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The effect of economic growth, oil prices, and the benefits of reactor standardization: Duration of nuclear power plant construction revisited

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HIGHLIGHTS

- We find that higher future economic growth speeds up nuclear reactor construction.
- Higher national capacity (measured by income per capita) results in faster projects.
- Higher oil prices during construction lead to faster construction times.
- Reactor standardization may result in faster building times.

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ABSTRACT

The profitability of nuclear power plant investment is largely determined by the construction duration, which directly impacts discounted cash flows, debt and interest payments, as well as variable costs, such as labor. This paper analyzes the key drivers of construction duration using survival models. We focus especially on the strategic expectation formation of private and public utilities engaging in such highly risky megaprojects. Using a balanced dataset of explanatory variables and the IAEA/PRIS dataset of reactor construction starts between 1950 and 2013 we find that the expectation of rising oil prices and higher economic growth, along with the higher per capita GDP of a country tend to reduce the time needed to grid connection. We also identify the reactor models with the fastest construction duration.

1. Introduction

The main legitimating rationale for constructing nuclear power plants in the face of geopolitical tensions and supply disruptions throughout the 1960s and 1970s apart from (energy) security considerations was to meet a continuous or even accelerating electricity demand. In this paper we argue that economic growth and the capacity of a country (Jewell, 2011) measured by income per capita, not only influenced the decision to engage in nuclear energy production, but also the speed with which nuclear constructions were finalized. While oil price shocks were not found to significantly impact nuclear energy consumption (Lee and Chiu, 2011) in the past, we show that continued high oil prices significantly influenced the speed of construction. As of June 1, 2015, 67 reactors were under construction worldwide,[1] with approximately 95 others planned, many of them in China and in Russia. The future of civilian nuclear energy among others crucially depends on the prospects of these projects.

Historically, many nuclear power plants proved to be megaprojects[2] (Sovacool et al., 2014; Sovacool and Cooper, 2013) with huge cost overruns and considerable delays in construction. Whereas financing organizations need precise schedules for calculating future repayment frameworks, a number of recent nuclear power projects ran over of planning horizons (eg.: Olkiluoto EPR, Finland; Flamanville, France), thereby running the risk of jeopardizing the survival of large companies, including utilities and construction companies, and negatively impacting on the energy supply security of a country.

We argue that the consideration of all past and currently operational reactors with respect to the construction time needed to

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[1] Source: https://www.iaea.org/PRIS/WorldStatistics/UnderConstructionReactorsByCountry.aspx, accessed on June 13, 2015.

[2] Flyvbjerg (2014) defines megaprojects as "large-scale, complex ventures that typically cost US$1 billion or more, take many years to develop and build, involve multiple public and private stakeholders, are transformational, and impact millions of people".

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grid connection helps us to create an objective indicator to assess their economic viability under different economic, political and technological conditions. Construction time (see Thurner et al. (2014)) is a major factor influencing the investment return of such megaprojects, as it determines the time until the first cash inflow, the length of the financed period including debt and interest payments, and gravely impacts on the variable costs of the project, such as labor expenses. The risks connected to economic and political costs, to damages caused by long construction times and to possible delays of nuclear projects therefore have to be hedged against properly, if nuclear power was to compete with other energy sources.[3]

Since nuclear construction projects require extensive financing for several years, utilities may not be able to bring up the necessary equity or secure institutional financing, or both, especially in developing countries. As a means of exporting its technology, Russia currently offers full state financing in building nuclear power plants in several countries, for example in Argentina, or for the Akkuyu nuclear plant in Turkey (Jewell and Ates, 2015). Likewise, build & operate agreements are at place in Sinop, Turkey to build a second plant by a Franco-Japanese consortium, to be operated by GDF Suez.[4] While the reason for Turkey and also for China to support the building of nuclear power plants is to meet their rapidly growing electricity demand, the United Kingdom with Hinkley Point C is merely replacing its aging fleet.

In liberalized markets however, mega-investments in nuclear power compete with alternatives such as gas power plants or renewable power generation, which need much shorter time until the investment breaks even. Mari (2014) notes that the main risks of nuclear power plant projects relate to the enormous up-front investment requirements, and to the uncertainties about costs and construction times. Heffron (2013) also argues that the cost effectiveness and investment risk of a nuclear power project is the major cause making new nuclear builds unattractive. At the same time Ahearne (2011) finds that the reluctance of US utilities to commit themselves to nuclear energy projects has more to do with the general economic situation in the United States than with the actual advantages or disadvantages of nuclear power “per se”.[5]

In addition to the relatively long estimated construction duration, megaprojects are characterized by both notorious delays, and considerable cost overruns (Flyvbjerg, 2014).[6] Because of the high rate of return demanded on both the debt and the equity of these risky projects, the generation costs may rise rapidly. Should however wholesale prices of electricity fall below the required level to repay the investment, the project could turn into a financial failure. Recent examples of massive delays in construction schedules include the Olkiluoto 3 EPR project in Finland, which is approximately 10 years behind its scheduled opening (Jolly and Reed, 2014), but also the Flamanville 3 ERP plant in France, which is currently estimated to be five years behind schedule (Matlack, 2015).

Thurner et al. (2014) argue that the poor prediction of the construction duration of nuclear power plants by practitioners so far not only impacts on the financial interest of the owners and operators of the plant, but may also endanger the energy security programs of entire nations. Therefore, quantifying the influencing factors of construction duration is not only of significance to owners and operators, but also to governments responsible for ensuring the electricity supply of a country, especially in countries without much excess capacity or alternatives. In the next decades up to 2040, approximately 200 nuclear power plants will be retired throughout the world (International Energy Agency, 2014). Whether these will be replaced by additional nuclear capacity, or by other forms of energy projects will depend among others mainly on the achievable return on investment, which is greatly driven by the construction time.

The focus of our paper lies on the influence of economic growth, national capacities and oil prices as the main factors in the expectation formation of actors, with respect to the urgency, economic pressure and financing possibilities to realize such projects. The impact of higher anticipated economic growth and higher achievable profits through energy prices should speed up the finalization of nuclear power plants. An additional major control variable will be a nuanced differentiation between reactor types in order to find out whether standardization and cumulated experience in large infrastructure projects lead to faster construction times.

This paper is organized as follows: Section 2 elaborates on the potential drivers of nuclear construction duration and presents our hypotheses. Section 3 presents our methodology, followed by our results in Section 4. In Section 5 conclusions and implications for the future of nuclear energy are drawn. Our data sources are presented in the Appendix.

2. Hypotheses: why engage in nuclear programs, and what determines the speed of its implementation?

When investigating the role of nuclear power in the energy mix of a country, there are two important questions to be asked: Why do countries engage in nuclear energy production in the first place? And: Can nuclear energy be competitive against other energy forms on its own?

