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Backstop technology: model keystone or energy systems transition guide

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Few papers by young academics have been as influential on energy economics as 'The Allocation of Energy Resources' by William Nordhaus (1973). To me, the influence of Nordhaus' work causes mixed feelings. His 'backstop technology' concept is a source of inspiration. Although mainly used as keystone to seal his model, his square choice for nuclear power as backstop supply was unfounded. The enduring influence of 'econometric-engineering' models on public energy policy-makers often precludes a necessary broader decision-making approach.

Eye catcher and eye opener

'The Allocation of Energy Resources' was published in 1973 at the right time, was launched at an outstanding forum (Brookings Institute), and was refereed and discussed by a panel of highly respected experts. The fertile sowing ground was receptive for Nordhaus' fresh and ambitious addressing of the USA's major and painful energy questions at that time: Will oil scarcity cause economic doom? Is saving oil (and other fossil fuels) desirable, viz. necessary? Is USA oil autarky a recommendable target? In a period of much confusion and debate, the young economist provided clear 'NO' answers, backed by his 'econometric-engineering' model. By today's data availability, processing capabilities, and methodological refinements, the 1973 model is a simple one. Also, the analysis supported by the model was limited. Although the overall scope was global, very long-term and multi-sector supply and demand, the detailing of several crucial components remained poor. For example: 'A serious practical problem is Nordhaus' assumption that all demand elasticities are zero' (p. 572, Houthakker); 'Environmental constraints could embody a significant cost and their exclusion from the model is unfortunate' (p. 574, Solow). Also, markets and policy sector interactions, assessment of energy supply technologies, contentious aspects of nuclear power, non-hydro renewable energy, demand side and energy end-use efficiency, … were all issues under debate at that time in the USA (Daly, 1973; Freeman et al., 1974), but not taken up by Nordhaus. Several criticisms are repeated here, not for blaming the contribution by the young academic, but as warning for reckless use of unbalanced economic logic and recommendations.

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Essay in honor of William Nordhaus' 1973 contribution to the energy economics profession.

Precarious 'econometric-engineering' models

Nordhaus stepped over the limitations of his analysis and model in his search for answers on the major energy questions confronting the USA constituency and policy-makers. Although the models of the twenty-first century are far more extended and sophisticated, 'stepping over' remains accepted practice. Two issues are highlighted here.

Long-term scenarios versus consecutive recommencing

Nordhaus' temporal forward perspective runs through four 50-year periods, with the year 2170 as the end of the study period. I skip the discount rate problem (Lind et al., 1982; Portney & Weyant, 1999), and discuss backstop technology later, and focus on how the model incorporates future timelines.

Nordhaus (1973, p. 536) mentions 'myopic decisions' as 'possible complication', with: 'In the present context "myopia" means that the planning horizons of economic agents are relatively short'. Shortness in forward looking by most economic agents (and politicians!) is real because it corresponds to individual efficient behavior. Modelers extrapolate evolutions very far in the future, beyond the capacity of human control and imagination. They project scenarios, as would the future follow today's script within predictable and orderly environments. Real life at personal, community, national and global levels is regularly disrupted by unforeseen events and developments. Understanding what is going on today is already a hell of a job; it is impossible to foresee what will occur in the next century, neither is it necessary in a numerical sense. Processing future time as a sequence of relatively short (for example 5 or 10 years) time slots is the appropriate substitute for prolonged scenarios. Then, one deals with 'myopia' not as a 'possible complication' but as a natural phenomenon: life is a consecution of rather short-running periods. The present is not only today's present, but over and over again the beginning of every new future period, considering the accumulated history and adapted expectations and plans for the future.

Time sequential analysis was at the core of decision analysis theory deployed in the 1960s. Its concepts and rules penetrated public decision-making slowly, for example, as quasi option theory (Arrow & Fisher, 1974). Dixit and Pindyck (1994) discussed time sequential analysis in investment theory. In the 1990s USA scholars employed decision theory for finding the proper pace of mitigating carbon dioxide emissions from combusting fossil fuels (Kolstad, 1996; Manne & Richels, 1991). Nordhaus (2013) shared in the debate with his Dynamic Integrated model of Climate and the Economy (DICE) model.

Models are helpful tools when applied within their proper context, respecting limits on human foreseeing imposed by distant time, uncertainty, ignorance, and irreversible processes. When the latter conditions prevail, models often turn into concealing the impossibility to know the unknown. However, this impossibility is no one's responsibility and is better recognized than obscured. Decision-making processes other than cost–benefit based model logic are more apt to deal with contentious choices stretching awesomely far in the future (Ethics Commission on a Safe Energy Supply, 2011).

