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Firm behavior under quantity controls: The theory of virtual quantities ☆

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ABSTRACT

The theory of virtual quantities, the dual to virtual prices, provides a framework to analyze competitive multiproduct firm behavior under multiple quantity controls on inputs and outputs, including command-and-control quotas and transferable property rights. The framework addresses the firm's reactions to regulatory controls, impacts of adding or dropping quantity controls, inferring unrationed from rationed production, and conversion from command-and-control quotas to cap-and-trade systems with transferable property rights and secondary market behavior. The paper develops reasons for failure of quasi-concavity of technology, extends the elasticity of intensity's properties, and integrates the virtual price and virtual quantity frameworks. Virtual quantities are applied to assess potential firm responses to quantity controls and a potential transferable property right in a Malaysian fishery.

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Introduction

How should competitive multiproduct firm behavior be analyzed in a positive framework when there are multiple quantity controls on inputs and outputs? Bennear and Stavins (2007, page 113) emphasize that, “The use of multiple policy instruments is the norm, rather than the exception in environmental and natural resource management.” Nearly all policy analysis evaluates the relative merits of different – and single – policy instruments, and when analyzing the economic properties of combinations of multiple instruments, hybrid instruments receive particular attention, but these combinations of a quantity and a price instrument are rare (Bennear and Stavins, 2007).

Instead, regulation is often implemented through multiple quantity controls, notably command-and-control quotas, and these are increasingly converted to transferable property rights in cap-and-trade systems. Unique issues arise when regulating multiple inputs and outputs that the literature has yet to fully appreciate and which pose problems for the regulator. The competitive multiproduct firm's reaction to multiple quantity controls can be difficult to predict, because firm behavior – due to the interaction between the controls and unregulated inputs and outputs – can be unexpected. The firm's reaction is rooted in the production technology and the multiproduct structure of costs and revenues. The regulator would clearly benefit from understanding the competitive multiproduct firm's behavior under multiple quantity controls.

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The theory of quantity controls that analyzes competitive firm behavior under multiple quantity controls has largely focused upon an ex ante framework through virtual prices.[1] This theory of rationing and quotas has given less attention to a framework in which some of the inputs and outputs are already rationed, fixed, or primary, existing quotas are removed or added through deregulation or changes in regulations, or command-and-control programs are converted to cap-and-trade systems with transferable rights or credits.

The theory of virtual quantities provides the framework for positive analysis of existing quotas, rations, credits, property rights, fixed or primary factors and outputs, public goods and bads, or common resources – hereafter collectively referred to as quantity controls. Virtual quantities, dual to virtual prices, were originally called virtual endowments and analyzed effects of imposing fixed prices upon otherwise flexible prices in international trade (Neary, 1985). This framework has yet to be developed for a more general regulatory context or applied empirically.

This paper extends the theory of virtual quantities to analyze the competitive multiproduct firm's behavior under multiple in situ quantity controls for a normal technology (Sakai, 1974), in which input–output relationships are not regressive, and which is joint-in-inputs. The paper develops the firm's equilibrium inverse derived demand functions for existing quantity controls that underpin secondary markets for transferable property rights (credits) and cap-and-trade systems and develops their comparative statics to show secondary markets' and firms' responses to changes in quantity controls and market or accounting prices.[2] The paper clarifies several issues that arise when applying virtual quantities and virtual prices. First, it examines the relationship between rationed and unrationed production.[3] Second, it clarifies the relationship between shadow and virtual prices, unit quota rents, and implicit unit tariffs. Third, it examines failure of quasi-concavity, which potentially becomes more severe as additional quantity controls are added or regulated outputs or inputs are disaggregated, such as total greenhouse gasses into individual regulated gasses or total fish catch into individual species. Fourth, it rigorously decomposes quasi-rent into quantity control surplus and income. The paper develops additional properties under multiple quantity controls for the elasticity of intensity, which measures substitution or complementarity possibilities between an unregulated variable input or output and quantity control (Diewert, 1974). The paper integrates the dual virtual price and quantity frameworks for quantity controls. Finally, the paper integrates the virtual quantity framework with the closely related production framework of fixed factors (Sakai, 1974; Diewert, 1974; Lau, 1976), developing unique aspects that arise with quantity controls.

The virtual quantity framework is applied to an empirical study of input regulation in an industry exploiting a common resource, a Malaysian fishery. Multispecies tropical fisheries rely upon input rather than output controls to limit catches and fishing mortality due to the complex multitude of species and difficulties in resource stock assessments in data-poor environments, plus limited infrastructure for monitoring and enforcement. Program success depends, in part, on whether firms can substitute unrestricted inputs for the quantity-controlled inputs, which would then expand potential fishing capacity and fishing mortality beyond regulatory targets. The empirical results demonstrate no potential for firms to substitute unrestricted for restricted inputs. The pervasive input complementarity instead points to input controls that can lower harvest pressures on the common resource stock. The empirical section, through a simulation of a cap-and-trade, transferable property rights program for vessel length, demonstrates considerable potential for arbitrage efficiency and rent gains.

Virtual quantities establishes the virtual quantity framework and equilibrium inverse derived demand functions that underpin cap-and-trade markets, firm behavior, and local Le Chatelier effects for changes in price-quantity relationships when adding or dropping quantity controls. *Quasi-concavity of fixed inputs and outputs* develops conditions under which quasi-concavity fails with multiple quantity controls or fixed inputs or outputs. *Shadow prices and virtual prices* clarifies the difference between shadow and virtual prices and relates the unit rent, inverse derived demand, shadow price, and virtual price functions under the rationing, production, and welfare theory frameworks. *The elasticity of intensity* extends the elasticity of intensity to multiple quantity controls. *Empirical application* empirically illustrates virtual quantities by analyzing public regulation of fishing firms using input controls in Malaysia. *Concluding remarks* concludes. Five online appendices provide supplementary information. Appendix A gives proofs of propositions, Appendix B gives details and derivations for empirical profit function formulae, Appendix C discusses data, Appendix D derives fundamental equations, and Appendix E discusses calculation of, and provides formulae for, quota quasi-rent in a transferable effort program with a cap-and-trade secondary market.

[1] Virtual prices are those prices that would induce an unconstrained firm to demand the level of the rationed variable input or output or quota. Neary and Roberts (1980) give a formal definition and proof of existence. Virtual prices with production are formally defined later in the paper. Rothbarth (1941) first proposed the virtual price approach to (consumer) rationing, which Neary and Roberts (1980) extended to consumer duality theory. Neary (1985), Squires and Kirkley (1991), Anderson and Neary (1992), Fulginiti and Perrin (1993), Segerson and Squires (1993), Squires (1994), and Roberts (1999) extended the virtual price approach to producer rationing and quotas; Thomsen (2000) to fixed factors; Squires and Kirkley (1995, 1996) and Vestergaard (1999) to transferable quotas, property rights, and inverse derived demand systems; and Mäler (1974), Hanemann (1991), and Carson et al. (1998) to consumption and valuation of public goods.

[2] Accounting price is used rather than shadow price to distinguish situations other than those arising with quantity controls and fixed netputs. Accounting prices capture all sources of economic value and account for missing, incomplete, and distorted markets. The accounting price of a netput is defined as the marginal effect on social welfare of the availability of an extra unit of the specified netput (Dréze and Stern, 1996). Shadow price in this paper refers to quantity controls.

[3] Quantity controls exceeding their virtual quantities correspond to forced or subsidized production, but are not explicitly considered here.