Burke (2013) in his study of national energy ladders of 134 countries between 1960 and 2010 finds evidence for countries moving up the energy ladder as they become richer. This includes a transition from biomass towards fossil fuels and later towards nuclear energy and renewables, which are found at the upper rungs of the energy ladder. Similarly, Csereklyei et al. (2016) note that with the growth of GDP per capita, countries switch to “higher quality” energy forms. Increasing real income seems therefore a necessary, but non-sufficient condition for countries to engage in nuclear energy.

Jewell (2011) introduces a framework detailing the financial, institutional, and technical capacities necessary for a country to engage in nuclear energy programs. Only countries with high capacity and at the same time high motivation are likely to successfully implement nuclear energy programs. The motives of

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[3] Examples of such future hedging include among others government loan guarantees, fixed-priced contracts, and other policy support. A good example of government backed fixed-price contracts is the planned Hinkley Point C project in the United Kingdom, with a strike price of 92.5 GBP per MWh offered to EDF and a 10 billion GBP loan guarantee (Nelsen, 2014). The offer of the United Kingdom government was subsequently under investigation by the European Commission, to determine whether the contract violated the EU's state aid rules. However, in October 2014 the European Commission approved the project, with the reasoning that the market would not undertake sufficient investment in nuclear energy without the aforementioned state aid, nor would other forms of aid be sufficient to achieve this effect (European Commission, 2014). Further examples of risk mitigation may include fixed price construction contracts, where the costs of delays and overruns are born by the constructor (for example in Olkiluoto, Finland) or financing costs recovery during construction (for example Vogtle 3 & 4, USA).

[4] http://www.world-nuclear.org/info/Country-Profiles/Countries-T-Z/Turkey/.

[5] These theoretical framework conclusions were also found by the European Commission (2014) in the Hinkley Point C case, concluding that significant economic (high upfront capital costs, long construction times, and long operation times) and “political hold up” risk existed for nuclear investments. This, coupled with the lack of market-based financial instruments necessitated state aid to enable the investment at all, that the market would not have otherwise undertaken.

[6] The reasons for the escalating construction times are various, including (but not limited to) increasing technical complexity and the building of larger plants in general (Damian, 1992; Thurner et al., 2014). It is also caused by changing regulations, increasing or changing safety standards during construction (Ebinger, 2011), financing constraints (International Atomic Energy Agency, 2012), management failures (Ahearne, 2011; Kanter, 2009), or by the genuine pilot-megaproject nature of the investment and by delays in the regulatory process (Heffron, 2013).

countries possessing already the sufficient financial and technological background (Jewell, 2011) to engage in nuclear energy generation may include technological transfer amongst historical (Cold War) allies (Drogan, forthcoming) and current geopolitical interest driven technological transfer. Jewell (2011) notes however that politically-motivated generous and unconditional support from superpowers is nowadays less likely than during the Cold War.

Several studies have found empirical evidence for the influence of energy supply security (Fuhrmann, 2012; Miller and Sagan, 2009; Gourley and Stulberg, 2013; Goodfellow et al., 2011; Apergis et al., 2010; Lester and Rosner, 2009) and increasing energy demand (Csereklyei, 2014; Jewell, 2011) on the commencement of civilian nuclear programs. Connected to that notion, national security and greenhouse gas mitigation potential have been mentioned (Apergis et al., 2010; Goodfellow et al., 2011; Adamantiades and Kessides, 2011; Jewell, 2011; Baek and Pride, 2014; Sullivan et al., 2014; Socolow and Glaser, 2009) as potential drivers of nuclear energy generation. While the building of a nuclear infrastructure does require certain institutional and technical requirements in a country, Jewell (2011) finds that when nuclear weapons aspirations or capabilities accompany the quest for nuclear energy (or vice versa), resources for such programs can be summoned even in comparatively poor countries.

The second question regarding the competitiveness of nuclear energy under free market conditions depends on many factors, including but not limited to the incentivizing regulations surrounding the industry, and a stable, predictable legal framework for investors. Construction time, which is a crucial determinant of the general profitability of plants,[7] depends on a number of factors including the size and technical complexity of plants (Thurner et al., 2014), the authorization processes (Csereklyei, 2014), the experience of the builders (Boccard, 2014), the management of the construction itself (Ahearne, 2011), but also on financial, economic (Cohen, 1990; International Atomic Energy Agency, 2012) and regulatory factors,[8] and the capacities of the building country (Jewell, 2011).

In a recent contribution, Thurner et al. (2014) showed that at least in the West, average nuclear power plant construction times escalated during the past forty years. At the same time, nuclear construction duration seems much faster in Asian countries with 56 months median construction time.[9] Faster construction times may be one of the drivers, besides different ownership and financing structures, lower labor and engineering expenses and standardization, that lead to significantly lower construction costs of power plants in the Asia-Pacific region (Csereklyei, 2014). Higher standardization is connected to significant economies of scale (Joskow and Parsons, 2009), higher probability of discovery of mistakes, and in an accumulation of experience. This would imply that countries that actively steer and standardize their nuclear fleet composition and development such as France, China, or South-Korea are likely to achieve comparatively lower costs per unit of capacity (Morton, 2012). This paper tests a number of hypotheses about the determinants of nuclear power plant construction speed over and above the recently proposed explanatory variables by Thurner et al. (2014), which will serve as controls.

Nuclear power plants have been known to be built relatively fast during periods of high economic growth (such as the 2000s in China or the 1960s in the United States). At the same time economic downturns may negatively affect construction duration, and the economic viability of the investment. To test this hypothesis, we introduce the annual average of the 5-year-ahead economic growth in a country after the beginning of the construction, which is a good indicator of the economic development and conditions in a country, and indicates the availability of capital, and investment (for the finance-growth nexus, see Levine et al. (2005)), all of which are crucial in financing power plant constructions. Economic growth is also very strongly correlated with energy consumption, therefore a good indicator and proxy of energy and electricity consumption growth. In their metastudy, Bruns et al. (2014) find after the examination of the very large literature on causality between energy and economic output that GDP causes energy use when energy prices are controlled for. We choose five years, as this is the lower bound of the mean construction time of reactors, regardless of the region or type of reactor we examine. Therefore we expect favorable economic conditions during these five years to greatly enhance construction speed. While several studies found that nuclear energy consumption and economic growth had some form of causality between them, our results are the first investigating the nexus between economic growth and construction time.

Another equally important determinant of reactor construction duration that has not been investigated up to now is the development of international oil prices. Oil demand during the 1970s was largely inelastic, and only after the two oil shocks did Western economies embark on a transition to a less oil-fueled economy. At the same time the oil price has been steadily increasing for most of the first decade of the 21st century, which also coincidentally saw an increased interest in nuclear power, at least in Asia. While the price of fossil fuels may fluctuate in the market, nuclear electricity generation is possible at very predictable prices (and potentially higher profits, when the general cost of fossil-based electricity generation rises on free markets). Therefore we expect that the anticipation of continued higher oil (energy) prices generally may speed up construction time, in anticipation of future profits, as an economy switches away from oil based electricity production.