Uniformity versus specificity

In 1973, Nordhaus had the ambition to cover the supply side and demand side of the energy markets. He stated: 'Unfortunately, the calculation required to get the answers is extremely complex. Since there are many sources and grades of energy resources, many uses, and many demand categories, each with peculiar specifications, calculation of the optimal and the switch points for different resources is cumbersome' (Nordhaus, 1973, p. 537). Nordhaus experiences that the real world is fully diverse, and that diversity is cumbersome to fit in economic models. Economic model results remain contingent on many simplifications and assumptions embedded in the models. Economic theory adopts uniformity as a key attribute for increasing efficiency, whereas diversity is considered as costly (Weitzman, 1992). The lack of specificity in economic analysis and modeling creates problematic failures. For example, most model algorithms juxtapose low-carbon electricity supply capacities or deliveries (in case: nuclear and renewable flow supplies like wind, photovoltaic power, non-dam hydro), notwithstanding ample logical and practical evidence that they are mutually exclusive (IEA [International Energy Agency], 2013; Verbruggen, 2008).

Yet, since the 1970s the economists' modeling discourse has grown overly influential. For example, in the latest Intergovernmental Panel on Climate Change (IPCC) Working Group III report (IPCC, 2014) integrated assessment models play a predominant role.

Backstop technology

The 1973 events in global oil markets were mainly an overnight quadrupling of crude oil prices, with repositioning of power among countries on a scene of warfare between Arabic countries and Israel, and of Western concerns about limits to growth. Oil prices and depletion of fossil fuel, in particular oil, resources were focal points of societal debate and of academic research.

Nordhaus presented an inventive coupling of both issues. He writes the price of oil as the sum of the marginal cost of oil extraction plus royalties 'which are a reflection of the presumed scarcity of a particular resource' (Nordhaus, 1973, p. 531). The scarcity price would rise exponentially at the interest rate (for a given resource base in a world of certainty), and its use would run unto 'a time horizon of T years', with as footnote: 'The terminal point can be a sticky issue. If there exists what I later call a "backstop technology" (roughly, a substitute process with infinite resource base), then T is the time at which transition to it is completed; if resources are finite and essential, and no backstop technology exists, T is the time of extinction'. He continues (p. 532): 'Over the next century or so, many low-cost energy resources will be largely depleted, leaving more abundant but also more expensive resources. Ultimately, if and when the transition is completed to an economy based on plentiful nuclear resources (either through breeder or fusion reactors), the economic importance of *scarcity* of resources will disappear, and capital and labor costs alone will determine prices. This ultimate technology—resting on a very abundant resource base—is the "backstop technology" and is crucial to the allocation of scarce energy resources'.

By the ingenious concept of 'backstop technology' Nordhaus is, presumably unintended, an early prophet of the transitions movement (www.transitionsnetwork.org). Modern energy system transitions are pushed not by fossil fuel scarcity but by limited atmospheric capacity in greenhouse gas emissions assimilation without irreversible climate change impacts. Striking innovations in renewable energy technologies and in end-use energy efficiency further pull transitions forward. Overall, where in practice the transition from fossil fuels to low-carbon backstop technology is ongoing (Germany is an example in case, see Agora Energiewende, 2013), the experiences reveal an opposite reality as the one projected by Nordhaus' long-term model scenarios. Major differences are highlighted here.

First, there exists no constraining scarcity in fossil fuel resources. Contrary, there are massive reserves and resources that have to be kept underground when carbon dioxide emissions mitigation is organized to keep global temperature increase below 2°C with safe likelihood (IEA, 2013; IPCC, 2014).

Second, environmental issues, receiving minor attention by Nordhaus in 1973 (this fully changed afterwards, e.g., Nordhaus, 2013), are actually determining which energy technologies are acceptable by developed societies. The energy systems' future must match the imperatives of sustainable development (World Commission on Environment Development [WCED], 1987). Energy is an important, yet subordinate part of the sustainability paradigm, in 1992 at the Rio Summit, globally accepted by the world leaders.

Third, technological innovations were the most dynamic and to a large degree unpredictable (r)evolutions, shaping the post-World War II economies and societies, also supporting their globalization. Technological innovation is the determining factor of making energy transition paths, yes or no, economically feasible. Nuclear power, the technology favored by Nordhaus as the backstop solution, has not delivered. Renewable energy technology, ignored by Nordhaus, did surf on the most successful innovation waves: electronics, IT, special materials, and so on.

