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Editorial

Robert B. Wilson - Beyond the 2020 Nobel prize for economic sciences

1. Introduction

What looks like a puzzling dilemma to the buyer and the seller of a common object — whose value is uncertain beforehand but, in the end, is the same for everyone — makes a fascinating problem to Robert Wilson, who won the 2020 Nobel Prize in Economics for his contribution to the theory for auctions with a common value. The insights from the theory led to better auction format designs for natural resources and commodities such as offshore oil tracts, radio spectrum and electricity. The seminal work enables traders in the marketplace to understand and avoid the winner's curse dilemma in such auctions. However, while the Nobel Prize recognizes Wilson's direct contribution to auction theory, an important part of his legacy are his contributions to the theory of nonlinear pricing and power market design which can be viewed, broadly speaking, as an outgrowth and extension of his auction work. This article provides a glimpse of his important contributions to the theory of nonlinear pricing and power market design in ways that illuminate, though only partially, his huge legacy. The electric power industry, and the world, is clearly better for his work.

2. How it began

With the great fortune and privilege as his student (one of us), colleagues and friends, we have a longstanding relationship in working closely with Robert (Bob) Wilson for over forty years. In late 1970s, we met Wilson separately at Stanford and the Xerox Research Center in Palo Alto, California. In 1977, at Stanford, Wilson was a member on Hung-po Chao's doctoral thesis committee chaired by the late Professor Alan Manne. In 1982, they jointly published a paper on the MCW algorithm for computing competitive equilibria which was applied to economies with exhaustible resources or constraints under climate change uncertainty (Chao et. al, 1982). In 1979, Wilson met Shmuel Oren and Steve Smith at Xerox where they started studies on pricing strategy. The work focused on markets with interdependent demand and network externalities and on product differentiation in telecom. (Oren et. al, 1982a, 1982b, 1984). In 1983, we ran into each other during a seminar at the Stanford Operations Research Department where Chao was discussing his work on peak load pricing and capacity planning with demand and supply uncertainty. Subsequently, Oren and Wilson as well as Smith regrouped with Chao then at Electric Power Research Institute (EPRI) to explore collaboration on the pricing work. Since 1984, with Chao at EPRI, the collaborative work has taken off with a new focus on the electric power industry. During this period, the power industry was undergoing restructuring under significant influence from the global movement of market liberalization that fundamentally changed the regulatory and business landscape of the electric power industry. To highlight Wilson's legacy, selected works are discussed below in three topical areas: 1) rate design: demand subscription pricing, (Chao et. al, 1986a, 1988; Oren et. al, 1985, 1987) 2) service design: priority service methods, (Chao and Wilson, 1987, 1990; Wilson, 1989a,b, 1993, 1997, 1998a,b; Chao et. al 1986b) and 3) market design: architecture of power markets. (Wilson, 2002a; Chao and Wilson 2002, 2005; Chao et. al, 2000; Chao et. al, 2006, 2008)

3. Theory and practice

As plainly explained in the monumental book Wilson (1993), nonlinear pricing works in practice much like a product line or service menu that allows each customer to choose preferred quantities or qualities and pay the associated prices. In the power industry, nonlinear pricing is a common practice as an integral part of long-term power supply contracting. Two-part tariffs are commonly used by regulated public utilities to recover fixed capital costs. The two-part tariff structure allows tradeoffs between the high capacity cost and low variable operating cost for capital-intensive baseload generating units and the low capacity cost and high variable operating cost for peaking units.

Nonlinear pricing has been used in various forms in both regulated and competitive industries to differentiate or 'unbundle" quantity and quality increments. Its implementation relies on the knowledge of the distribution of price elasticities that can be estimated from the demand profile data. The optimal nonlinear price schedule for a competitive profit-maximizing firm optimizes the marginal prices charged for each increment in the purchase size. The optimal nonlinear price schedule for a regulated firm, or Ramsey pricing, maximizes the aggregate of consumers' net benefit subject to recovery of the firm's full cost. Compared to uniform pricing, nonlinear pricing increases net customer benefits while meeting the same revenue requirements. In other words, it provides a regulated firm an efficient way to earn sufficient revenue to recover its full costs. This is known as the Ramsey pricing principle.

4. Multi-level demand subscription pricing

Oren et al. (1985) investigate capacity pricing, or the optimal design of a two-part Wright tariff with a fixed demand charge based on maximum demand for capacity plus a variable rate for energy consumption. Under the condition with synchronous customer demand profiles, the optimal two-part tariff achieves the same efficient capacity investments as does the optimal time-varying peak-load pricing. For electric rate design applications, the above condition could become restrictive in large-scale power networks, as diverse customers create the widespread phenomenon of non-coincident peak loads.