Undoubtedly, the oil crises of the 1970s have sent a shock through the economy of the Western Word, and while they raised legitimate energy security concerns, they have also resulted in a high inflation period that has done much harm to large baseload investments, and in an economic slump. Very importantly, we can thus distinguish two effects of high or rising oil prices: firstly, we expect shorter construction times, due to higher achievable profits and substitution away from oil, secondly we anticipate that higher oil prices negatively impact economic growth, which in turn slows down energy demand and the constructions of large projects. At the same time if continued growth also drives commodity prices, the impacts of high oil prices and sustained economic growth on reactor construction are additive. Therefore the impact of oil prices on

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[7] Construction duration in general is correlated with the total costs of the nuclear plant through later revenue inflows, higher financing and interest costs, and possibly through higher risk of inflation (Cohen, 1990). Investment decisions incorporate construction duration into the planned return on investment in the form of discounting and later cash flows. Not planned however, are the significant delays in construction, which might go hand in hand with the escalation of costs (Felder, 2013), even though Boccard (2014) demonstrates that the degradation of construction time must not mean higher reference unit costs for reactors in France. Contrary to Boccard (2014) are the findings of Koomey and Hultman (2007) who show a historical increase for total levelized busbar costs for US reactors, and of Grubler (2010), who even identifies cases of negative learning with respect to the French nuclear program.

[8] Just how important policies are, is demonstrated by the US Administration's advocacy of a clean energy standard (CES) which includes nuclear power (Felder, 2013). Sullivan et al. (2014) note the importance of the change in regulations (e.g.: 10 C.F.R. Part 52) to improve the efficiency and the predictability of the licensing process in the United States, leading to the possibility of a combined license. This allows reactor vendors to acquire design certifications and for developers to attain an early site permit and a combined construction permit and operating license. All of these regulations not only ease the administrative burden, but also contribute to faster construction times. Besides this, the US Department of Energy is a supporting research into advanced reactor concepts (US Department of Energy, 2015).

[9] Own calculation based on IAEA PRIS data.

nuclear construction duration is not intuitively clear, given these complex relationships. The purpose of this paper is not to disentangle the effect of economic growth and oil prices or *vice versa*, but to investigate which effect dominates. Similarly to economic growth, we choose the average five-year-ahead oil price as our explanatory variable. We also introduce the share of nuclear energy generation in the electricity mix, to control for the general reliance on nuclear energy, which is important when investigating the effect of oil prices on construction duration.

Analogously to Jewell's (2011) framework investigating the capacity of countries to engage in nuclear energy generation, we introduce PPP adjusted real income per capita as a similar measure of the capacity to implement nuclear programs rapidly. Lee and Chiu (2011) claim that as the long-run income elasticity of nuclear energy is larger than one, it is rather a luxury product. Burke (2013) also finds higher probability of increased investments in nuclear projects as countries get richer. The wealth of a country indicates that (utilities in) countries possessing the necessary financial and structural resources will be completing their projects faster. Therefore we would expect the same capacities that enable countries to engage in nuclear programs to complete them faster.

Accordingly to the above, we introduce the PPP adjusted real GDP per capita (Csereklyei et al., 2016; Jewell, 2011), the average 5-year-ahead real GDP growth rate at the beginning of a construction start, the 5-year-ahead oil price, and the share of nuclear energy generation in the electricity mix, as explanatory variables.

Another important achievement of this study is to empirically test the role of standardization on nuclear construction duration (Boccard, 2014; Joskow and Parsons, 2009; Ebinger, 2011). In France, China and the U.S., the strategy regarding reactor standardization was very different. While China and France embarked on building identical batches of reactors (French Court of Audit, 2012), in the United States new reactors were often of unique design. At the same time Boccard (2014) notes that the licensing of US technology in 1968 saved France the cost of developing a technology from scratch.

Therefore we identified from the IAEA PRIS databank 12 fine-grained groups (group of models) of nuclear reactors, all of them either pressurized or boiling water reactors, which account for almost 80% of plants currently in use. Using this finer categorization we would like to test the impact of standardization, economies of scale and construction experience accumulation on reactor construction duration. However, while the delays with the new ERP projects in France and Finland as well as with the Vogtle project (New York Times, 2015) might sound spectacular, all of these projects are “first of a kind” (FOAK) according to the International Energy Agency (2015), and thus represent the first nuclear build after several decades in Europe and in the United States. The IEA notes that much of the experience of the 1970s must be first regained, therefore it would be very misleading to generalize based on a few examples. We test for the first time in a large-N design, whether reactor standardization significantly speeds up construction times as we expect.

As controls we include the impact of energy import dependency as put forward in the recent paper by Thurner et al. (2014), the type of political regime, population density, regional differences, and reference unit power. Reference unit power[10] can be seen as a proxy for the size and complexity of a plant, while regional dummies cover for geopolitical differences in energy policy. Because we control for the time effect in our regressions, the reference unit power will act as a measure of complexity irrespective of the time trend observable in construction duration. We test the impact of political regimes, as public opposition towards the technology might be considered less in non-democratic countries. In addition, we investigate how the number of reactors in use and in construction, on the one hand account for the lock-in effect of nuclear energy (Csereklyei, 2014; Fuhrmann, 2012), on the other hand for increases in the demand for baseload power (Ebinger, 2011). We also control for the impact of nuclear accidents (Chernobyl and TMI).

As noted by several authors (Ahearne, 2011, Kanter, 2009) efficient project management and good quality control would be absolutely necessary to achieve planned or faster than average construction times. At the same time, the industry may be still plagued by weak management (Ahearne, 2011). Therefore we will elaborate on the importance of management issues in connection with reactor standardization.

3. Methods

We use duration models (Xiong et al., 2006; Finkelstein and Esaulova, 2006; Wang and Hu, 2006; Box-Steffensmeier and Jones, 2004) in investigating reactor construction times. The model measures the time (T) until a certain event occurs, such as the connection of a reactor to the grid. The detailed description and the source of the data used can be found in the Appendix.

We examine in total 709 reactor construction starts sourced from the PRIS (IAEA) database, which covers the large majority of commercial reactor construction starts in the world.[11] The dependent variable is defined as the time span for each reactor measured in months between the reactor's construction start and its grid connection date. Our data runs from 1951 to the end of 2013. As the fastest construction time ever measured was 22 months, we subtracted uniformly 18 months from the construction time of the reactors. We assume thus, that no plant is being built in less than 18 months. In the notation of the Cox model, we can say that the base line risk (of completion) is zero for this time. Furthermore, reactors, which are under construction for less than 18 months, because they cannot be realistically finalized as of 31.12.2013, carried no information content. It is practically impossible to finalize the building of a reactor under this time.[12] This resulted in the dropping of 17 reactors from the original sample. These are reactors, the construction of which started 18 or fewer months before 31.12.2013.

