerman et al. (1999) for the US. However, the approach adopted here allows for the establishment of an empirical estimate of the trade-off relationship between stringency and VDR. In order to assess the trade-off between VDR and policy stringency we undertake a similar exercise controlling for the absolute level of emissions. We fix emissions from 2012 (e.g. NO_X emissions = 10.6 Mio. tonnes[9]) and calculate any combination of stringency (or the emissions limit) and VDR imposed by each country that yields the same level of emissions as was observed in 2012. The intuition is that regulatory agencies face a trade-off between the level of stringency that they implement and the extent to which they favour existing plants relative to prospective new plants. Stated equivalently, the trade-off reflects the extent to which regulatory agencies "compensate" existing plants for increasing levels of policy stringency by giving them a degree of protection relative to prospective new plants.

Figure 6.1 provides graphical representations of this trade-off. For example, an average performance standard of 400 mg/m^3 of NO_X with CV equal to 1.0 would have the same air pollution outcomes as a more constraining standard of 200 mg/m^3, coupled with higher degree of preference for existing plants relative to new plants (CV = 2.0).

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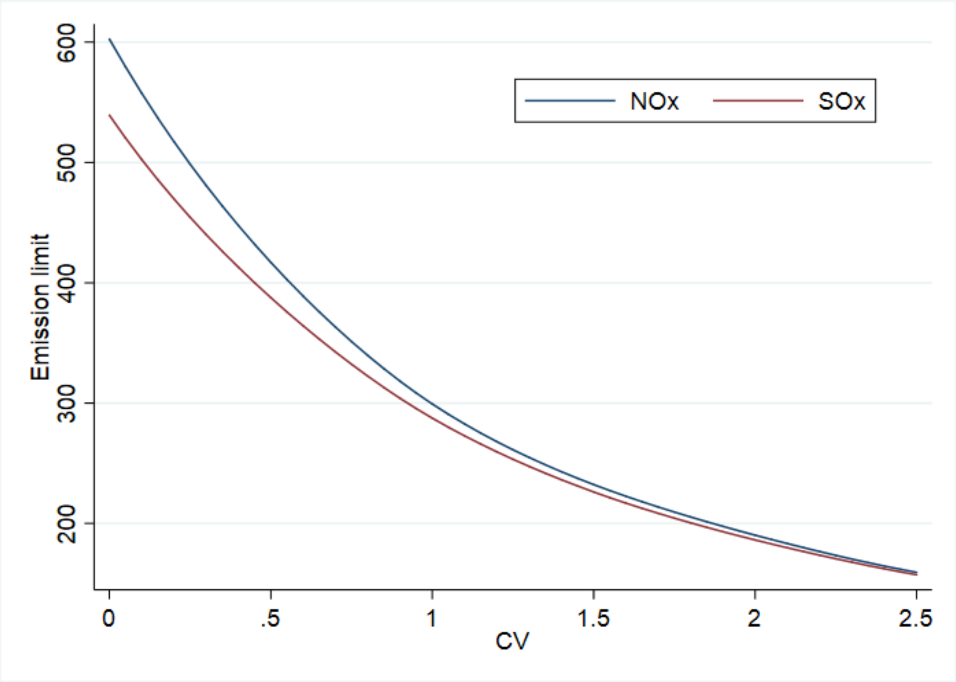
[8] The date was chosen to reflect the importance of allowing a period of time to elapse to capture the effect of policy settings on capital stock turnover. The precise year also coincides with the year in which the European Commission passed its regulation on large coal-fired plants.

[9] This value is derived from applying the emission factors used in our analysis to all power plants that actually operate in 2012 in our dataset.

Figure 6.1. The Trade-Off between Average Policy Stringency and Vintage Differentiation



Source: Authors' calculation.

7. Discussion and conclusions

This paper provides evidence consistent with a trade-off between policy stringency and vintage differentiated regulations in terms of the level of NO_X or SO_X emissions. Policy makers may achieve the same environmental outcome either by implementing a more moderate standard for both existing and new plants without differentiating between them or by setting a rather less demanding standard for existing plants, with more stringent standards for new plants.

Many of the lessons learned are also relevant for other policy instruments. For example, in emission trading schemes "grandfathering" of tradable permits to existing emitters is common. However, there is an important distinction in such cases. If free emission allowances are allocated upfront, existing plants which decide to cease operation can still cash in (at least some of) the value of the allowances received even if they close operations. The extent to which they are able to do so is a function of the details of policy design but creates an opportunity cost for survival.

Areas for further research could include:

- More comprehensive analysis of the effects of slowed capital and plant turnover on broader economic and environmental outcomes, e.g. in form of a life-cycle analysis;
- Analysis of VDRs in goods and services (i.e. product safety standards);
- The political economy of VDRs; and,
- Analysis of the impact of ownership (in particular state ownership, privatisation and mergers and acquisitions) on plant turnover.

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Annex A.