Chao et al., 1986a investigate a general formulation of multi-dimensional pricing, called multi-level demand subscription pricing with a menu of service options for assigning different interruption probabilities. This is a justified generalization as multi-level demand subscription pricing is compatible with economical system operations and

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optimal capacity investments in the presence of diverse generating technologies and load profiles on a large-scale power network. A general policy form for the optimal price schedule is derived in a way that can be practically implemented under broad conditions.

Oren et al. (1987) investigate a general formulation based on multi-product pricing in which electricity is characterized by multiple product attributes including maximum capacity, energy usage, time of use and the contracted interruptibility level of the service. The optimal price schedule is based on essentially the same principles of nonlinear pricing for competitive and regulated firms. A significant feature of the optimal multi-product price schedule is its strong dependence on the quantities of other products each customer purchase.

Multi-level demand subscription pricing presents a general framework for designing retail tariffs though practical implementation of the underlying concepts that relies on technologies that were not commercially viable in the 80's.

5. Priority service methods

Chao and Wilson (1987) and Wilson, 1989a investigate the theory of priority service pricing as a tool for electric service design. Priority service refers to an array of contingent forward delivery contracts offered by a seller. Each customer's selection of one contract from the menu determines the customer's service order or priority. Priority service pricing is a special form of service differentiation that expands an essential quality dimension of electric service. Reliability has been one of the most important criteria that measure the quality of electricity service. Priority service methods leverage the diverse customer values for reliability by designing service offers that enable utilities to offer plans more responsive to customer preferences leading to the prospect of transforming system reliability which has traditionally been treated as a public good into a private good. The key idea is to unbundle the basic electricity service into a menu of contract choices giving customers an opportunity to select from the menu plans that are more closely aligned with their individual preferences for reliable services. For instance, some customers may be willing to tolerate the inconvenience of more frequent power interruptions in exchange for a lower price, and others would be willing to pay a premium for even more reliable service than regularly provided. In each contingency, the seller rations supply by serving customers in order of their selected priorities until the supply is exhausted or all customers are served. Further efficiency gains are obtained if a customer can adapt the end-use technology to the option selected.

The electric power industry represents an ideal candidate for implementing priority service. In part, this is because recent advances in the microelectronic technologies of metering, control, and communication have made it feasible. In theory, priority service provides a unified construct that is closely related to three distinct types of economic activity: 1) product differentiation, 2) rationing, and 3) spot and future markets. Besides its theoretical justifications of product differentiation, the construction of priority service contracts in terms of service orders has practical aspects as an efficient form of rationing. Aspects of priority service typically are embedded within any auxiliary futures contracts and other contingent forward contracts. Priority service is a way for electric utilities to ration scarce supplies under emergent contingencies unequivocally more efficient than random rationing. For instance, if the priority service premia are refunded equally to customers as dividends, then the priority service is Pareto superior to random rationing, as prescribed by the Ramsey pricing principle.

Compared with spot pricing, priority service is an innovative form of contracting that reduces the transaction cost of market organization. Priority service offers the advantage of yielding important information about the distribution of customers' valuations that can be used to guide capacity planning, while this information is unavailable from the observed choice behavior of customers in a spot market. That is, a spot market is essentially an algorithm to determine an efficient allocation in a particular contingency, namely, the particular maximum reservation price to be served in that contingency. In contrast, the process of self-selection among priority service contracts enables the seller to infer the allocation rule for every contingency. Although spot pricing is used in wholesale markets for bulk trades among power producers, proposals to use spot pricing in retail markets have not been as successful. A common explanation for the lack of success in retail markets is that customers want prior assurance about what their monthly bills will be. One advantage of priority service pricing is that it enables supplemental insurance provisions to be incorporated into the contracts. When the role of customers' risk aversion is recognized, efficient risk sharing requires that any form of market organization be accompanied by insurance provisions. If, as seems realistic, the producer or a third-party underwriter is the most efficient bearer of risk, then the efficient insurance contracts cover all or most of the customers' risk. With perfect insurance (i.e., offered at actuarially fair premia) the efficient incentive scheme entails allocation of supplies according to customers' valuations of service.

6. Architecture of power markets

In his 1999 Presidential Address to the Econometric Society (Wilson, 2002a), the title of the speech was “architecture of power markets,” which conveys double meanings for the word “architecture”. Its first meaning refers to the structural features of a market. Its second meaning refers to the professional discipline for market design using economic theories and practical skills as tools. In essence, this landmark paper describes an expanding role for economist as an engineer for market design with practically useful tools and capabilities developed from game theory and its derivative theories of incentive and information. This paper discusses three issues. It begins with the overall market organizations: an integrated system and an unbundled system. Next, it discusses microstructure of forward and spot markets. Lastly, it summarizes central lessons from California crisis on the allocation of risk.