On the 31st of December, 2013, 55 reactors were still actively under construction (not including the 17 reactors), which we censored with the above date. These so-called “right censored” observations, meaning that we observe their construction start but they have their completion time beyond our observation period. Unlike in case of the 17 reactors we dropped, there was a realistic

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[10] “The reference unit power expressed in units of megawatt (electrical) is the maximum (electrical) power that could be maintained continuously throughout a prolonged period of operation under reference ambient conditions. The power value is measured at the unit outlet terminals, i.e. after deducting the power taken by unit auxiliaries and the losses in the transformers that are considered integral parts of the unit. The reference unit power is expected to remain constant unless following design changes, or a new permanent authorization, the management decides to amend the original value.” definition from https://www.iaea.org/PRIS/Glossary.aspx.

[11] We excluded from the dataset North Korea and Taiwan due to missing data in the explanatory variables.

[12] The results of the Cox model for the decreased sample however do not change, whether or not the 18 months are subtracted. This only matters for the exclusion of 17 reactors.

Table 1
Descriptive statistics of all variables.

Variable	Construction time	Population density	Energy import dependency	GDPpc
Type	Censored	Continuous with linear effect	Continuous with linear effect	Continuous with flexible effect
Min.	22.00	1.92	−100.00	786.90
1st qu.	56.00	22.13	5.54	9202.70
Median	72.00	96.38	19.69	16132.20
Mean	87.34	126.51	30.17	15177.60
3rd qu.	101.00	217.58	72.57	20763.40
Max.	493.00	506.51	90.79	32774.50

Variable	Year	In use	Under construction	Share of nuclear electricity generation
Type	Continuous with flexible effect	Continuous with linear effect	Continuous with linear effect	Continuous with linear effect
Min.	1.00	0.00	1.00	0.00
1st qu.	19.00	2.00	4.00	0.01
Median	25.00	11.00	10.00	0.03
Mean	27.55	17.53	19.61	0.08
3rd qu.	33.00	24.00	23.00	0.10
Max.	62.00	79.00	95.00	0.77

Variable	Reference unit power	5-year-ahead economic growth	5-year-ahead oil price
Type	Continuous with linear effect	Continuous with linear effect	Continuous with linear effect
Min.	0.00	−0.03	11.94
1st qu.	471.00	0.01	16.51
Median	890.00	0.01	44.41
Mean	767.30	0.01	47.46
3rd qu.	1020.00	0.02	72.30
Max.	1660.00	0.05	112.40

Variable	Regime	Chernobyl	TMI	Region
Type	Discrete	discrete	discrete	Discrete
#Obs	Anocracy: 29 Autocracy: 190 Democracy: 490	0: 660 1: 49	0: 556 1: 153	Asia: 165 America: 204 Europa: 202 East Bloc: 138

Variable	Reactor type	Reactor model	Reactor model cont.
Type	Discrete	Discrete	Discrete
#Obs	BWR: 135	APR&OPR: 14	M (2-3-4-loop): 21
	FB: 14	BWR(1-2-3-4): 45	other PWR/BWR model: 208
	GCR/HTGR: 56	BWR(5–6): 32	Others: 10
	LWGR: 30	CNP class: 11	P4: 20
	Others: 10	CP class: 36	PHWR: 64
	PHWR: 60	CPR-1000: 20	VVER V-320: 33
	PWR: 404	FBR: 14	VVER213_230: 38
		GCR/HTGR: 56	W (4-loop): 35
		LWGR: 30	W (1&2&3-loop): 37

chance that these reactors could have been finished by the end of our observation period. The descriptive statistics of reactor construction duration can be seen in Table 1.

In this study we use a multivariate Cox Proportional Hazards model (Therneau and Grambsch, 2000), to investigate the drivers of reactor construction times. The exact source and description of the explanatory variables is found in the Data Appendix, their descriptive statistics in Table 1. Generally we can say that the higher risk of an event (reactor grid connection) translates into shorter construction times. The hazard rate is defined as the conditional risk that an event occurs for observation "*i*", within the examined interval, given that this observation is still in the risk set. The model takes thus the following form:

$$\lambda\left(t, x_{i1},\ldots x_{i15}\right)=\lambda_0(t)\exp\left(\beta_1 x_{i1}+\ldots+\beta_{12}x_{i12}+f\left(x_{i13}\right)+f\left(x_{i14}\right)+f\left(x_{i15}\right)\right)$$

where $\lambda_0(t)$ is the baseline hazard, which is identical for all observations, but may change over time, and x is the vector of explanatory variables. The model assumes that the quotient of the hazard rate of two observations (i,j) for the covariates x_i and x_j is constant and not dependent on the baseline hazard.

We include in our model discrete factors, in the form of binary variables (reactor type, regime type, and continent), continuous variables with a linear or a flexible effect. Discrete variables are measured with respect to a reference category, where $\exp(\beta_k)$indicates the multiplicative change in risk compared to the reference category. In case of the continuous variables, $\exp(\beta_j)$ measures the *ceteris paribus*, multiplicative change of risk "j" as a response to a one unit increase in variable x_j. Flexible effects $f(x)$ arise in case of potential nonlinearities, and are addressed with penalized splines (Marx and Eilers, 1996), to estimate the smooth functions, with five degrees of freedom. The higher values of the function can be interpreted as lower construction duration.

4. Results

The Cox model was estimated with a total of fifteen variables including three discrete factors including regime type, geographical dummies and reactor types, ten continuous factors with a linear effect including the five-year-ahead economic growth, the five-year-ahead oil price, energy import dependency, population density, reference unit power, reactors under construction and in use, the share of nuclear energy in electricity generation (%), the Chernobyl, Three Mile Island dummies, and two continuous factors with a flexible nonlinear smooth effect, containing real GDP per capita, and the year variable.

We present two sets of results with (a) a more aggregate and (b) a finer reactor categorization, to account for accumulated experience in building certain reactor types.

4.1. Model with aggregated reactor types

Table 2 presents the results of our basic model. The results of the variables with flexible effects can be also seen in Fig. 1, as plots of the function $f(x)$.

Two important conclusions we can draw from the coefficient estimates of the variables with a flexible smooth effect is that reactor construction duration has continuously been increasing *ceteris paribus*, and that wealth levels matter. The wealth of a country, measured by the PPP adjusted real income per capita indicates that (utilities in) countries possessing the necessary financial and structural resources will be completing their projects faster. This supports the results of both Burke (2013), who finds higher probability of increased investments in nuclear projects as countries get richer, and of Jewell (2011), who notes that necessary technical and financial infrastructure must be present in order for countries to engage in nuclear energy. Apparently, the presence of such infrastructure, and the higher capacity of the country to implement nuclear projects also impacts on the speed with which these projects are likely to be completed.