Table A.1. Exit by decade and country, and units per country, within estimation sample

	Exits						Total number of units
	1962 - 1972	1973 - 1982	1983 - 1992	1993 - 2002	2003 - 2012	Total	
Australia	0	0	9	7	15	31	131
Austria	0	0	0	0	0	0	16
Belgium	0	0	0	6	2	8	20
Brazil	0	0	0	0	0	0	25
Bulgaria	0	0	2	0	1	3	48
Canada	0	0	1	2	15	18	61
Chile	0	0	0	0	0	0	28
China	0	0	0	7	270	277	3131
Croatia	0	0	0	0	0	0	2
Czech Republic	0	0	1	10	3	14	101
Denmark	0	1	0	7	1	9	26
Finland	0	0	0	0	1	1	23
France	0	0	0	2	4	6	64
Germany	0	0	8	70	21	99	392
Greece	0	0	0	0	0	0	20
Hungary	0	0	0	0	1	1	24
India	0	0	2	8	17	27	1052
Ireland	0	0	0	0	0	0	4
Israel	0	0	0	0	0	0	10
Italy	0	0	0	2	3	5	44
Japan	0	0	2	2	3	7	172
Mexico	0	0	0	0	0	0	15
Netherlands	0	0	1	3	0	4	14
New Zealand	0	0	1	0	0	1	12
Norway	0	0	0	0	0	0	2
Poland	0	0	0	1	7	8	381
Portugal	0	0	0	1	0	1	7
Slovakia	0	0	0	0	0	0	25
Sweden	0	0	0	0	0	0	5
United Kingdom	0	0	2	22	4	28	98
USA	1	9	6	17	66	99	930
Total	1	10	35	167	434	647	6883

Source: UDI’s World Electric Power Plant Database (WEPP), March 2016 release.

Table A.2. Results for the Cox proportional hazard model, various age-class dummies

	(1)		(2)		(3)		(4)		(5)		(6)	
	β	*z*	*β*	*z*	*β*	*z*	*β*	*z*	*β*	*z*	*β*	*z*
Stringency	0.31**	1.97	0.30*	1.93	0.31**	1.98	0.31**	2.00	0.30*	1.82	0.29*	1.75
CV	-0.07	-0.26	0.13	0.70	-0.04	-0.30	-0.16	-1.43	-0.29**	-3.04	-0.39***	-4.12
CV * Units older than 15	-0.39	-1.55										
CV * Units older than 20			-0.65***	-3.68								
CV * Units older than 25					-0.58***	-4.09						
CV * Units older than 30							-0.56***	-3.88				
CV * Units older than 35									-0.69***	-3.44		
CV * Units older than 40											-0.79***	-2.64
Capacity (MW) Ψ	-0.99***	-10.16	-0.99***	-10.17	-0.99***	-10.20	-0.99***	-10.23	-0.98***	-10.14	-0.98***	-10.07
Coal type lignite	0.21	1.50	0.21	1.46	0.21	1.45	0.21	1.48	0.21	1.51	0.21	1.48
Cogeneration technology	-0.44***	-3.31	-0.44***	-3.31	-0.43***	-3.28	-0.43***	-3.23	-0.42***	-3.18	-0.43***	-3.23
Steam type supercritical	0.52	1.46	0.54	1.50	0.54	1.50	0.53	1.48	0.51	1.42	0.50	1.40
Electric production type												
Autoproducer	-0.91***	-4.11	-0.93***	-4.15	-0.94***	-4.18	-0.94***	-4.18	-0.92***	-4.09	-0.92***	-4.10
Private power company	-0.35**	-1.99	-0.36**	-2.05	-0.36**	-2.02	-0.35**	-2.00	-0.35**	-1.96	-0.35**	-1.97
Single-unit firm	1.21***	6.31	1.22***	6.35	1.23***	6.37	1.22***	6.36	1.21***	6.29	1.21***	6.32
Share of coal in electricity (%)	0.19***	9.45	0.19***	9.27	0.19***	9.23	0.19***	9.30	0.19***	9.24	0.19***	9.32
Growth in coal (%)	-0.08***	-5.40	-0.08***	-5.37	-0.08***	-5.31	-0.08***	-5.25	-0.08***	-5.44	-0.09***	-5.63
HHI	-0.02	-0.80	-0.02	-0.70	-0.02	-0.66	-0.02	-0.70	-0.02	-0.70	-0.02	-0.83
Year fixed effects	yes		yes		yes		yes		yes		yes	
Country fixed effects	yes		yes		yes		yes		yes		yes	
# of failures	532		532		532		532		532		532	
# of observations	4785		4785		4785		4785		4785		4785	

Notes: *p<0.10, **p<0.05, ***p<0.01 based on robust standard errors.
Ψ Capacity is normalised with s.d. = 1, to assist interpretation of results.