In power markets, with pervasive network externalities and continuous balancing needs, it is not feasible to rely solely on spot markets to meet security requirements. Moreover, in a short time frame, spot markets are vulnerable to localized market power due to technical rigidities. Therefore, markets are necessarily incomplete. In practice, two main organizational forms that have been in use include an *integrated* system that relies to a significant extent on system operator for tight control and an *unbundled* system that relies to a much less extent on system operator and more on markets for voluntary coordination, and the system operator's authority to manage transmission and real-time energy balancing is expected to have minimum intrusion into forward markets. Integrated systems have been adopted by the power markets in the Northeastern U.S., include ISO New England (ISO-NE), New York ISO (NYISO) and to a lesser extent Pennsylvania-Jersey-Maryland (PJM). Unbundled systems have been adopted by Australia, Scandinavia, Texas, as well as California's old system during 1998–2000 and Britain's new system that began in 2001. Were markets complete and perfect, it follows from the principle of primal-dual equivalence that the two systems would achieve the same performance. When competitive forces are weak and designs ignore incentives, no system can assure performance.

An integrated system features a unified market, including both real-time operations and forward planning to assure adequate installed capacity. The objective is to maximize the gains from trade as measured by the market surplus based on the submitted costs and values or when the demand side is not included or demand is inelastic, minimizing the total cost of serving customer loads. In contrast, an unbundled system features transparent price formation, as every price can be contested by competing offers. In principle, unbundled markets solve the dual of the primal optimization used by integrated systems. However, the devil is in the details. An unbundled system's multiple markets for each of the various resources require explicit specifications and market clearing prices. Unbundled markets are judged deficient when they are incomplete and loosely coordinated. Incomplete markets are explicit in unbundled systems but implicit in integrated systems.

The initial experience justifies integrated designs as incumbent's long-term hedging or vesting contracts induced strong incentives for maximizing outputs and producing low spot prices. Nonetheless, when competitive forces are weak, designs that ignore incentives are vulnerable to manipulative bidding. The only alternative is strong regulatory enforcement. In integrated systems, price formation is essential for its incentive effects. Absent strong incentives to ensure that bids reflect actual costs, cost minimization is a fiction. Price formation is distorted when optimization is imperfect such as ignoring non-convex costs, imperfect generator modeling and optimization with a rolling horizon that ignores contingencies. Integrated systems usually spread the uncovered start-up costs over all participants in the form of “uplift” charges. In some cases, prices are related vaguely to optimized shadow prices on scarce resources or reserve prices are calculated ex post to justify what actually occurred. Integrated systems are judged deficient when optimization models are incomplete.

Combining the features of integrated and unbundled system, a hybrid system relies on firm transmission rights in ways that enhance market completeness and foster unified markets leading to enhanced price formation. In the spot market, all aspects are consolidated. The forward markets comprise separate markets for energy, transmission and reserves. A main deficiency in the current power market design is the lack of energy and reserve options on the demand side. The transmission pricing reflects nodal price differences including the marginal congestion costs and marginal losses. In energy markets, sophisticated trading arrangements and activity rules for auction design would enhance intertemporal and spatial considerations to be factored in the market clearing process. Lastly, a central lesson from the California crisis is the critical role of risk allocation in restructuring power markets. Retail sector must be prepared for the downstream impacts of competitive wholesale markets. Utilities can offer a variety of retail options that induce price-responsive demand behavior. Beyond these obvious lessons, there is the deeper problem of restructuring the regulatory compact to overcome impediments to offer innovative retail service options to make price responsive demand a reality.

7. Conclusion

Today, with the proliferation of advanced metering and smart grid edge technologies, the theoretical framework developed in the 80's offers a sound economic foundation for mobilizing distributed energy resources and energy customer's load flexibility in ways that empower customer choice and innovative electric service designs in modernized market organizations for managing supply risks associated with renewable energy sources under climate uncertainty. The technology has finally caught up with the economic theory. Indeed, Wilson's works are expansive, often ahead of the times, and the impacts of his huge legacy will be longstanding.

Selected publications

Book

Wilson (1993), Nonlinear Pricing. New York: Oxford University Press, 1993. ISBN 0–19–506,885-8. Paperback edition 1997.

References

Chao, H., Wilson, R., 1987. Priority service: pricing, investment and market organization. Am. Econ. Rev. 77 (5), 899–916.

Chao, H., Wilson, R., 1990. Optimal contract period for priority service. Oper. Res. 37 (4), 598–606.

Chao, H., Wilson, R., 2002. Multi-dimensional procurement auctions for power reserves: robust incentive-compatible scoring and settlement rules. J. Regul. Econ. 20 (2), 161–183.