Other crucial new insights relate to the five-year-ahead

Table 2
Cox model output: the determinants of construction duration.

	coef	se.coef.	p
Population density	−0.001	0.001	0.553
Energy import dependency	0.003	0.003	0.332
pspline(GDPpc_merged,df=5), li	0.000	0.000	0.000
pspline(GDPpc_merged,df=5), no			0.000
pspline(year1, df=5), l	−0.037	0.004	0.000
pspline(year1, df=5), n			0.000
TMI	0.329	0.290	0.257
Chernobyl	−0.147	0.253	0.562
Autocracy	0.197	0.399	0.622
Democracy	0.801	0.356	0.025
Type FBR	−2.040	0.415	0.000
Type GCR/HTGR	−1.184	0.320	0.000
Type LWGR	1.155	0.316	0.000
Type others	−2.021	0.426	0.000
Type PHWR	−0.547	0.254	0.031
Type PWR	0.030	0.145	0.837
Africa/Asia	2.501	0.425	0.000
West Europe	0.786	0.314	0.012
East Bloc	0.408	0.419	0.330
In Use	−0.008	0.007	0.234
Under construction	−0.016	0.006	0.003
Reference unit power	−0.001	0.000	0.004
5-year ahead economic growth	40.154	8.768	0.000
5-year ahead oil price	0.016	0.005	0.000
Share of nuclear electricity generation	−1.374	0.679	0.043

average economic growth and to the five-year-ahead average oil price, which are modeled as continuous factors with a linear effect. Both variables are *ceteris paribus* statistically significant, resulting in faster construction times.

The results support our previous hypotheses that future financing opportunities, the connected energy consumption growth, as well as a positive business climate, indirectly captured by economic growth during construction all make it likelier for a project to be completed faster. We present a number of examples in Table 3, displaying the effect of changes in economic growth on the expected construction duration of specific reactor types. We can see that for instance a 10% increase in the five-year-ahead average economic growth (for example from 1% to 1.1%) in the first year of construction reduces the expected construction time between zero and three months, everything else held constant. This, on the one hand emphasizes the importance of demand projections (especially baseload demand projections) for the future, but most importantly it signifies the importance of sustained financing and investment possibilities.

We may thus conclude that economic slowdowns or crises will negatively impact on the construction time of nuclear plants. For example the 2008–09 economic crisis may also have contributed to the delayed construction of mega-projects in the Western World, but possibly lesser so in China. Currently in China the operators of the plants are required to have more than a 50% stake in the plant, but the rest of the investment may come from government support, from provincial governments, national utilities, and local investment companies (Zhou et al., 2011). We have to mention however, that China was not massively hit by the 2008-09 crisis, which was more of a European/American phenomenon. Nor do we observe any significant delays in case of Chinese built power plants, while all currently built power plants in the European Union and in the United States show some degree of delay. While it is not possible to blame such delays exclusively on economic downturns and financing problems, they certainly contribute.

We also find that higher sustained and expected oil prices during construction will result in faster building times. While controlling for the impact of successive economic growth (or downturn), and the share of nuclear electricity generation, this might imply that if the prices of substitute energy carriers increase, investment projects in nuclear energy may be finished faster. Calculations detailing the expected effect of a 10% increase in the five-year-ahead average oil prices are shown in Table 3. If the average oil price of the next five years starting from the date of construction will be 10% higher, specific reactors are expected to be completed zero to seven months faster. Currently Lee and Chiu (2011) find that nuclear energy consumption and oil are substitutes in the U.S. and Canada, while they are complementary in France, Japan, and in the U.K. Toth and Rogner (2006) conclude that oil power plants are not any more in direct competition with nuclear energy, as they were in the 1970s. It is notable that the effect of the oil price does not however decrease over time, which might signal that oil prices work also as a proxy for general fossil fuel and commodity prices.

Therefore our results may be also driven by the period starting in the 2000s until the Great Financial Crisis, which saw not only increased oil prices but also increased prices of all commodities

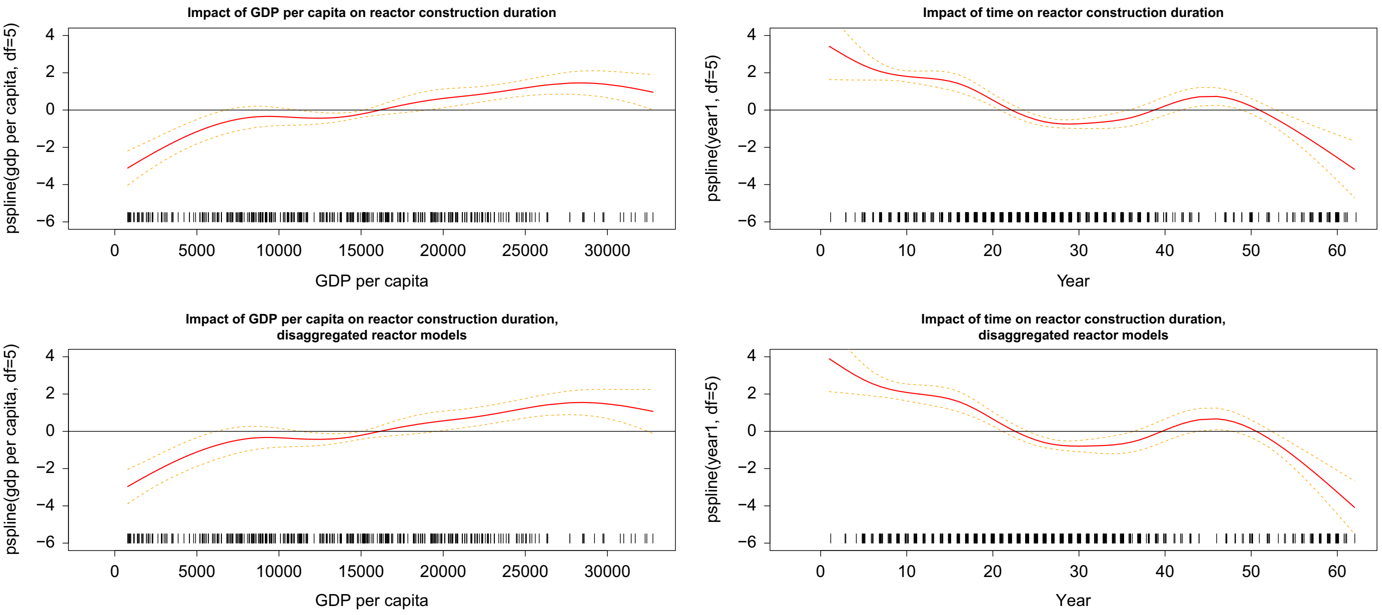

Fig. 1. Estimated effects of variables using P-splines.