Table A.3. Results for the Cox proportional hazard model, without lignite dummy

	(i) Country and year fixed effects			(ii) Year fixed effects only		
	exp (*β*)	*β*	*z*	exp (*β*)	*β*	*z*
Stringency	1.30	0.26*	1.70	1.11	0.10***	3.19
CV	1.03	0.03	0.36	1.33	0.29***	4.91
CV * Units older than 30	0.48	-0.73***	-5.41	0.65	-0.43***	-5.35
Capacity (MW) $^{\Psi}$	0.43	-0.84***	-10.49	0.44	-0.83***	-10.92
Cogeneration technology	0.70	-0.35**	-3.13	0.59	-0.53***	-4.74
Steam type supercritical	1.22	0.20	0.53	1.08	0.08	0.20
Electric production type						
Autoproducer	0.31	-1.16***	-6.20	0.20	-1.62***	-9.22
Private power company	0.62	-0.49***	-3.25	0.65	-0.44**	-3.04
Single-unit firm	3.38	1.22***	7.49	2.69	0.99***	7.05
Share of coal in electricity (%)	1.15	0.14***	7.15	1.01	0.01***	3.87
Growth in coal (%)	0.93	-0.07***	-4.80	1.01	0.01*	1.83
HHI	0.99	-0.01	-0.28	1.00	0.00	0.14
Year fixed effects	yes			yes		
Country fixed effects	yes			no		
# of failures	643			643		
# of observations	6644			6644		

Notes: *p<0.10, **p<0.05, ***p<0.01 based on robust standard errors.
The dependent variable is years of operation. A hazard ratio exp(β) above one implies a higher probability of failure (increase in the hazard rate), as does a positive β-coefficient.
$^{\Psi}$ Capacity is normalised with s.d. = 1, to assist interpretation of results.

Table A.4. Results for the Cox proportional hazard model, utilities only

	(i) Country and year fixed effects			(ii) Year fixed effects only		
	exp (β)	β	z	exp (β)	β	z
Stringency	1.49	0.40**	2.26	1.20	0.19***	5.26
CV	0.82	-0.20	-1.51	1.12	0.11*	1.80
CV * Units older than 30	0.55	-0.60***	-3.52	0.76	-0.27***	-3.19
Capacity (MW) $^{\Psi}$	0.36	-1.01***	-8.95	0.40	-0.91***	-8.73
Coal type lignite	1.48	0.39**	2.48	1.61	0.48***	3.31
Cogeneration technology	0.63	-0.46***	-3.10	0.53	-0.64***	-4.54
Steam type supercritical	2.05	0.72**	1.98	1.81	0.59	1.36
Single-unit firm	3.48	1.25***	5.21	2.40	0.87***	4.22
Share of coal in electricity (%)	1.21	0.19***	9.05	1.01	0.01***	5.23
Growth in coal (%)	0.95	-0.05***	-3.26	1.02	0.02***	3.73
HHI	0.97	-0.03	-1.12	1.00	0.00	0.64
Year fixed effects	yes			yes		
Country fixed effects	yes			no		
# of failures	457			457		
# of observations	3773			3773		

Notes: *p<0.10, **p<0.05, ***p<0.01 based on robust standard errors.
The dependent variable is years of operation. A hazard ratio exp(β) above one implies a higher probability of failure (increase in the hazard rate), as does a positive β-coefficient.
$^{\Psi}$ Capacity is normalised with s.d. = 1, to assist interpretation of results.

Table A.5. Results for parametric survival model with Weibull-distributed baseline hazard

	(i) Country and Year fixed effects			(ii) Country fixed effects only		
	exp (*β*)	***β***	***z***	**exp (*β*)**	***β***	***z***
Stringency	1.33	0.29**	2.00	2.52	0.93***	6.13
CV	0.77	-0.26**	-2.52	0.80	-0.23***	-2.74
CV * Units older than 30	0.76	-0.27***	-2.75	0.76	-0.28***	-3.05
Capacity (MW) $^{\Psi}$	0.39	-0.94***	-8.86	0.51	-0.68***	-6.64
Coal type lignite	1.23	0.21	1.44	1.24	0.22	1.51
Cogeneration technology	0.65	-0.43***	-3.55	0.69	-0.37***	-3.08
Steam type supercritical	1.68	0.52	1.25	1.26	0.23	0.56
Electric production type						
Autoproducer	0.42	-0.87***	-4.11	0.50	-0.70***	-3.26
Private power company	0.73	-0.31*	-1.88	0.76	-0.28*	-1.66
Single-unit firm	3.51	1.26***	8.37	3.66	1.30***	8.68
Share of coal in electricity (%)	1.19	0.18***	10.93	1.10	0.10***	7.68
Growth in coal (%)	0.92	-0.09***	-5.85	0.92	-0.09***	-6.37
HHI	0.98	-0.02	-0.59	0.97	-0.03	-1.30
Year fixed effects	yes			no		
Country fixed effects	yes			yes		
# of failures	532			532		
# of observations	4786			4786		

Notes: *p<0.10, **p<0.05, ***p<0.01 based on robust standard errors.
The dependent variable is years of operation. A hazard ratio exp(β) above one implies a higher probability of failure (increase in the hazard rate), as does a positive β-coefficient.
$^{\Psi}$ Capacity is normalised with s.d. = 1, to assist interpretation of results.