Chao, H., Wilson, R., 2005. Resource adequacy and market power mitigation via option contracts. Chapter 1 of “Implementation of Resource Adequacy Requirements via Option Contracts,” Report 1010712. Electric Power Research Institute (October 2005).

Chao, H., Manne, A., Wilson, R., 1982. Computation of competitive equilibria by a sequence of linear programs. Econometrica 48 (7), 1595–1615.

Chao, H., Oren, S., Smith, S., Wilson, R., 1986a. Multi-level demand-subscription pricing for electric power. Energy Econ. 8, 199–217.

Chao, H., Oren, S., Smith, S., Wilson, R., 1986b. Priority service: Managing risk by unbundling electric power service. Proceedings of Energy Technology Conference XIII, March 1986, pp. 1610–1618.

Chao, H., Oren, S., Smith, S., Wilson, R., 1988. Priority service: market structure and competition. Energy J. 9 (4), 77–104 special Issue on Electricity Reliability. November 1988.

Chao, H., Peck, S., Oren, S., Wilson, R., 2000. Flow-based transmission rights and congestion management. Electr. J. 38–58 October 2000.

Chao, H., Oren, S., Wilson, R., 2006. Alternative pathways to electricity market reform: A risk management approach. IEEE Proceedings of the 39th Hawaii International Conference on System Sciences.

Chao, H., Oren, S., Wilson, R., 2008. Restructured electricity markets: Reevaluation of vertical integration and unbundling. chapter 1. In: Sioshansi, F.P. (Ed.), Competitive Electricity Markets: Design, Implementation, Performance. Elsevier, New York, pp. 27–64.

Oren, S., Smith, S., Wilson, R., 1982a. Nonlinear pricing in markets with interdependent demand. Mark. Sci. 3 (1), 287–313.

Oren, S., Smith, S., Wilson, R., 1982b. Linear Tariffs with Quality Discrimination. Bell J. Econ. 13 (2), 455–471 (Autumn 1982).

Oren, S., Smith, S., Wilson, R., 1984. Pricing a product line. J. Bus. 57 (1 [Part 2, supplement]), S79–S99.

Oren, S., Smith, S., Wilson, R., 1985. Capacity pricing. Econometrica 53 (3), 549–566.

Oren, S., Smith, S., Wilson, R., 1987. Multi-product pricing for electric power. Energy Econ. 9, 104–114.

Wilson, R., 1989a. Efficient and competitive rationing. Econometrica 57 (1), 1–40.

Wilson, R., 1989b. Ramsey pricing of priority service. J. Regul. Econ. 1 (3), 189–202.

Wilson, R., 1993. Priority service methods. In: Chao, H., Oren, S., Smith, S. (Eds.), New Service Opportunities for Electric Utilities: Creating Differentiated Products, 1993, Chapter 2. Kluwer Academic Publishers, Norwell MA, pp. 7–29.

Wilson, R., 1997. Implementation of priority insurance in power exchange markets. Energy J. 18 (1), 111–123 (January 1997).

Wilson, R., 1998a. Design principles. chapter 11. In: Chao, H., Huntington, H. (Eds.), Design of Restructured Power Markets, 1998. Kluwer Academic Press, Norwell MA.

Wilson, R., 1998b. Pricing issues. chapter 6. In: Chao, H., Huntington, H. (Eds.), Design of Restructured Power Markets, 1998. Kluwer Academic Press, Norwell MA.

Wilson, R., 2002a. Architecture of power markets. Econometrica 70 (4), 1299–1340 (July 2002).

Further Reading

Chao, H., Wilson, R., 1993. Option value of emission allowances. J. Regul. Econ. 5 (3), 233–249.

Chao, H., Wilson, R., 2019. Coordination of electricity transmission and generation investments. Energy Econ. 86, 1–16.

Chao, H., Oren, S., Papalexopoulos, A., Sobajic, D., Wilson, R., 2005. Interface between. Eng. Market Oper. Restruct. Electr. Syst. 93 (11), 1984–1997.

Wilson, R., 1978. Management and financing of exploration for offshore oil and gas. Publ. Pol. 26 (4), 629–657.

Wilson, R., 1989c. Nonlinear pricing and mechanism design. In: Amman, Hans, Kendrick, David, Rust, John (Eds.), Handbook of Computational Economics. vol. 1. Elsevier Science Publishers, New York, pp. 253–293 Chapter 5. 1996.

Wilson, R., 2002b. Electric power pricing. In: Ozer, Ozalp, Phillips, Robert (Eds.), Chapter 4 in Handbook of Pricing Management. Oxford University Press, pp. 93–98 2012.

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