Table 3
The impact of economic growth and oil price changes on the construction duration of specific reactor models.

	Model	Construction year	Country	Real construction time	Expected constr. time (month)	Expected constr. time (5-year-ahead economic growth increases 10%)	Expected constr. time (5-year-ahead oil price increases 10%)
1	CP class	1971	FRA	68	67	67	67
2	CP class	1980	FRA	73	74	73	71
3	BWR(1-2-3-4)	1973	USA	109	129	128	126
4	BWR(1-2-3-4)	1976	USA	126	148	145	140
5	BWR(5-6)	1977	USA	106	145	143	136
6	CPR-1000	2006	CHN	60	67	65	65

and energy carriers, along with relatively rapid nuclear plant constructions in predominantly Asian countries. As far as oil prices can be regarded as a proxy for general energy price developments, they may indicate the influence of anticipated energy prices on the construction duration of energy-investment projects. This must be interpreted with caution however, as both coal and gas markets may exhibit local (rather than global) characteristics.

Similarly to Thurner et al. (2014) we do not find the impact of energy import dependency significant.[13] Many studies found energy dependency as a driver initiating nuclear plant construction, and of engagement in nuclear energy (Csereklyei, 2014; Fuhrmann, 2012). While energy security is a strategic concern for many states, and higher state support (whether in the form of authorization, state guarantees, financing or ownership) might result in the commencement of a nuclear construction in the first place, it does not seem to influence construction duration. Examining our other political variables modeled as discrete factors, compared to the reference category of anocracy, we find that both democracies and autocracies show slightly faster construction times. The results are however only significant for democracies. Population density was not found to be a significant driver of reactor construction duration.

To examine geographical patterns, we chose as the reference category America[14] (including both North America with 194 reactors, Central America with 4 and South America with 6 reactors). Compared to the American median duration time of 84 months[15] (which is dominated by the United States and Canada), all continents exhibit significantly faster construction times, and even the East Bloc states are at the same median level with 84 months. This phenomenon may be attributed partly to the decentralized authorization procedure and the many differing reactor models (Ebinger, 2011), but also to the fact that the United States pioneered civilian nuclear engineering, and thus many countries in the world later profited from the experience gained by the US (Boccard, 2014). This has saved likely both development costs and time for other states. Changed safety requirements and canceled projects in the wake of Three Mile Island may also have contributed to this number. Currently Asia exhibits regionally the fastest construction duration with 56 months.

Besides financing and external factors such as energy prices, technical, managerial factors and accumulated experience also greatly influence the success and the duration of a megaproject, like a nuclear reactor. Firstly, we use reference unit power to measure the complexity of the project. Reference unit power exhibits a negative impact on construction duration while we control for a general time trend, as expected in light of the evidence on megaprojects (Flyvbjerg, 2014).

Total reactors in use, reactors under construction, and the share of nuclear power in the electricity mix account for accumulated construction experience on one hand, and for the reliance on nuclear energy on the other hand. The coefficient on the share of nuclear generated electricity is negative. Similarly, the more reactors are under construction the slower the building process seems. Thurner et al. (2014), who found similar results explained this on one hand with higher visibility of the projects and thus resistance, and on the other hand with partially achieved energy security. Additionally, supplier delays such as currently witnessed both at the Finnish and French EPR project might also become a contributing factor (Jolly and Reed, 2014). What we do not see here however, whether the reactors under construction are identical batches, or many different types. Another reason might be thus, that the results are dominated by the United States with the largest number of and most heterogeneous reactors worldwide.

We examine different construction duration of broad reactor types in an aggregated manner with boiling water reactors as the reference category. We can see that with the exception of light water graphite moderated reactors all other groups have higher construction times. Graphite moderated light water reactors were Soviet built RBMK reactors, the most prominent of which is found in Chernobyl. Famous nuclear accidents were again and surprisingly not found significant in influencing construction times. While evidently enormous delays followed both the Three Mile Island and the Chernobyl accident, the nuclear industry was already struggling with overcapacity and cost escalations before Three Mile Island in the United States (Csereklyei, 2014; Thurner et al., 2014). Cohen (1990) argues that TMI just finished what stagflation and the unfavorable economic situation has started. From our results it seems that economic factors and the development of international resource prices had a more significant influence on construction duration than the new safety regulations following the accidents. The next section of this paper is going to look at the results of finer reactor modeling closer.

4.2. Model with disaggregated reactor models

To test the hypotheses whether experience with a certain reactor type leads to faster construction, we categorized reactors into fine-grained model types that have been grouped together based on their technical characteristics. The exact description of these categories is found in the Appendix. The results of the new Cox model can be seen in Table 4.

As a reference category we took General Electric's BWR (1-2-3-4) loop reactors. These boiling water reactor models were very popular during the 1960s and 1970s, and a total of 45 reactors were built in the US, Japan, India, Switzerland, Taiwan, and in Italy. Save for a few examples, all other types took longer to build, or the difference in construction time compared to the reference group was insignificant. It becomes also immediately obvious that the

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[13] One outlier value, in case of Iran in 1975 was trimmed from -969 to -100. Without this trimming the import dependency variable would be significant.

[14] The geographical and reactor type reference categories were chosen in a historical context and relate to each other. In the early days of civilian nuclear power the United States emerged as a technological leader, thus the choice of the American designed BWR 1-2-3-4 General Electric reactors as a technological, as well as the choice of America as the geographical reference category.

[15] Representing the actual values without subtracting 18 months.

Table 4
Cox model output: the determinants of construction duration (with exact reactor models).

	Coef	se.coef.	*p*
Population density	0.002	0.001	0.051
Energy import dependency	0.002	0.004	0.537
pspline(GDPpc_merged,d*f*=5), li	0.000	0.000	0.000
pspline(GDPpc_merged,d*f*=5), no			0.000
pspline(year1, d*f*=5), l	−0.043	0.005	0.000
pspline(year1, d*f*=5), *n*			0.000
TMI	0.351	0.330	0.287
Chernobyl	−0.307	0.227	0.175
Autocracy	0.228	0.455	0.616
Democracy	0.707	0.527	0.180
Model APR&OPR	−0.321	0.395	0.415
Model BWR (5–6)	−0.249	0.249	0.317
Model CNP Class	0.760	0.617	0.218
Model CP Class	0.635	0.291	0.029
Model CPR-1000	1.323	0.713	0.063
Model FBR	−2.335	0.549	0.000
Model GCR/HTGR	−1.573	0.378	0.000
Model LWGR	1.150	0.472	0.015
Model M (2-3-4-loop)	0.306	0.424	0.470
Model other PWR/BWR	−0.454	0.238	0.057
Model others	−2.159	0.472	0.000
Model P4	0.378	0.280	0.177
Model PHWR	−0.680	0.303	0.025
Model VVER V-320	0.503	0.600	0.402
Model VVER 213-230	−0.130	0.386	0.736
Model W (4-loop)	−0.716	0.190	0.000
Model W (1-2-3-loop)	0.000	0.257	0.999
Africa/Asia	1.905	0.402	0.000
West Europe	0.355	0.296	0.230
East Bloc	−0.039	0.530	0.942
In use	−0.007	0.008	0.352
Under construction	−0.017	0.005	0.001
Reference unit power	−0.001	0.000	0.039
5-year ahead economic growth	35.022	8.696	0.000
5-year ahead oil price	0.014	0.005	0.002
Share of nuclear electricity generation	−1.323	0.898	0.141