Fourth, energy end-use efficiency has brought more productivity and comfort, with less energy input than the consumptive USA lifestyle in the postwar decades. Nordhaus opened his 1973 paper with 'abundant energy at low cost is fundamental to a high-industrialized economy like the United States' (p. 529), and in his model demand price elasticity was set at zero. Disregarding half of the market, the demand side, distorts the analysis and results.

After 1973 another world has taken shape, more in the direction of cross-views developed by mainly non-economists (e.g., Freeman et al., 1974; Lovins, 1977), than along the engineering-econometric model projections. This is illustrated by the substitution of renewable energy for nuclear power as backstop technology, and by the prominent role of end-use energy intensity at the demand side.

Figure 1 shows the major components of the energy demand and supply context. Gross Domestic Product (GDP) is the sum of spending on numerous (priced) activities, being generic or specific. The activities are assigned to various sectors, and their performances require a set of energy services. Energy intensity expresses the quantities of energy used in creating value hold by the activities.

There are three energy supply sources: renewable, nuclear, and fuels (fossil and bio). Electricity is the major conveyor of commercial end-use energy, converted from the three supply sources. When nuclear energy is assigned the backstop role, electricity obtains a pole position in the analysis, because commercial nuclear energy is limited to power generation. Renewable energy is a versatile energy source, with direct energy services (e.g., daylight, natural ventilation), delivery of biofuels, input for electricity generation, low-carbon and truly inexhaustible.

Nordhaus (1973) presented nuclear power as apparent backstop energy supply technology with little consideration of its technological attributes and its real performance. However, his referees Houthakker and Solow ventilated criticisms, in particular on breeders, for Nordhaus being the ticket to inexhaustible supplies. Already, before 1973, evidence accumulated that nuclear power was not delivering, and was subject to major, costly risks. Breeders failed in the USA (in 1966, meltdown at Fermi-1, Michigan) and in Europe (Superphénix, Kalkar).

In 1973, Solow (p. 574) labeled fusion and solar power as 'really exotic energy technologies'. Indeed, nuclear fusion is energy Eden on Earth whose advent is receding

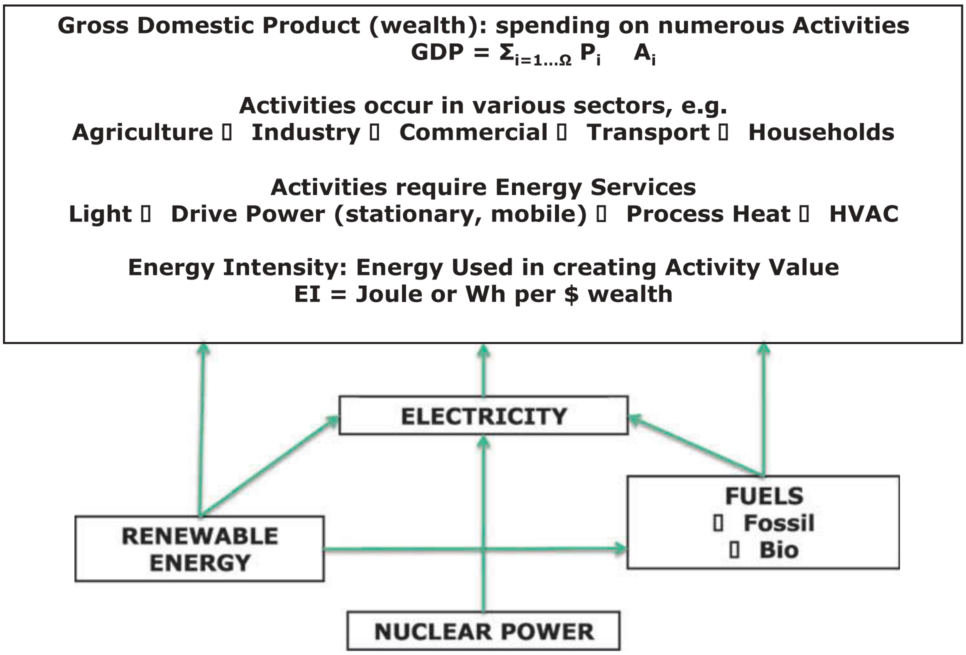

Figure 1. (Colour online) Economic activities linked to energy services and energy supplies.

with time elapsing. Contrary, after too long smoldering, solar power witnessed technological breakthroughs and falling production costs (IPCC, 2012).