French built reactor batches including the CP class exhibit faster construction times at the 5% level than the reference category, as does the Chinese built CRP-1000 model at the 10% level, which was originally developed from the CP class French reactors. Other Chinese reactors (CNP class) are also built – albeit insignificantly – faster, while the construction on the French P4 class seems also faster, but the results are not significant. This supports the claim of Joskow and Parsons (2012) an the conclusions of Boccard (2014), that France reached economies of scale with standardization, and also accumulated experience and speed in constructing identical reactors.

The South-Korean APR and OPR reactors are on the other hand built slower, even though the results are not significant. Westinghouse's newer PWR models have significantly higher construction times, while the earlier PWR models showed very little difference to the GE BWR models. Japan's M (2-3-4) loop reactors would also show a faster construction time, however the coefficient is not significant. We mentioned France, China, and South-Korea as examples of countries where the nuclear program is relatively standardized. After a detailed examination of the exact reactor types, we can however only distinguish significantly faster construction times compared to the reference BWR category in the case of the French, and partially the Chinese nuclear program. This indicates that other factors, such as experience with the same supplier/builder within a same country (Smith and Rose, 1987) and management factors (Ahearne, 2011) are also expected to influence construction time.

In sum, this shows that a country might gain a strategic advantage through reactor standardization from the beginning, but likely only if the accumulated experience is with the same supplier/buyer. None of the other variables change significantly after controlling for the detailed reactor groups. We also conducted a robustness check eliminating the first of a kind reactor within each group in each country, which resulted in the dropping of 102 reactors from the sample. However the main conclusions of our study do not change.

5. Conclusion and policy implications

While the reasons for countries to engage in, or to support nuclear programs are various, especially in today's liberalized energy markets, nuclear energy is facing massive challenges (Felder, 2013), due to its required enormous economies of scale, large up-front investment costs and long-construction times, therefore comparatively long and inherently more uncertain returns on investments (Mari, 2014).

The future of civilian nuclear power faces different questions in countries with existing nuclear capacities and in countries potentially engaging in nuclear energy use in the future. In the existing nuclear states most of the plants were built during the 1970s and 1980s. Even with granted lifetime extensions, the majority of these power plants will have to be decommissioned in the next decades. According to the International Energy Agency (2014) this impacts approximately 200 reactors in Europe, North America, Japan and Russia in the period up to 2040. Whether these decommissioned nuclear plants will be replaced by new nuclear capacities or by other forms of energy is an open question, because especially in liberalized markets, nuclear energy will be competing with renewables, coal, or gas plants. Some countries such as Germany clearly positioned themselves in favor of a renewable energy future (Wittneben, 2012). Other countries may act differently. Goodfellow et al. (2011) note that a key driver of UK nuclear power is the shut down timescale associated with the existing fleet of plants. It is likely that newcomer states currently engaging in nuclear power or in the future will likely have to draw on the experience of other established nuclear states such as France, Russia, or China or South Korea.

Much of the decision to engage in, or to redeploy nuclear power will depend on the profitability of the sector (Ahearne, 2011), which is greatly influenced by the expected construction duration. In the face of spectacular delays with new mega-construction projects in Europe, the International Energy Agency (2014) remarked that much of the experience gained during the construction of the 1970s, will have to be regained. We saw that the key factors influencing reactor construction duration are among others the wealth and capacity of a country, future economic growth, and expected oil prices (energy prices). Reactor standardization may speed up construction times, but only if additional factors such as a same supplier-buyer relationship and good management are present.

A strategy of standardization may be therefore of importance in the future for any country pursuing nuclear power on a large scale. Simultaneously, government support programs, guarantees, or carbon pricing would be essential for nuclear energy to become a profitable player on liberalized markets. Selfevidently, finding solutions for waste-disposal and addressing the question of potential proliferation (Miller and Sagan, 2009) continue to be pressing issues.

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Data Appendix

Reactor construction duration information

Reactor construction and duration information comes from the IAEA's PRIS database from 1950 to 2013.

In addition to that, we use a balanced dataset of explanatory variables between 1950 and 2013.

Real GDP per capita on PPP terms

In comparing real income per capita of countries, it is highly recommended to account for differences in price levels. We use PPP adjusted real GDP per capita from the Penn World Table 7.1, (Heston et al., 2012). The PWT 7.1 databank starts for most Western European countries and some North- and South American countries in 1950, however for most Eastern European countries only in the 1990s. For these countries, we sourced the PPP adjusted real GDP per capita for the years before 1990 from the Maddison Project Dataset (Bolt and van Zanden, 2013). As the Maddison Dataset (Bolt and van Zanden, 2013) includes data in real 1990-dollar terms, we converted it to real 2005 dollars to assume compatibility with the PWT 7.1 and the World Bank datasets.

For the years 2011–2013 we calculated the PPP adjusted data by taking the PWT 7.1, 2010 values, multiplying them with the World Bank's economic growth rates for the subsequent years (The World Bank, 2014). This way we assumed no change in purchasing parity terms over these 3 years, but accounted for economic growth. In certain cases such as for Cuba, and for the United Arab Emirates, where no World Bank data was available for parts of the period 2011–2013, we took the last available growth rate (2010 or 2011) for all following years. The GDP per capita data is thus a merged database consisting of the Maddison Project (converted to 2005 terms), PWT 7.1 (2012), and The World Bank, (2014) data. We calculated the GDP in real 2005 USD by multiplying the GDP per capita series with the population from the PWT 7.1 database between 1950 to 2010, and from the World Bank database from 2011 to 2013.

5-year-ahead average economic growth

We calculated the economic growth rate based on the real PPP adjusted GDP numbers, with the log method. For 1970, this is the average growth rate of the next five years:

$$gY_{t\rightarrow 5}=\frac{(\log Y_{1974}-\log Y_{1970})}{4}$$

For the last 4 years we have reduced this gradually to a 4, 3, 2, and 1-year average.

5-year-ahead average oil prices

The price of crude oil in 2013 dollars was taken from the British Petrol's (2014) Statistical Review of World Energy, the average is calculated similarly to the 5-year-ahead average economic growth.

Share of nuclear power in electricity generation

We use the IAEA's data on (the share of) nuclear electricity generation in all countries with civilian nuclear power plants before the year of the construction start. The data runs from 1965 to 2013. Nuclear electricity use in all countries before 1965 was allocated based on the annual cumulative capacity of reactors from the PRIS database. We assumed the same electricity generation per unit of capacity for 1950–1964 as in 1965, therefore the changes in nuclear power usage only reflect the changes in grid connected capacities. While this might not be absolutely correct, we judged the resulting bias less then excluding the years without the data altogether.

Population density

The population density data of the World Bank starts for most countries in 1961 and for Belgium in 2000. Assuming no territorial changes, we took the area of a country based on the 2011 World Bank data, by dividing the 2011 World Bank population by the 2011 World Bank population density, and thus arriving to the area of the country. This was then applied to the PWT databank (minor discrepancies exist between the population numbers of the PWT databank and the World Bank). The PWT population between 1950 and 1960 was then divided by the land area of the World Bank, to receive the population density for the first decade of our dataset. The data are very similar in all, but one case. For Pakistan the differences in population were so significant, that we took the 1961 calculated area based on the PWT dataset (PWT population in 1961/World Bank population density) and calculated the population density of the previous years based on this starting area value.

Energy dependency

The energy import dependency data of the World Bank, measured as net energy imports in % of energy use was only available from the 1960s or 1970s for most countries, thus leaving approximately 10–20 years uncovered in the panel data. Data for the ex-Soviet states was not available before 1990. We calculated energy dependency data for the U.S.S.R. (including the same data for all of its successor states) based on the Directorate of Intelligence's (1990) Soviet Energy Data Resource Handbook from 1970 to 1988, and based on the U.S. Bureau of the Census (1991) USA/USSR Facts and Figures publication for 1989. Energy dependence was calculated as net imports (imports–exports) in % of the total primary energy consumption.

To deal with further missing data, especially during the beginning of the period, we estimated the average 20-year annual change in energy dependency in the years first available, and estimated the previous periods based on these growth rates. The annual growth rates were between −3% and +3% on average, with some extreme values. For Argentina, Iran, Mexico, Romania, South-Africa and the United Arab Emirates we took the annual average over 40-years to avoid bias from short term fluctuations. Eventually missing values in 2012 and 2013 were not calculated with growth rates, but the last available (usually 2011 or 2012) value was taken.

Democracy data - Polity4 database

We source data from the Polity4 database (Marshall et al., 2014), taking the Polity2 variable. For Japan we allocated the value of +10 for 1950 and 1951. For Hungary, we allocated −7 in 1956 as the Hungarian Revolution of 1956 only lasted a few months, and the dataset marks it as transition period, similarly we allocated −7 for Czechoslovakia in 1968. We assigned the value of 0 for Russian in 1991, and 7 for Slovakia in 1992. For the United Arab Emirates we allocated −8 for the entire period, based on the Polity IV 2014 Country Report between 1970 and 2014 (Marshall et al.). Successor states of the USSR were allocated the USSR scores between 1950 and 1990.

Reactor types

The categorization of different nuclear reactor types into main models serves the purpose of determining whether building experience with certain types of models reduces construction time (standardization), and if yes, how much. As pressurized water (PWR) and boiling water (BWR) reactors constitute the majority of the operating power plants worldwide, we divided these categories into major models. At the same time these results have to be viewed with caution, as even for the same reactor models national requirements might vary. Therefore economies of scale are the likeliest to be realized by same models within the same country.

Newer PWR models under construction or planned for construction, such as the AP1000, or the European Pressure Water Reactor (EPR) are impractical to be included as no experience, or very limited experience is available on completed operating reactors.

The major groups of PWR and BWR models, with several operating plants worldwide are as follows:

- **CPY class reactors:** These French EDF operated 900 MWe PWR reactors were commissioned and built in France during the 1970s and 1980s (CP0, CP1 and CP2) with a total of 36 reactors belonging to the category (from that 34 in France). The design was also exported to South Africa (2), and further developed in China.
- **P4 class reactors:** The 1300 MWe PWR French-built reactors were constructed in the years following the CP class reactors. In this category we combine the P4 and P′4 types, but not the N4 type reactors. A total of 20 reactors were built in France.
- **CPRs (1000):** The Chinese built reactors were initially developed from the CPY class French reactors, at the time of the writing of this paper only 8 CPRs were in operation, and further 14 were being built in China.
- **CNP 600 and CNP300:** These reactor classes are of Chinese construction (CNNC), with currently five reactors in operation and 2 in use.
- **VVER 440/213, 440/230:** VVER pressure water reactors were developed in the former Soviet Union. Earlier 440–230 models were characterized by the lack of quality instrumentation, control and data processing, little automation, by the lack of a full pressure containment, and a full capacity emergency core cooling system (Böck, 2011). VVER 440–230 models were subsequently not permitted to operate in the European Union. Currently 38 reactors have been built or are under construction (some of them abandoned in construction.)
- **VVER 320/1000:** Newer VVER models include several VVER 1000 or 1200 types (referring to the capacity), under construction in Russia and several countries, including the Czech Republic, Bulgaria, and the Ukraine. VVER 1000 types already include a full pressure containment and an appropriate emergency cooling system. Earlier or later VVER models (such as VVER 428 models currently being built in China) were not considered, due to the low number of observations.
- **OPR and APR:** These South Korean built PWR 1000MWe reactors (OPR) and 1400MWe (APR) reactors are two-loop Korean designed units, based on the American (C–E) design. From the 19 units 6 are currently under construction, three of those in the United Arab Emirates.
- **W1, W2, W3, Westinghouse:** The 1, 2, or 3-loop Westinghouse Reactors were built in the USA, Japan, Switzerland, Belgium, Sweden, and Spain during the 1960s and 1970s. All reactors are finished, the category includes 37 reactors.
- **W4 (4-loop) Westinghouse:** Most of the 35 4-loop PWR reactors were built in the United States, with the exception of 2 reactor units in Japan and 1 in Italy during the 1960s and 1970s.
- **M2, M3, M4:** The Japanese pressure water reactors were exclusively built in Japan during the past 40 years, the first construction start being in 1968 and the last in 2004.
- **BWR (1-2-3-4) models:** The boiling water reactor models of General Electric, were very popular during the 1960s and 1970s, and a total of 45 reactors were built in the US, Japan, India, Switzerland, Taiwan, and in Italy. Very closely related to this design were the BWR5 and BWR6 class models of GE.
- **BWR (5–6) models:** These boiling water reactors built between the 1970s and the 1990s were a later class models of GE, popular in the US, Switzerland, Mexico, and especially Japan. All constructions in the 1980s and 1990s of the models took place in Japan.

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