Nordhaus' nuclear backstop technology was unilaterally positioned at the energy supply side as a horizontal line (inexhaustible supplies) and at a high unit price. Only when fossil resources became scarcer, their sloping-up marginal cost line would hit the horizontal ceiling line, triggering the transition. Exclusive attention for nuclear shrinks the analysis to electricity supplies. Figure 2 shows the horizontal supply curve with Electricity Intensity as demand variable dependent on the kWh price. Based on panel data of the most wealthy Organization for Economic Cooperation and Development (OECD) countries, Verbruggen (2006) found that $EI = \alpha.P^{\beta}$ with $\beta \approx -1$, or $EI \times P \approx$ the constant α, indicating the share of GDP spent by a country on electricity supplies. Given the panel statistics cover limited ranges of price and intensity data, the observed section of the orthogonal hyperbole curve $\alpha.P^{\beta}$ is a limited segment of the cross-sectional long-run relationship. Assuming the curve can be extrapolated, the abscissa of the crossing point S is called the 'backstop electricity intensity', where the rectangle with diagonal OS reflects α. Economies performing low electricity intensity maintain their shares of GDP spent on electricity supplies constant; what makes the transition to backstop supplies affordable.

Further, Verbruggen (2006) extended the conditions for a backstop supply technology from only inexhaustible to fully sustainable in the basic meaning assigned by the UN World Commission on Environment and Development (WCED, 1987). In addition, evidence is established that the backstop supply curve is not a fixed horizontal line, but shifts by learning and experience. Here again, nuclear power is losing ground compared to renewable energy. Grübler (2010) shows how the cost–price curve of nuclear power is increasing over time, plagued by 'negative learning'. The cost–price curves of

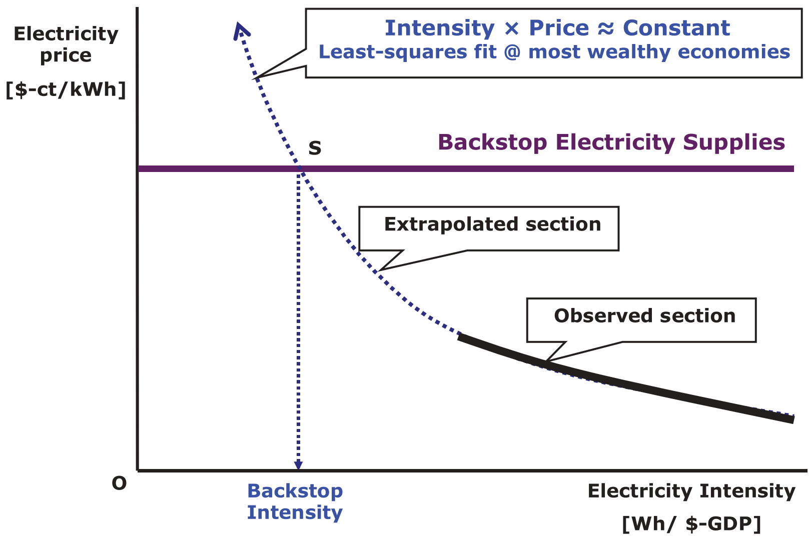

Figure 2. (Colour online) Backstop electricity intensity makes backstop electricity supplies affordable.

flow renewable energy supplies (mainly wind and PV-solar) are quickly decreasing (IPCC, 2012). Decreasing backstop supply costs and prices can accept higher electricity intensities with easier affordability of the energy transitions.

Epilogue

Transition of the energy systems of the world is climbing on the global agenda, mainly pushed by the risks of irreversible climate change. Nordhaus (1973) pioneered the transition concept by introducing 'backstop supply technology'. Nuclear fission (stranded, exhaustible (American Nuclear Society, 2001)), and ramping up costs (Grübler, 2010), breeders (tested, and failed) or fusion (stays in the announcement phase with receding horizons of availability) are no valid options in realizing the urgent transitions. With sustainable development adopted as global paradigm in 1992, the backstop technology also should meet the criteria of such development (WCED, 1987). Nuclear is failing on most criteria (Verbruggen, Laes, & Lemmens, 2014). Renewable energy is ready to fill the gap (IPCC, 2012).

The concept of backstop energy supply can be combined with the demand-side concept of backstop energy-use intensity, with the role of electricity intensity growing in importance.

Disclosure statement

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